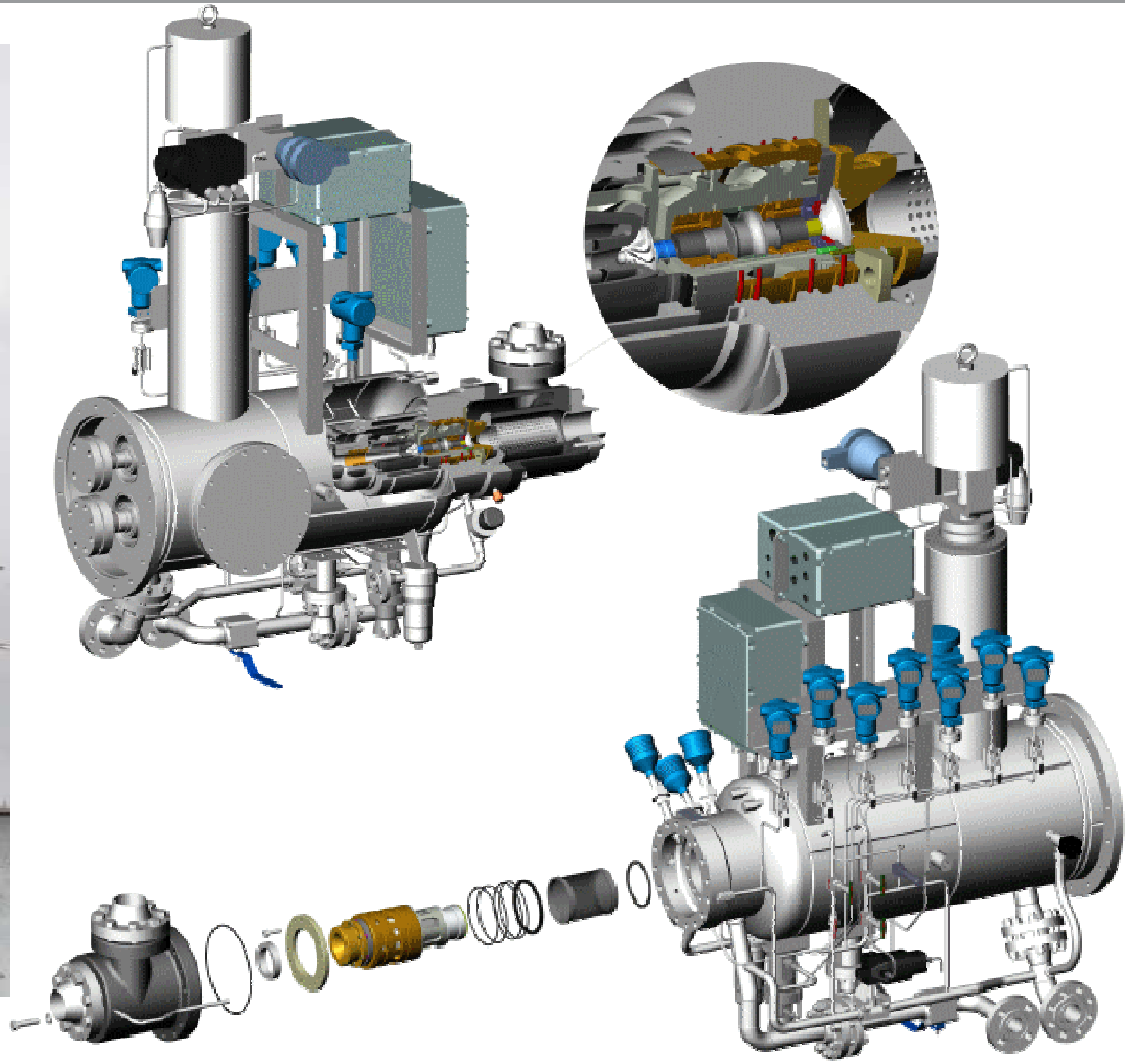
Helium Operators Familiarization Program

