Small scale liquefaction of:

- Biogas
- Natural gas
- Flare gas
Liquefaction: Air Liquide overall portfolio

- LIN-8 TPD
- TB-10 TPD
- TB-20 TPD
- TB-30 TPD
- Turbofin-600 TPD
- Smartfin 5500 TPD
- +15 000 TPD

Vysotsk (Russia)
Turbo-Brayton range – From standard to on-demand systems

<table>
<thead>
<tr>
<th>Refrigeration</th>
<th>From 35 to 300 kelvin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomethane liquefaction</td>
<td>From 10 to 30 ton per day</td>
</tr>
<tr>
<td>Liquid natural gas reliquefaction</td>
<td>From 0.2 to 1.8 ton per hour</td>
</tr>
</tbody>
</table>

Options – can be added to fully satisfy customer’s need

- Cryogenic circulator integrated on the refrigerator
- Liquefaction and refrigeration of fluids up to 70 bars
- Containerized system
- Air-cooled system
- Heat recovery (building heating, customer process needs, …)
- Specific architectures
- Extension of the temperature range down to 20 kelvin
Reverse Turbo-Brayton principle

1. Centrifugal compressor
   - High efficiency
   - Oil-free

2. High-speed synchronous motor and active magnetic bearings
   - Direct drive
   - No gear box
   - High compacity
   - Contact free
   - Unsurpassed lifetime

3. Centripetal expander
   - 50 years experience in the design and manufacture of expanders
   - High efficiency
**Turbo-Brayton - Introduction**

- Air Liquide Advanced Technologies has developed an **industrial cryogenic liquefiers**
  - Range: -258°C to -123°C
  - **High efficiency > 40% Carnot (0.8 kWh/kg of LNG)**
  - High reliability: MTBF = 105,000 h
  - Maintenance interval = 5 years
  - High life time > 50 years
  - Utility free: no compress air, no oil, no nitrogen make-up
  - Single skid: Plug and play design

---

### Turbo-Brayton range

<table>
<thead>
<tr>
<th>Name</th>
<th>Liquefaction range (ton per day)</th>
<th>Weight (t)</th>
<th>Footprint (L x W x H) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBF-350</td>
<td>0-10</td>
<td>17</td>
<td>11 x 1.7 x 3</td>
</tr>
<tr>
<td>TBF-525</td>
<td>0-17</td>
<td>25</td>
<td>12 x 3.5 x 3.5</td>
</tr>
<tr>
<td>TBF-700</td>
<td>0-20</td>
<td>30</td>
<td>12 x 3.5 x 3.5</td>
</tr>
<tr>
<td>TBF-1050</td>
<td>0-30</td>
<td>40</td>
<td>13.5 x 4.5 x 4</td>
</tr>
</tbody>
</table>

*Expected values given for 15°C cooling water.*
Simplified PFD of liquefaction plant:
From conventional Brayton to Turbo-Brayton

TBF-350

- High efficiency
- No maintenance
- High reliability
- High lifetime
- Hermetic design
- 100% Oil-free

The only rotating part of the system is the Moto-turbo-Compressor shaft
From conventional Brayton to Turbo-Brayton

TBF-1050
Turbo-Brayton – References

Turbo Brayton references

■ **ISS project**: TBF -- 100W@ -80°C
  - 3 TBF installed into ISS
  - 100,000 hours without maintenance nor failures

■ **LIPA II** project: TBF-80 – 13kW@ -163°C

■ **Institute 401**: TBF-80 – 18kW @ -120°C

■ **Shell STX**: TBF-350 – 350 kg/h LNG reliquefaction

■ **AMSC**: TBF-350 – 20kW @ -200°C

■ **Gaslog/SHI**: 2x TBF-1050 – 1300 kg/h LNG reliquefaction

Turbine, magnetic bearing and Brayton references

■ **600 gas-turbines** running on industrial plants, Helium, HyCo, Hydrogen, Natural gas

■ **50 cryogenic turbomachines** on magnetic bearings

■ **200 cryogenic plants**, installed over the world on the past 50 years
Turbo-Brayton – Efficiency at partial flow rate

- Partial load: electrical consumption is linear with liquefaction
- At 60% of nominal liquefaction rate, the overall efficiency of the refrigerator is only decreased by 3%

- The liquefaction rate is automatically adjusted from 0 to 100% by varying the speed of the motor.
- High turn-down ratio
The TBF is very flexible, user-friendly and remains ready-to-run along operations

It takes 3 hours from ambient temperature to cool-down the Turbo-Brayton and start liquefy LNG

The Liquefier can stay in stand-by mode with a low rotation speed (10% of electrical consumption), and immediately liquefy LNG at order

TBF is operated in following mode:

➢ **Automatic:** Liquefaction is managed with the TBF in the same way as it is with the Biogas Upgrading Package (BUP).
Utilities & Installation

- **Utilities required**
  - Electricity
  - Cooling water
  - No compressed air required
  - No nitrogen required
  - Oil free
  - Noise < 100dB

- **Turbo-Brayton refrigerator explosion proof**
  - Can be installed in explosive area

- **Electrical cabinets**
  - Must be installed in safe area
  - One instrumentation air cooled
  - Power motors cabinet water and air cooled (0,3 kg/s per cabinet)
On site installation

- **Liquefier on a single skid**
  - Plug and play

- Easy installation

- Only connections to make
  - Gas to LNG
  - Water
  - Electricity
Maintenance and cost

Trouble free system thank to:
- Oil free system
- Contact free for rotating part
- Hermetic System
- Low number of valves
- Single system, single skid, factory tested
- MTBF 105,000 hours
- No leakage of cycle gas make up is not required

Low maintenance is required on Turbo-Brayton systems thanks to the use of magnetic bearings
- Regular check of the sensors to check that no measurements are deriving (every month 10 minutes)
- Refill of process gas every 5 years (6 hours operation)
- Pumping of vacuum enclosure every 5 years for TBF-350 (12 hours operation)

⇒ 5 years maintenance free
⇒ High advantage compared to competitors for which the OPEX is much higher
1800 Nm3/hr of biogas to 17 TPD of bio-LNG

**Biogas Upgrading unit**
- In: 1800 Nm3/hr biogas with 55% CH4
- Out: 594 Nm3/hr bio-CH4 with 98% CH4

**CO2 polishing unit**
- In: 990 Nm3/hr bio-CH4 with 98% CH4 and 2% CO2
- Out: 594 Nm3/hr bio-CH4 with 98% CH4
- Regeneration of PSA:
  1. Hot water, or
  2. Nitrogen, or
  3. CH4

**Pre cooling**
- In: 990 Nm3/hr @ 20°C
- Out: -30°C

**TB-350 Liquefier**
- In: 990 Nm3 of gaseous CH4
- Out: 17 tpd bio-LNG

Total Energy demand is ~1227 kW from biogas to bio-LNG, i.e. ~12% of energy produced
Heat recovery (water @85°C is an extra)
End of presentation
Thank you for your attention

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