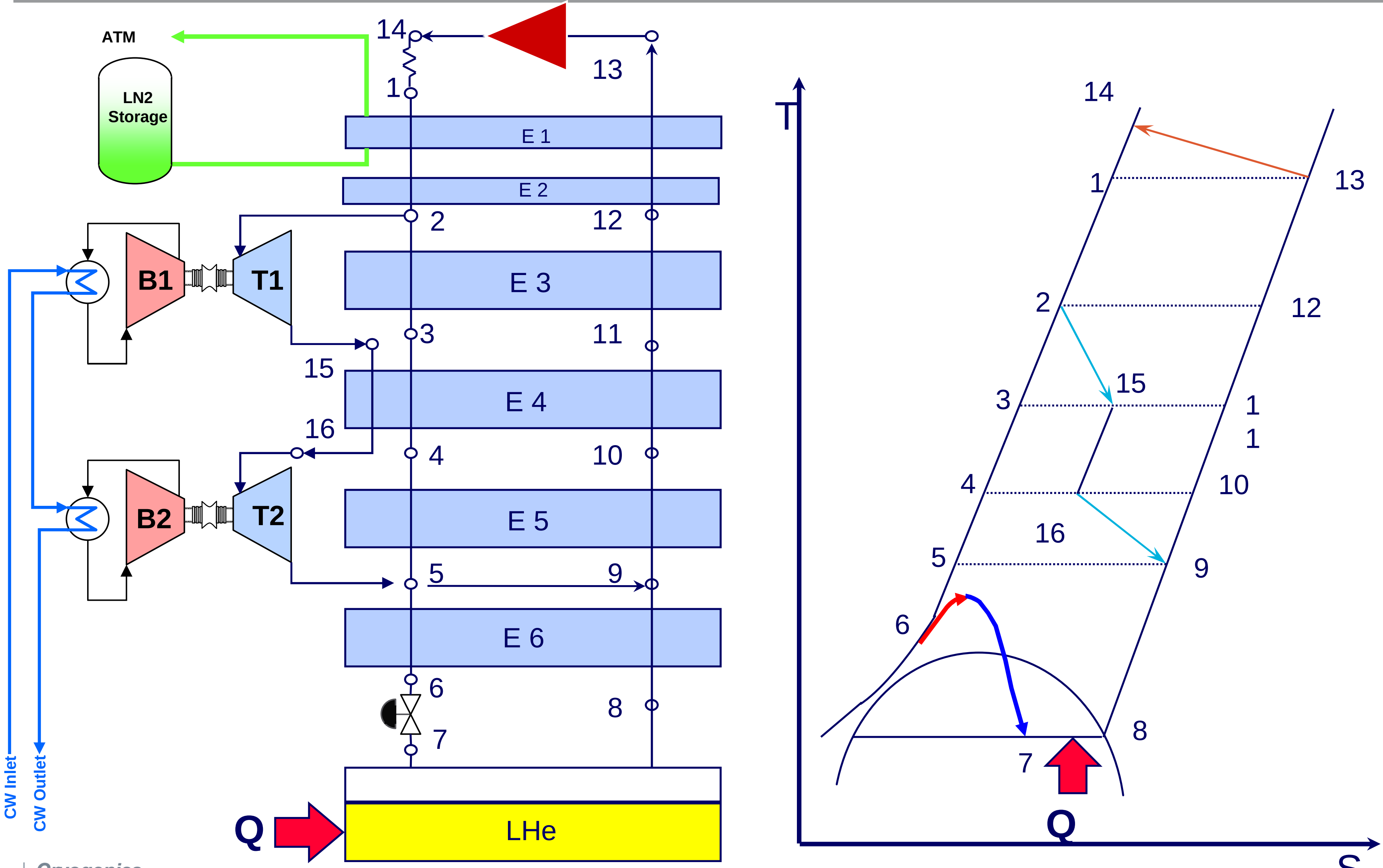
Cryogenic Expansion Turbines

Dec 2012 I Vincent HELOIN

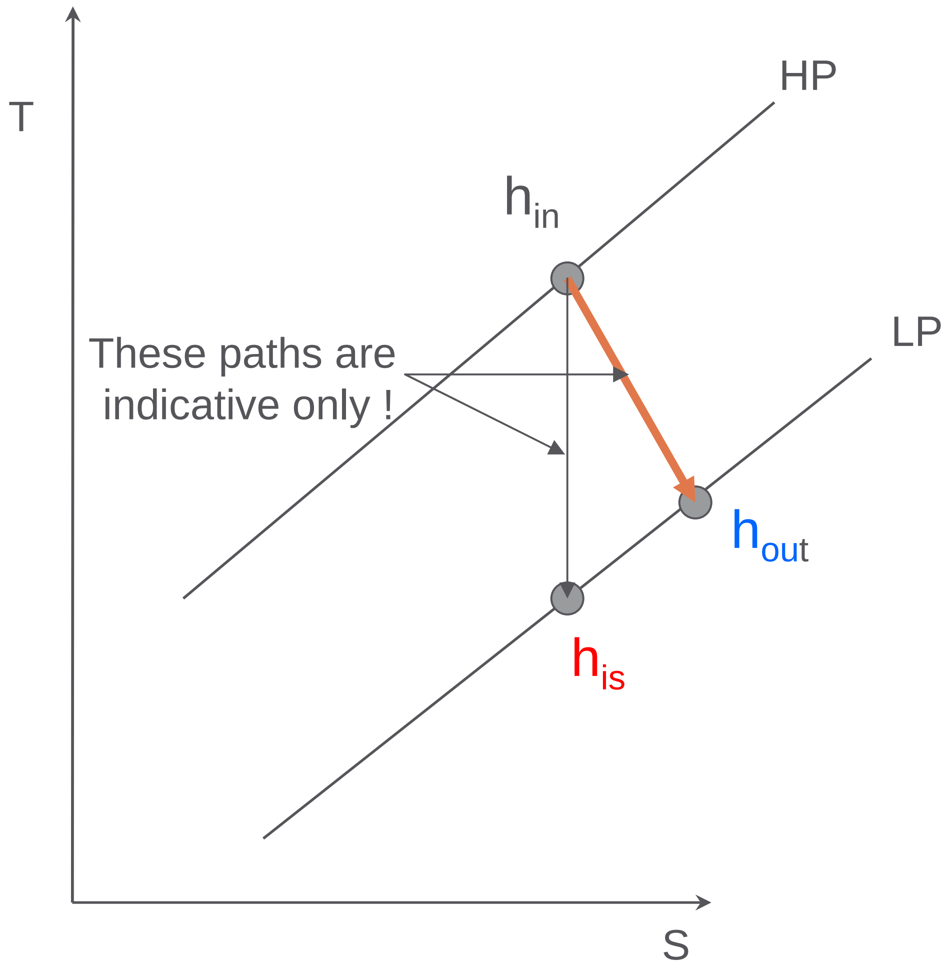
A Cartridge Concept



Simple Refrigeration Cycle



Expansion With External Work



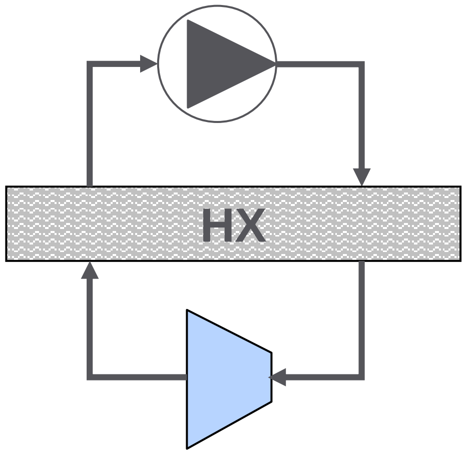
TEMPERATURE/ENTROPY DIAGRAM

Isentropic efficiency :

$$\eta_{is} = \frac{h_{in} - h_{out}}{h_{in} - h_{is}}$$

IN / OUT

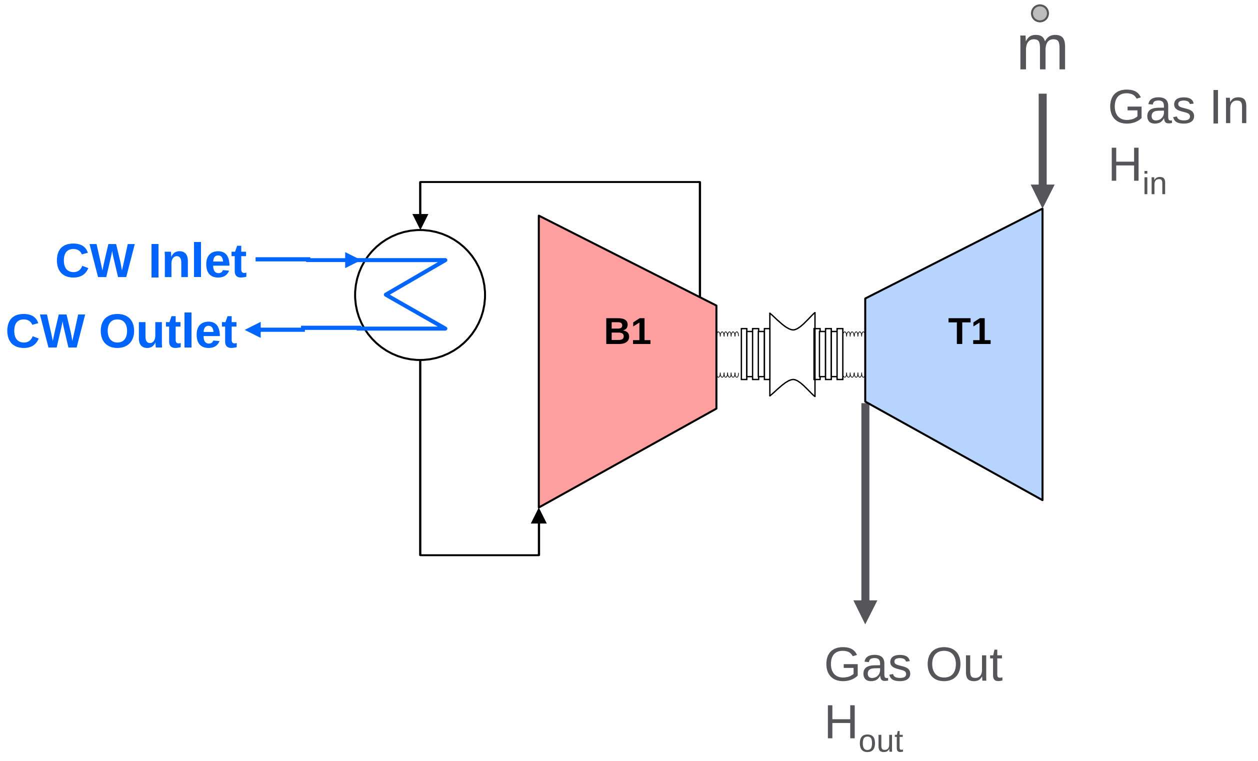
- What is provided to the turboexpander ?
  - Flow rate (cycle screw compressor)
  - Inlet and outlet pressure (cycle screw compressor)
  - Inlet temperature (process heat exchanger)
  - Cooling water



- The design of the turbo-expander is performed according to these process datas

- What is expected from the turbo-expander ?
  - To take the specified flow rate
  - To use efficiently the pressure difference
  - To be reliable

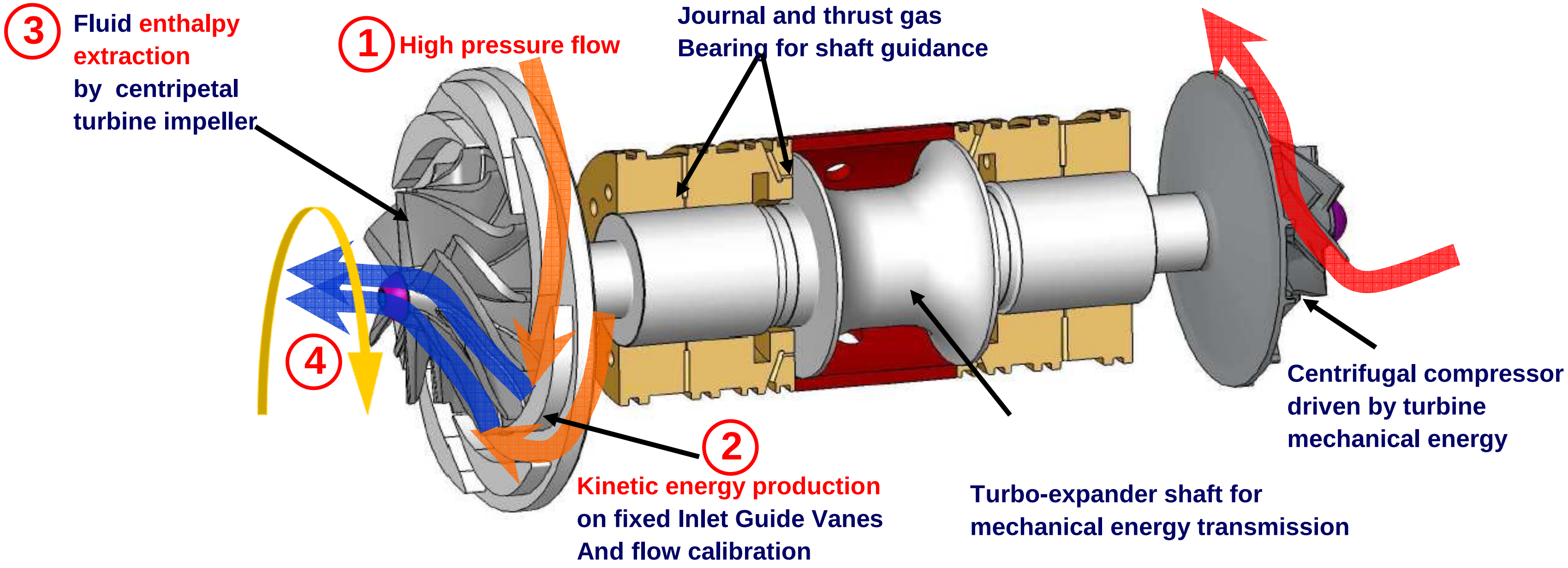
Energy Balance

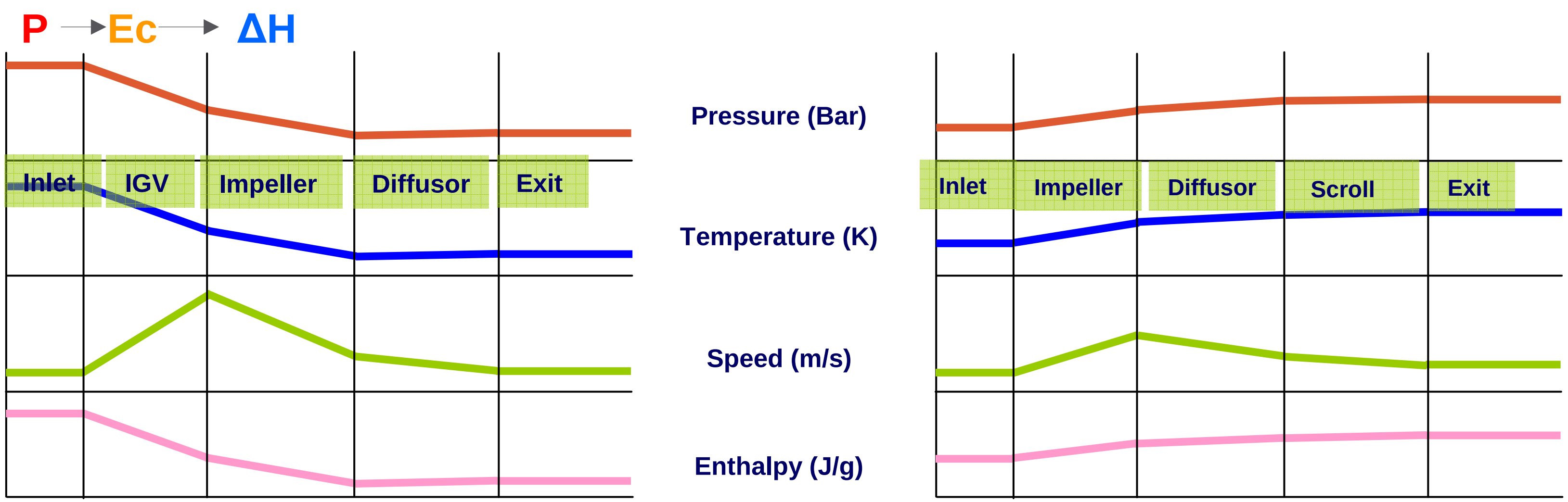


$$P = \dot{m} * (H_{in} - H_{out})$$

The Power is extracted by the brake

What Happens Inside Turbines





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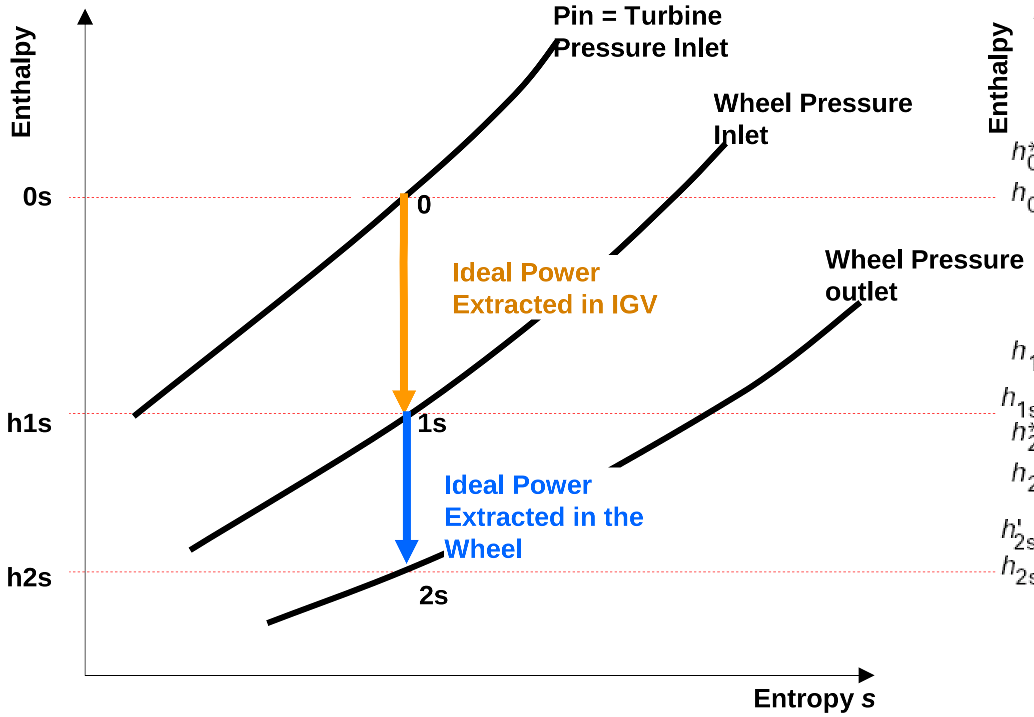
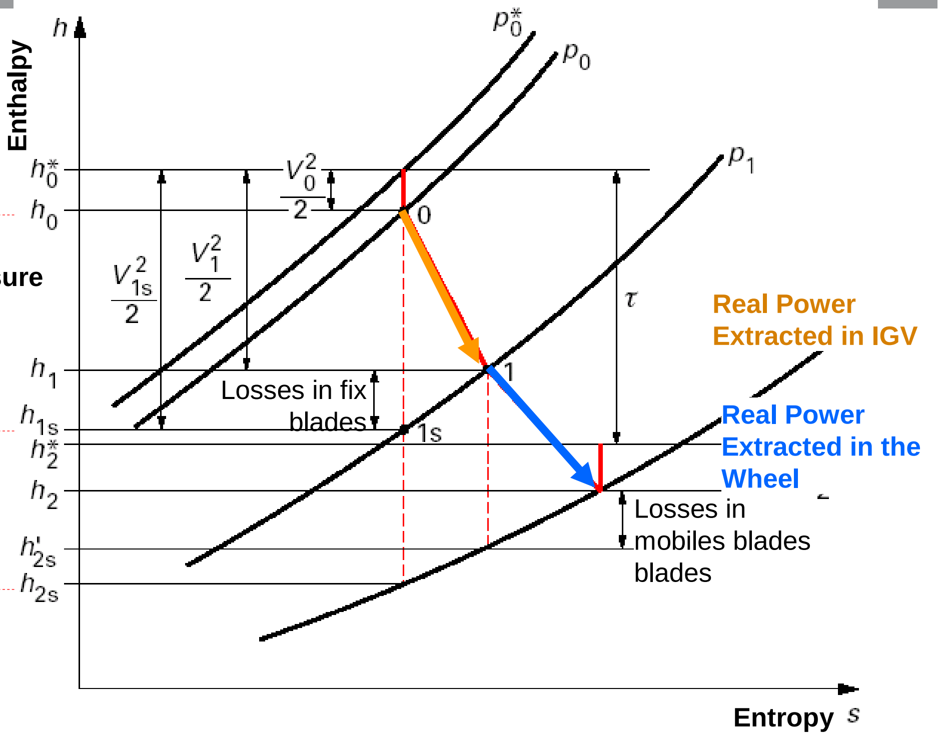




Energy conservation states $\Delta H = C^2/2$ and ΔP is related to speed by $\Delta P \sim k\rho C^2$

In the fix IGV, a part of the H is transformed to kinetic energy (acceleration)

$$\Delta H_D = C_D^2/2$$

In the Wheel kinetic energy and 'remaining' H is transformed to mecanical work :

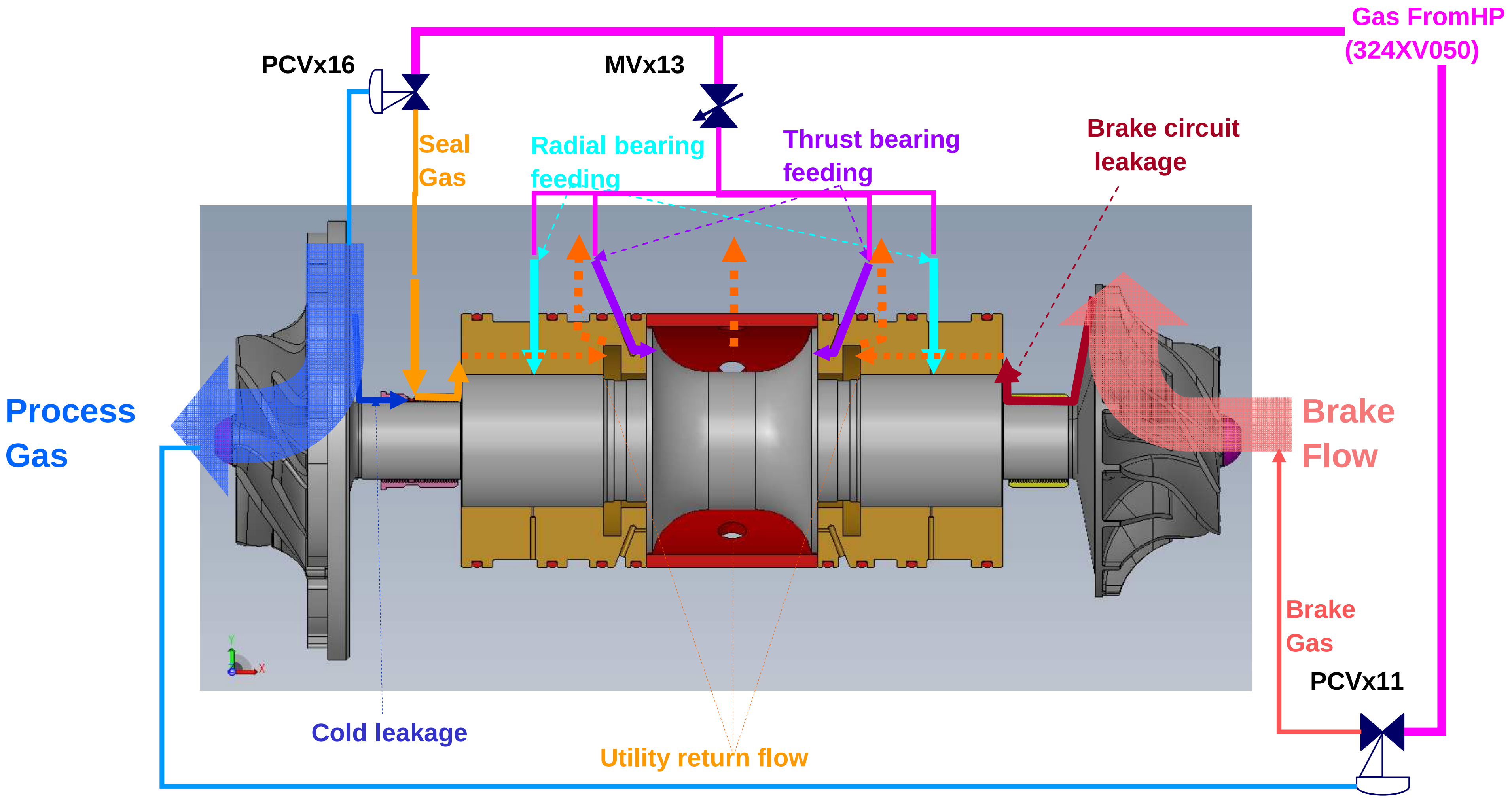
$$\Delta H_W = C_W^2/2 = \alpha U^2/2 = \alpha(\pi.D.N)^2/2$$

What Happens Inside Turbines

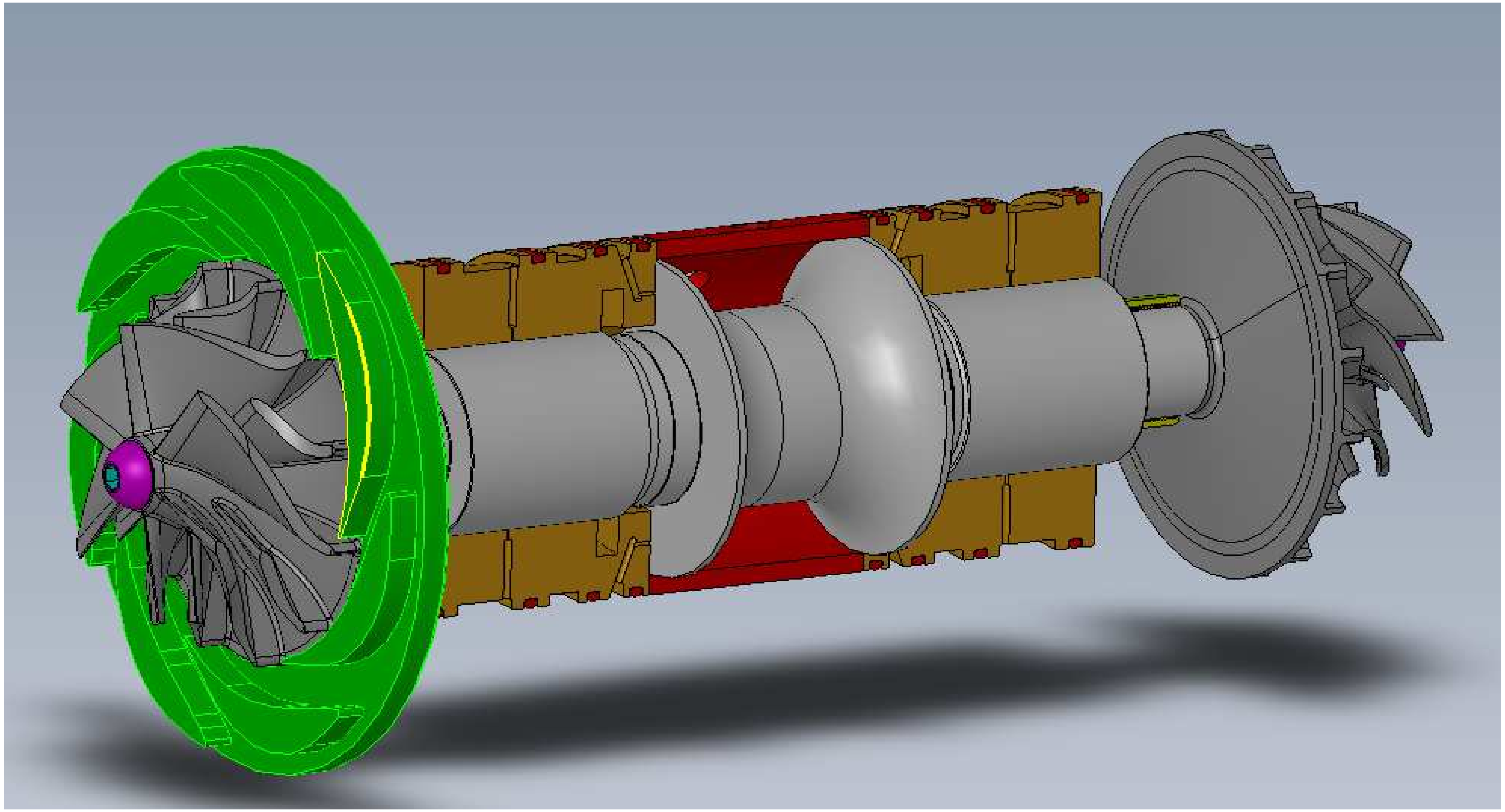
- Ideal Enthalpy extraction: ΔH_S (J/Kg)
- Real Turbine Enthalpy extraction: $\Delta H_R < \Delta H_S$
- Isentropic efficiency $\eta = \Delta H_R / \Delta H_S$ (70 % - 80 %)
  (Fo a perfect gas $\Delta H = C_p \Delta T$)
- Refrigeration Power
  - $P = \eta \Delta H_S Q_M$ (W)
  - Q_M : mass flow (Kg/s)

  (Power extracted from the fluid by the turbine)

General Structure

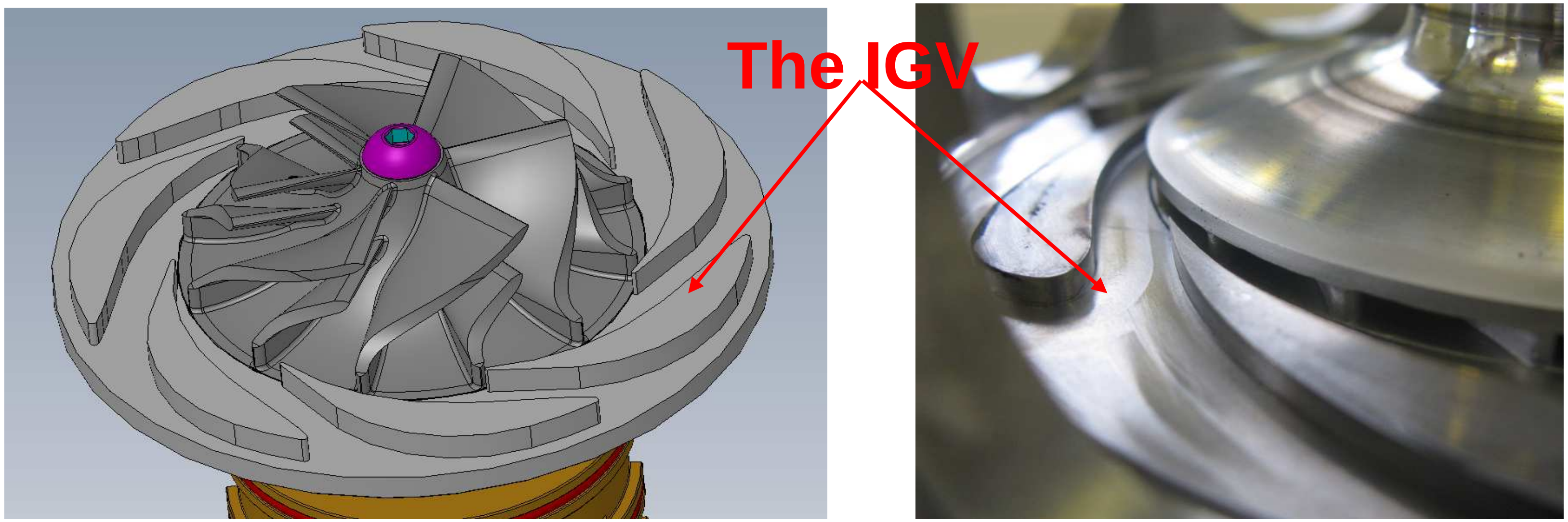


The Distributor (IGV)



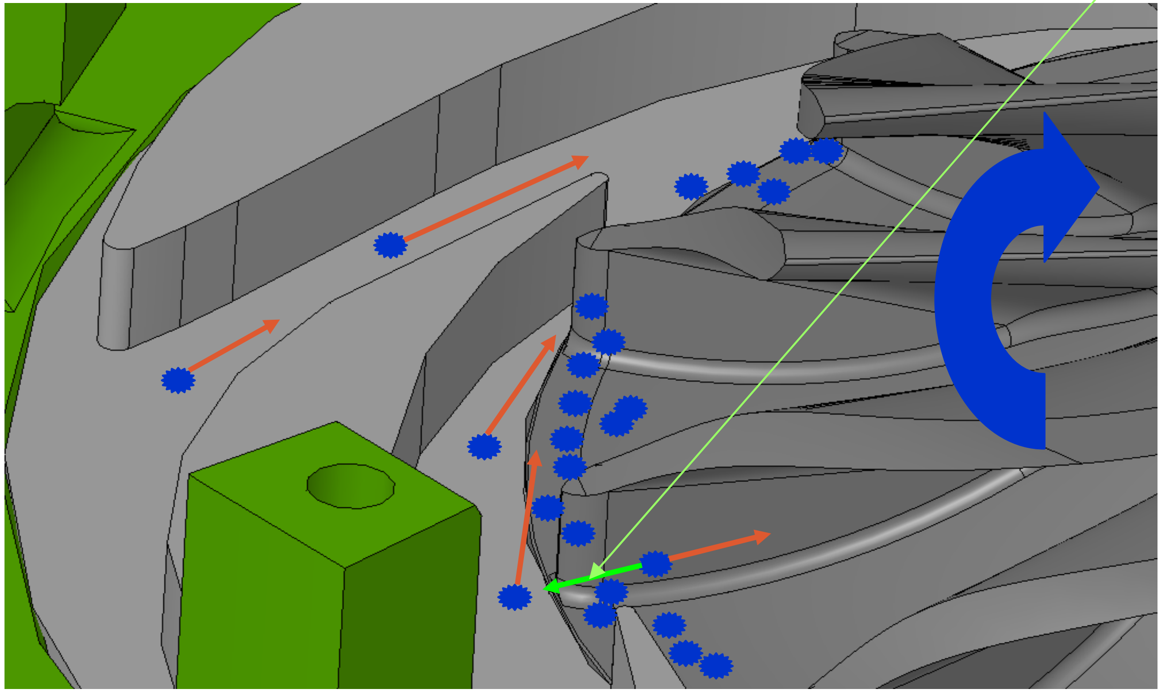
The Distributor (IGV)

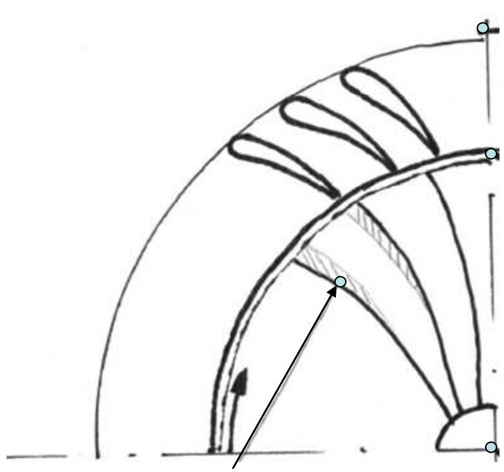
- The fixed blades of the IGV are designed to :
  - Fix the flow (smallest section). Flow variation is given by : $\alpha = \frac{\dot{m}\sqrt{zT}}{P}$
  - Accelerate the fluid (venturi effect)
  - Optimize the inlet angle inside the wheel
- Inside the fix IGV, enthalpy is transformed to kinetic energy
  - $\Delta H_{DIS} = C^2 / 2$
  - A part of the cooling is thus performed in the fix IGV



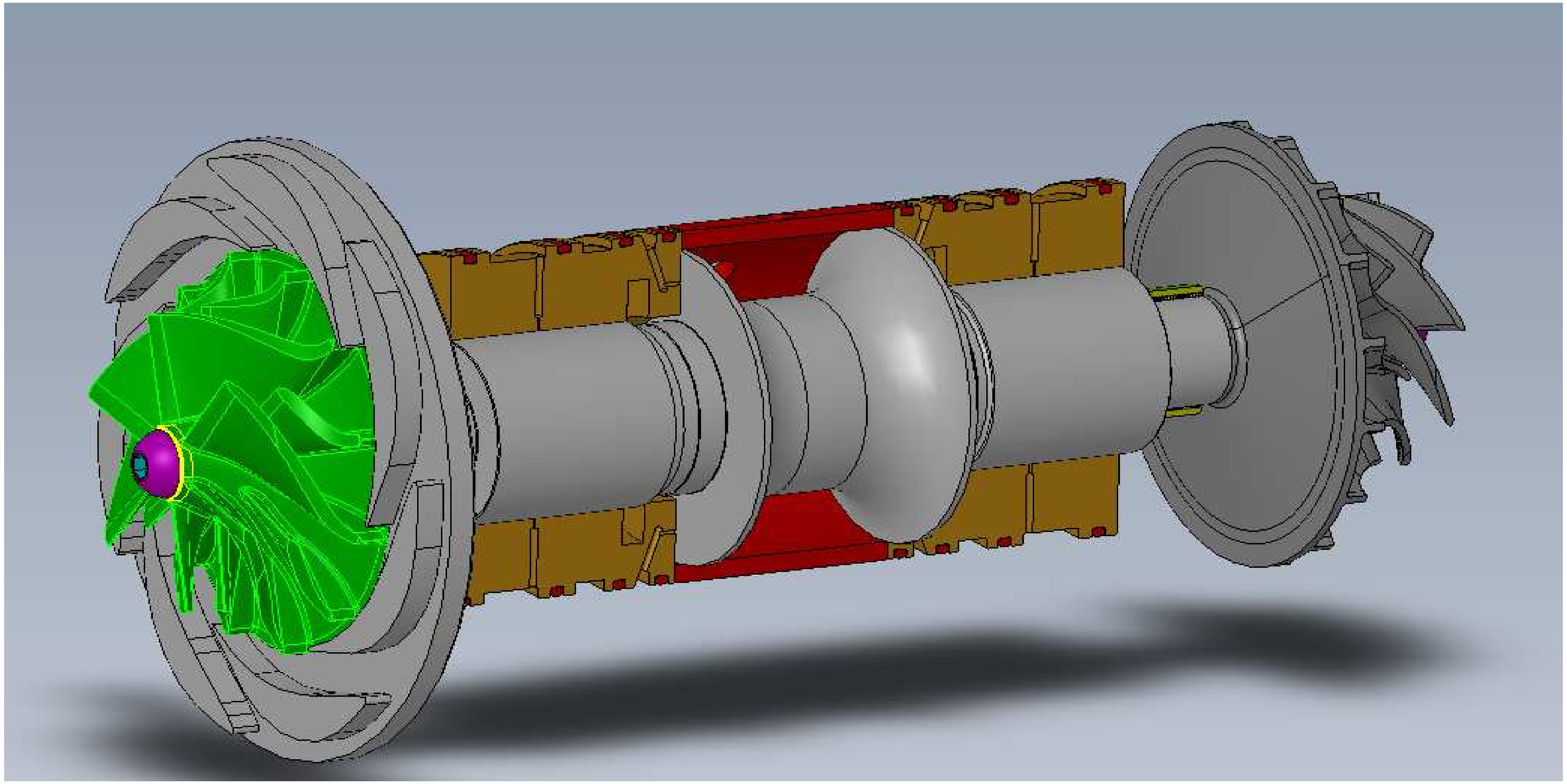
Wheel Inlet Pressure

- Any evolution of the Wheel Inlet Pressure with steady process conditions shows the presence of impurities in the process gas.
  - Solid particles stay at the wheel inlet due to centrifugal force
  - This clogs the inlet -> Pressure increases





Turbine Wheel



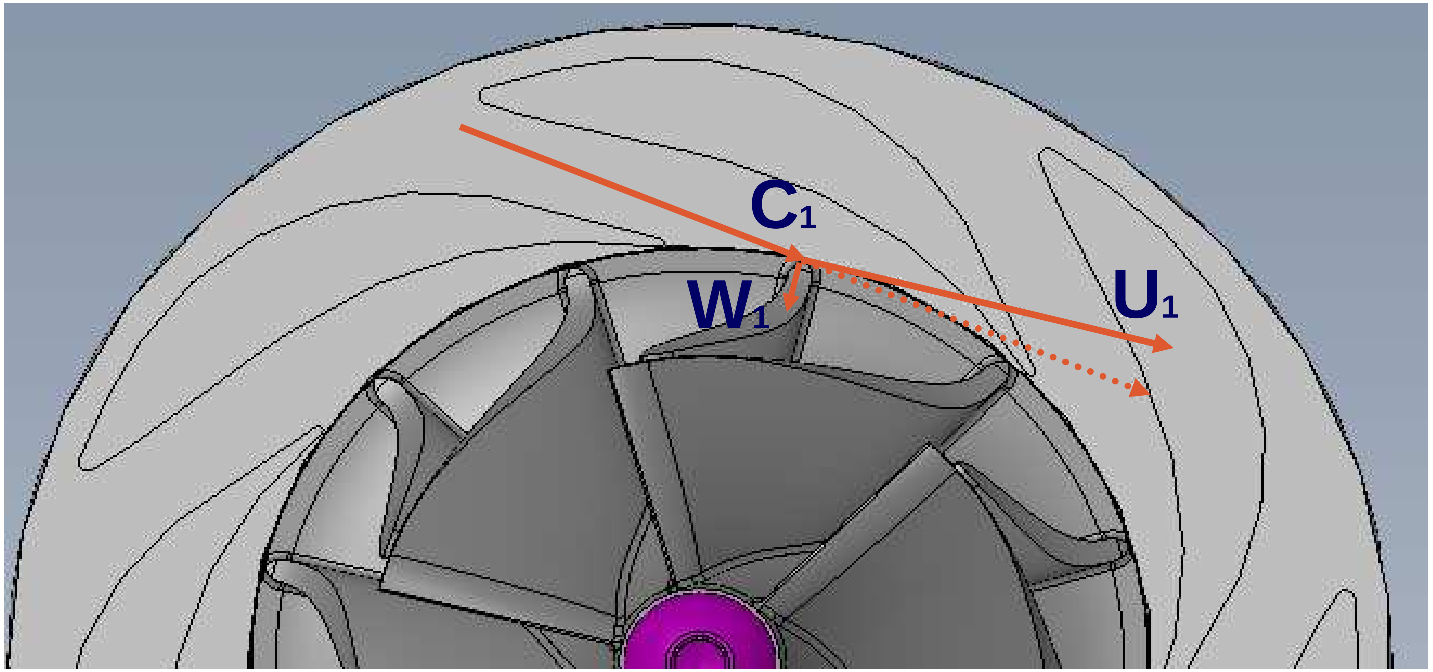
AIR LIQUIDE
GLOBAL E&C SOLUTIONS

Turbine Wheel

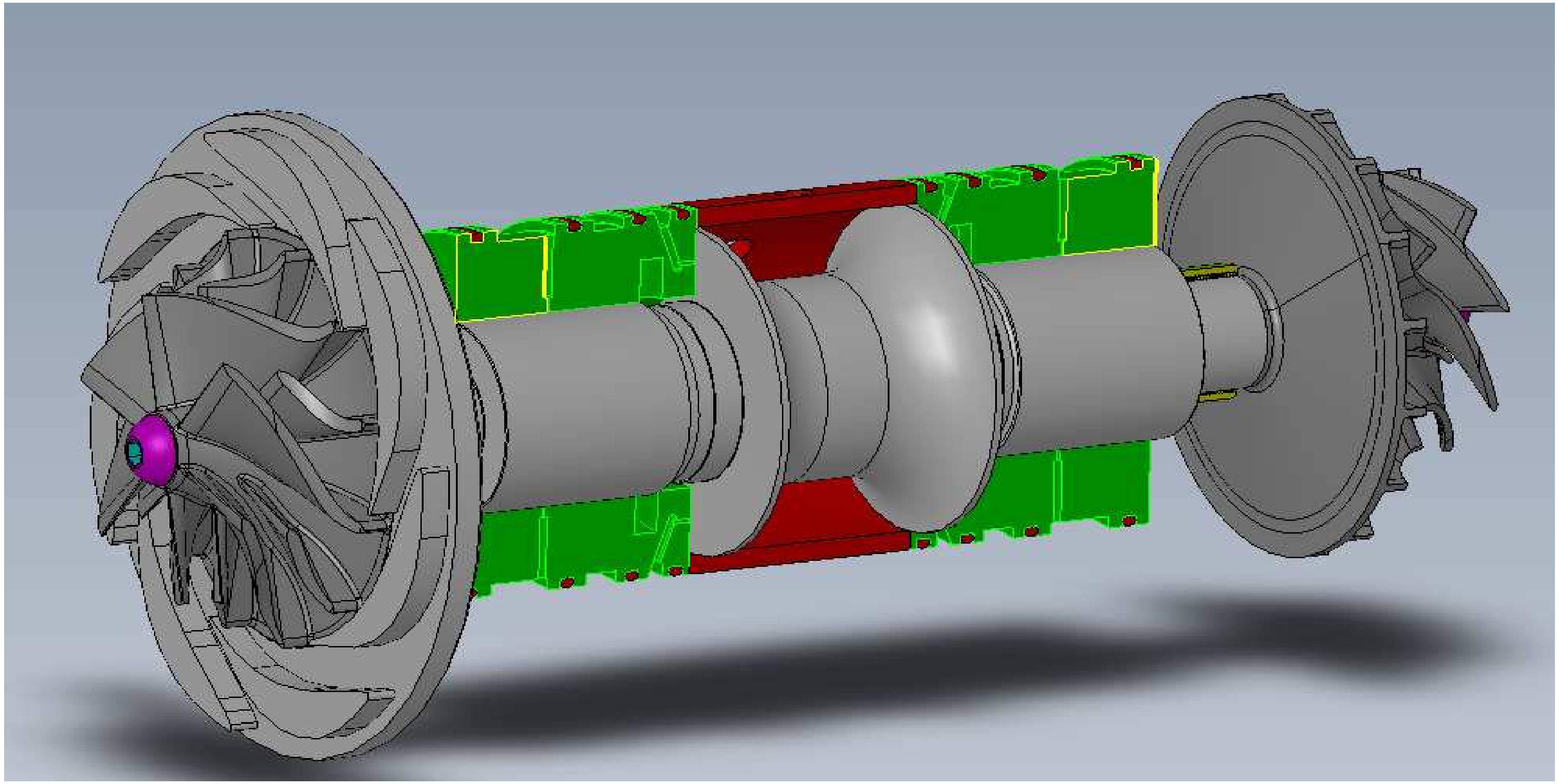
- The wheel
  - Transforms Ec (created in the IGV) to work
  - Ends up the enthalpic extraction and transforms it in works :

$\Delta H \propto U_1^2 . F$

Nota : The limit of the possible ΔH per turbine is mechanical

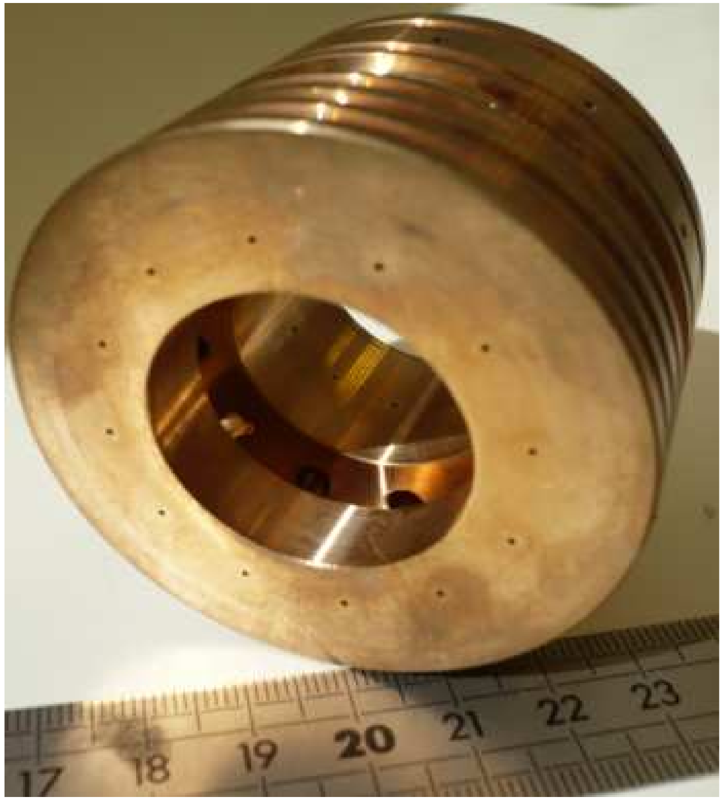


BEARINGS



GAS BEARINGS

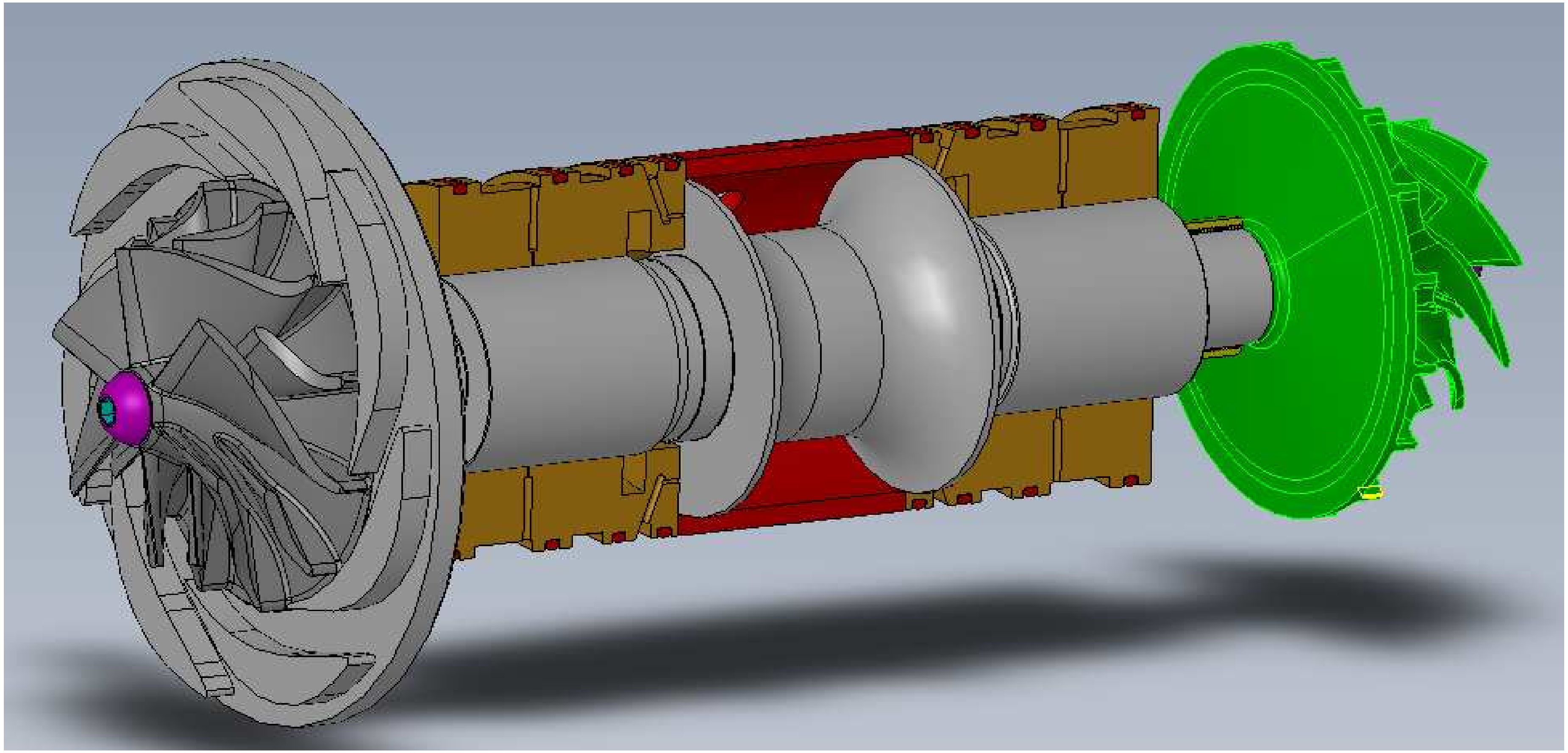
- Contact free technology => No wear rotation and start/stop phases.
- Increased availability due to high MTBF
- High stiffness (at every rotation speed) peripheral speed achievable gas bearings),
- Tolerant to temperature variations due clearances (with respect to bearings)
- Tolerant to load variations and speed changes (with
- No cooling needed



GAS BEARINGS

- Clearances from 20 to 40µm on the radial gas bearings
- Sensivity to gas cleanliness (water, formaldehyde …) due to cold areas
- Manage a warm temperature at gas bearing exhaust by adjusting the cold leakage at the labyrinth

BRAKE WHEEL



BRAKE WHEEL

- The brake remove the power extracted by the turbine

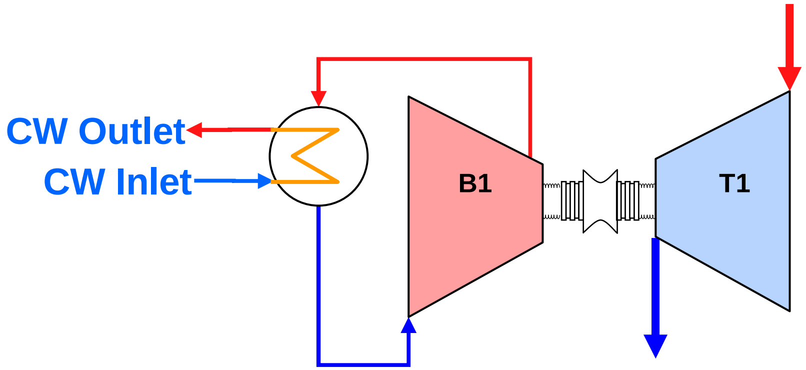
- The brake is a centrifugal compressor:
  - It warm up the helium used in the brake side.
  - The power is extracted from the brake by an water/helium exchanger.

- The absorbed power by the brake is :

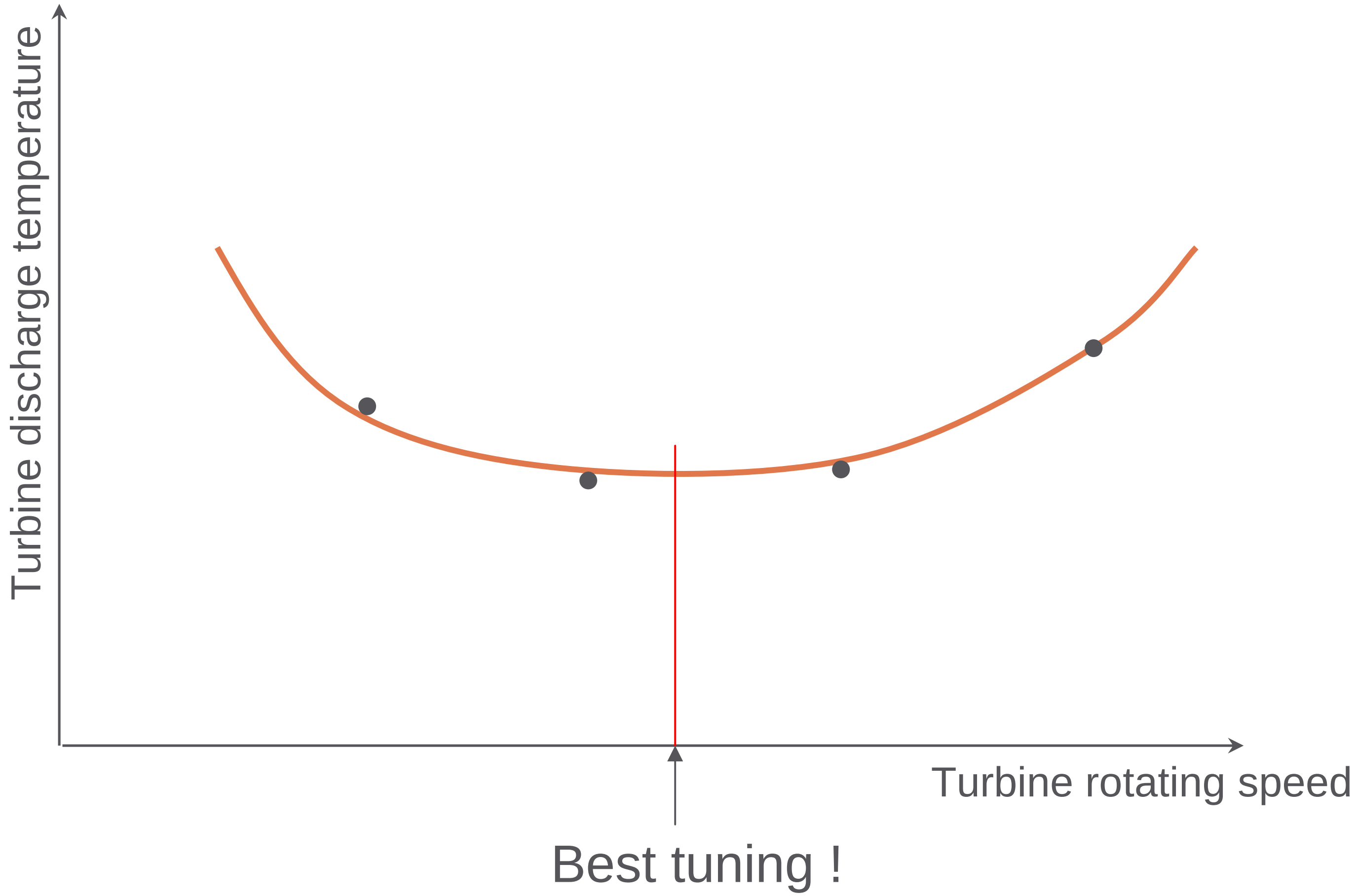
$$W \alpha P_{brake}.N^3$$

($Qm \alpha N$, $\Delta H \alpha N^2$)

  - Changing the rotation speed of the brake, change the turbine speed.
  - Tuning of the Turbine Speed can be done by changing the brake load.

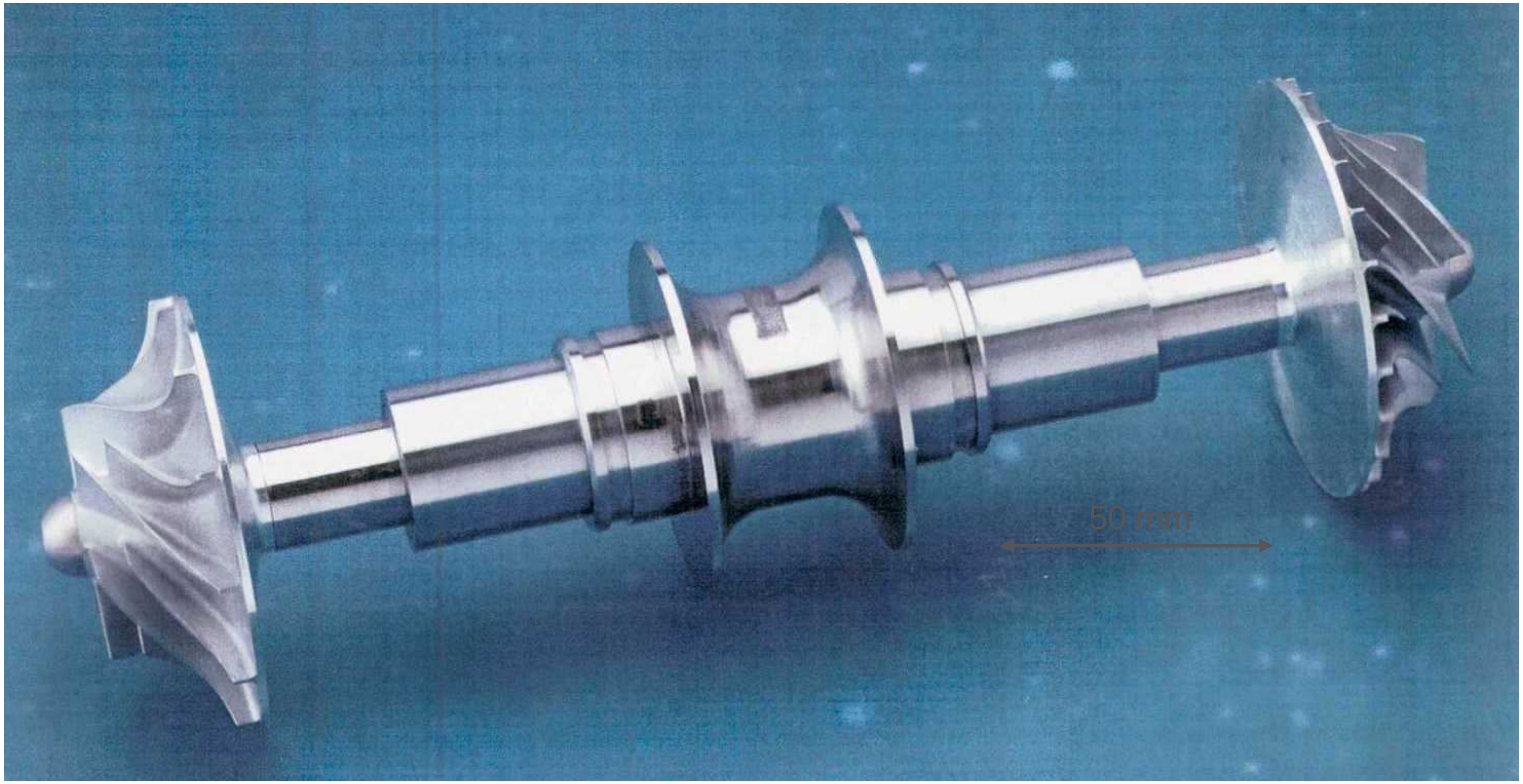


TUNING THE TURBINE SPEED

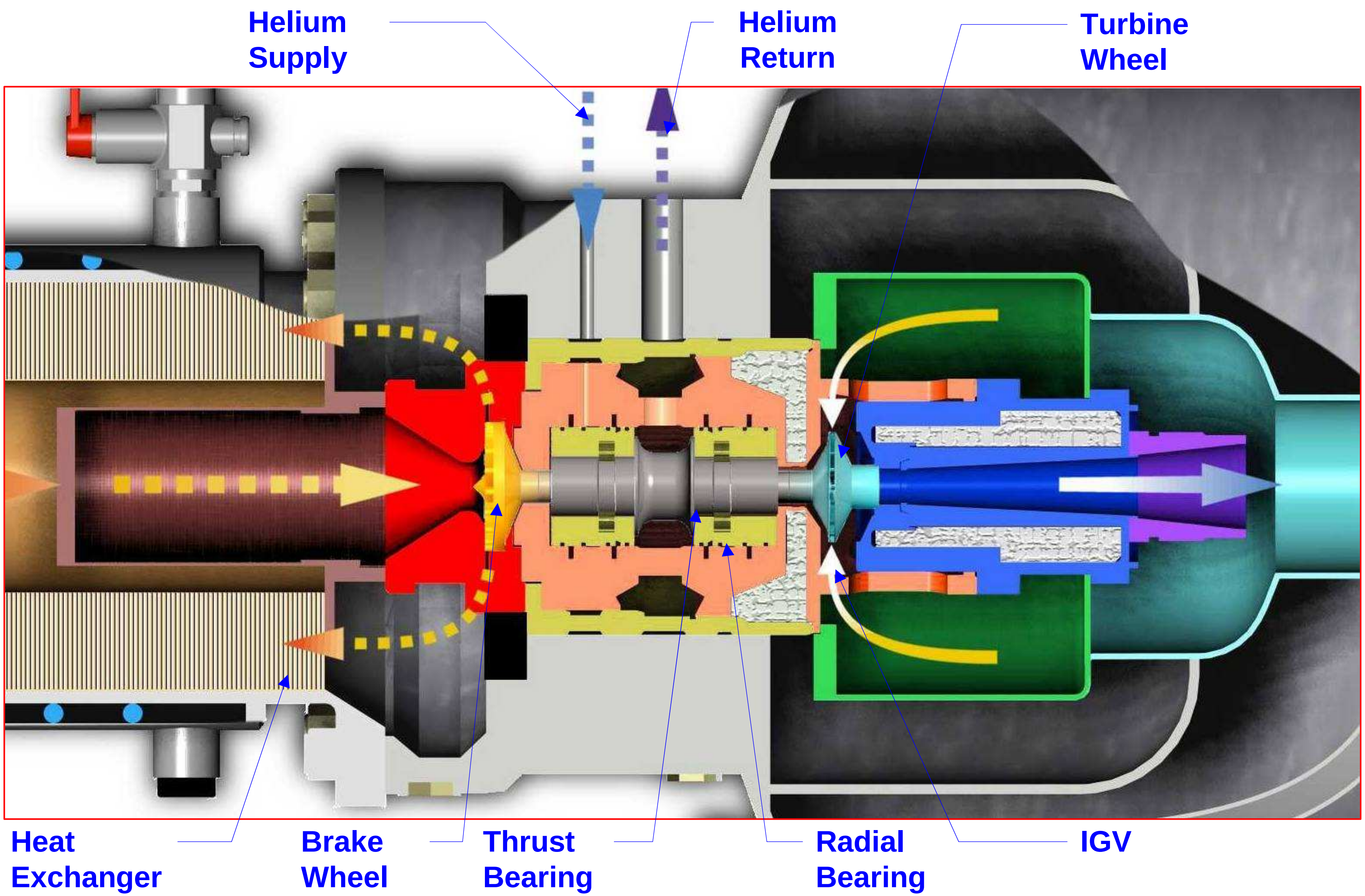


SHAFT, BEARING AND WHEEL

Shaft And Wheels



An Air Liquide Turbine



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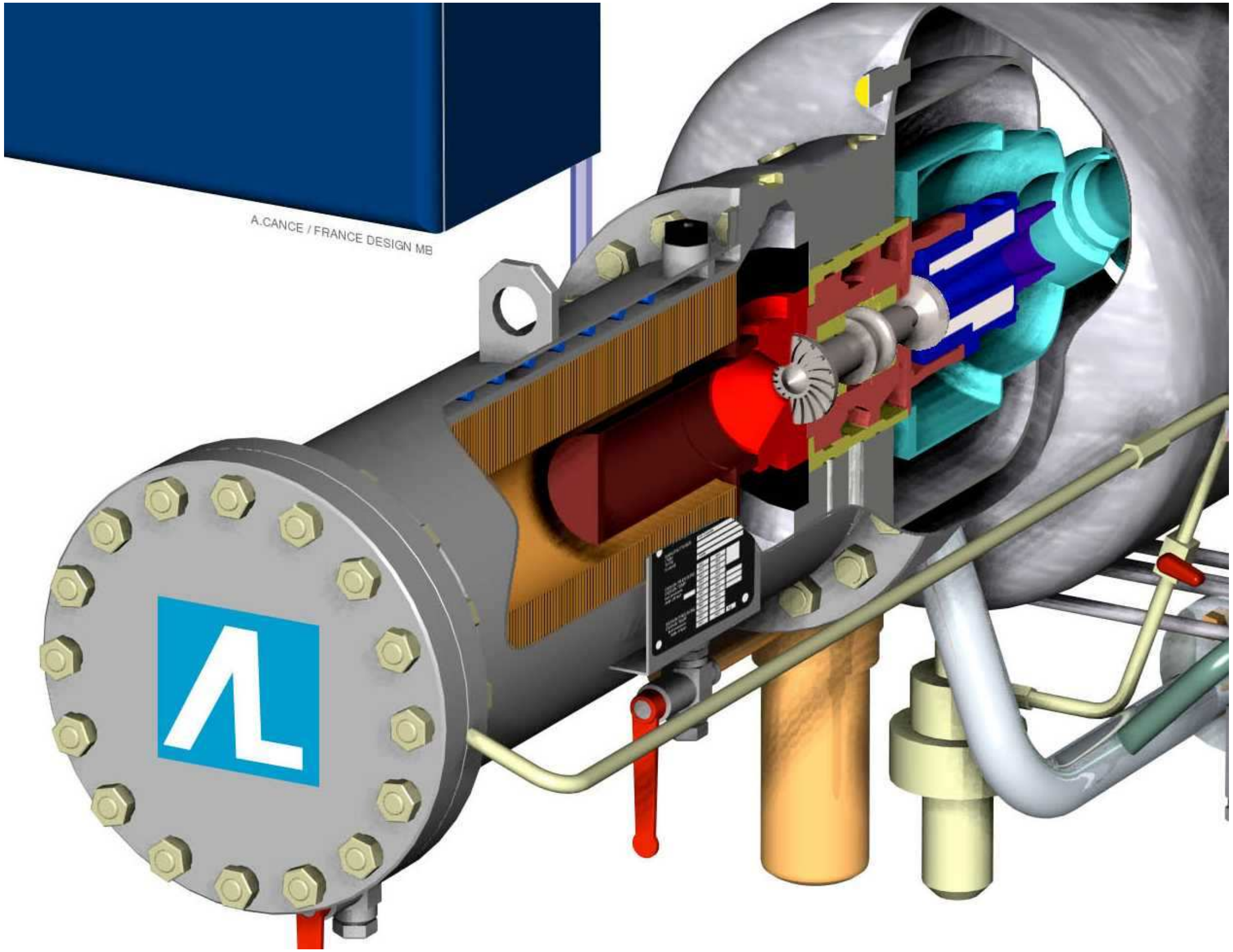
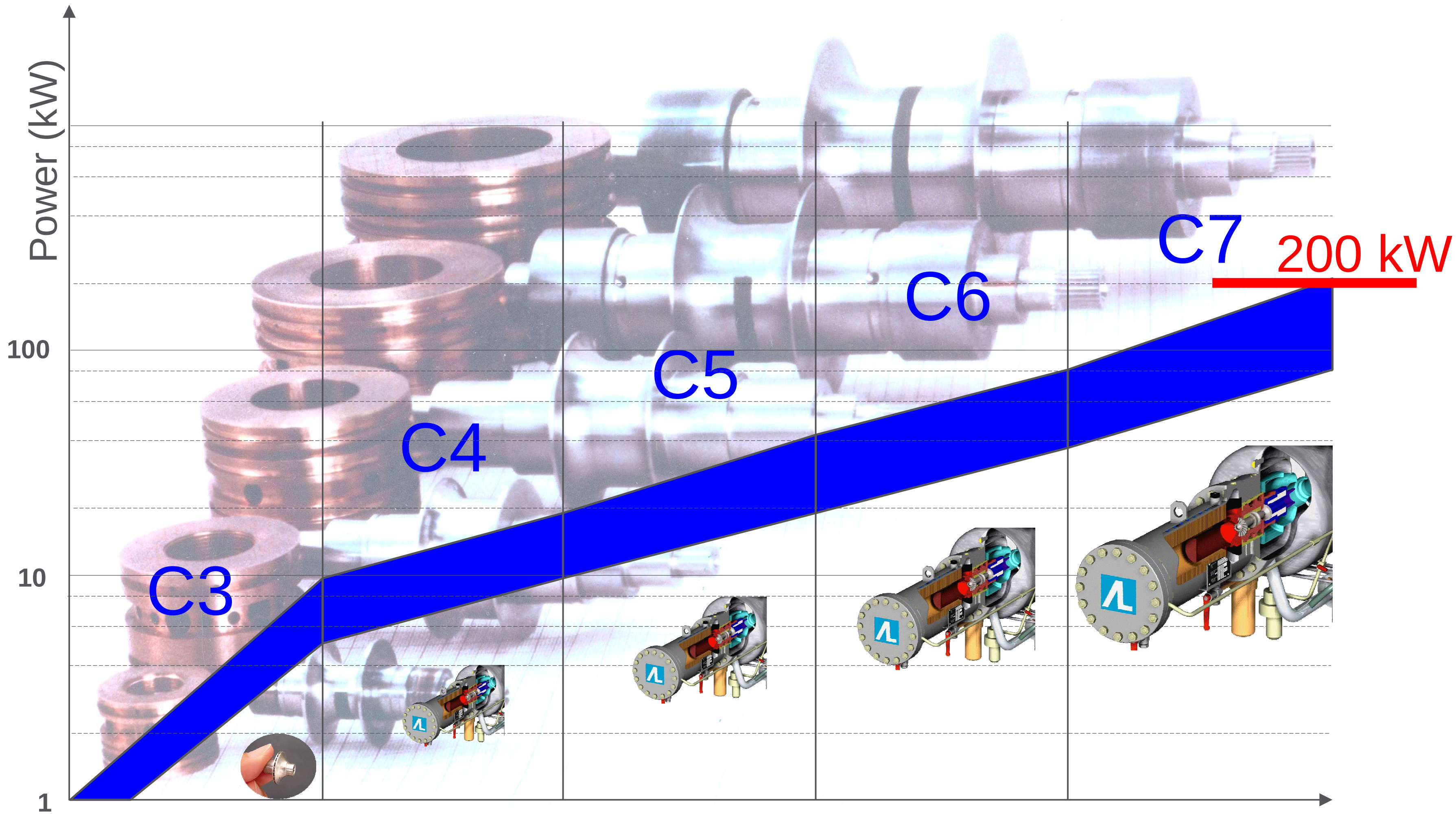


Air Liquide's Cryogenic Turbine Range



Helium 2 Turbines In The Workshop

The Air Liquide Turbine Test Bench

All turbines are cold tested
at the Sassenage AIR LIQUIDE

Measurement of
pressures, temperatures
and mass flows, calculation
of efficiency and power