NET POWER

Truly Clean, Cheaper Energy

March 2018

AGENDA

- NET Power Allam Cycle Introduction
- NET Power 50MW test plant and process diagram overview
- Atlas Copco Gas Turbine Driven Integrally Geared sCO2 Compressor
  - Technical challenges overview
- Next Steps

NET POWER'S ALLAM CYCLE ADVANTAGE

USING THE ALLAM CYCLE TO MEET THE WORLD'S CLIMATE TARGETS WITHOUT PAYING MORE FOR ELECTRICITY.

USING THE ALLAM CYCLE, NET POWER

- PRODUCES **ELECTRICITY FROM NATURAL GAS**
- DEMONSTRATES **SUPERIOR TOTAL ECONOMIC ADVANTAGE** TO EXISTING NATURAL GAS POWER PLANTS
- **CAPTURES OR ELIMINATES SUBSTANTIALLY ALL OF THE CARBON AND NON-CARBON ATMOSPHERIC EMISSIONS** WITHOUT ANY ADDITIONAL COST
- **DOES NOT REQUIRE WATER** (AT A SMALL REDUCTION IN EFFICIENCY)
- CAN **USE INEXPENSIVE FUELS** SUCH AS ACID GAS, SOUR GAS, ASSOCIATED GAS, AND PRODUCED GAS
- **PRODUCES VALUABLE GASES**, INCLUDING CO_2, N_2, O_2 AND AR


"NET Power does not make natural gas a bridge—or a pier.
It makes it a destination."
-Senior DOE official

ALLAM CYCLE NATURAL GAS PLATFORM

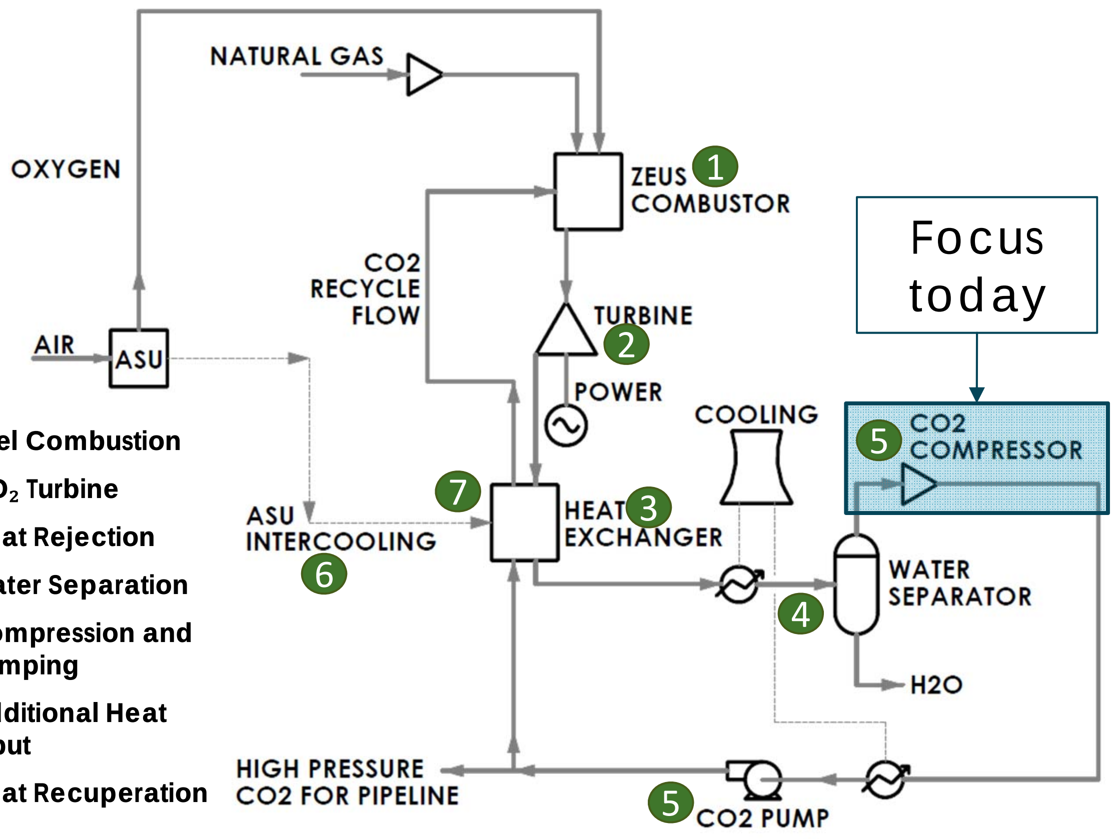
OXY-FUEL, SEMI-CLOSED-LOOP, WITH A CO_2 WORKING FLUID.

55 TO 59% (LHV) NET EFFICIENCY (CAN BE ADJUSTED DEPENDING ON NEEDS), WITH CAPTURE OF >97% OF CO_2.

CO_2 AND WATER ARE THE ONLY EFFLUENTS. ASU ALSO PRODUCES SALEABLE BYPRODUCTS.

A NEAR-TERM SOLUTION THAT UTILIZES MOSTLY EXISTING EQUIPMENT IN A NOVEL WAY.

1. Fuel Combustion
2. CO_2 Turbine
3. Heat Rejection
4. Water Separation
5. Compression and Pumping
6. Additional Heat Input
7. Heat Recuperation



INTEGRALLY GEARED COMPRESSOR SOLUTION

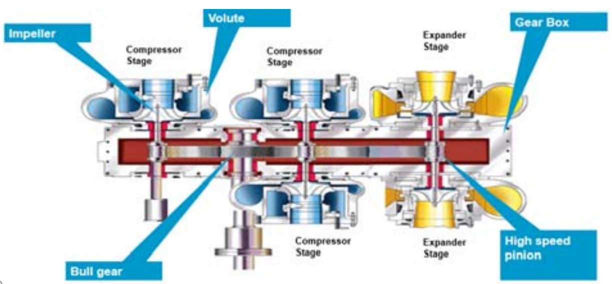
Gas Turbine Driven Atlas Copco Compressor Solution

Why integrally geared?

Comparison summary based on same process condition

	Atlas Copco Integrally Geared	Barrel Type (Single Shaft or Inline)
		
Size (L x W x H) m	2.5 x 3.5 x 3	4 x 3 x 2
Weight (tons)	12 tons	20 tons
Polytropic Efficiency %	80%	78%
Installation Cost Factor* (% of Compressor Cost)	50%	70%
Annual Compressor Maintenance Cost Factor** (% of Compressor Cost)	0.8%	1%
No. Of Impellers	4	5 (minimum)

* Based on Real Estate, Crane Capacity and Time, Labor etc.
** Based on Oil Consumption, Rotor Wear (Performance Degradation) and Replacement



What is different about this project?

- High speed driver
  - Almost twice normal 2-Pole driver speeds
- Compressor – Gas Turbine – Generator Train
  - Challenging Rotordynamic requirements
  - Extended Start and Stop Sequences
  - Lowest common denominator controls
- High pressure sCO2
  - Rotordynamic cross-coupling
  - Intricate Sealing Systems

INTEGRALLY GEARED COMPRESSOR SOLUTION

High Speed Driver Challenges

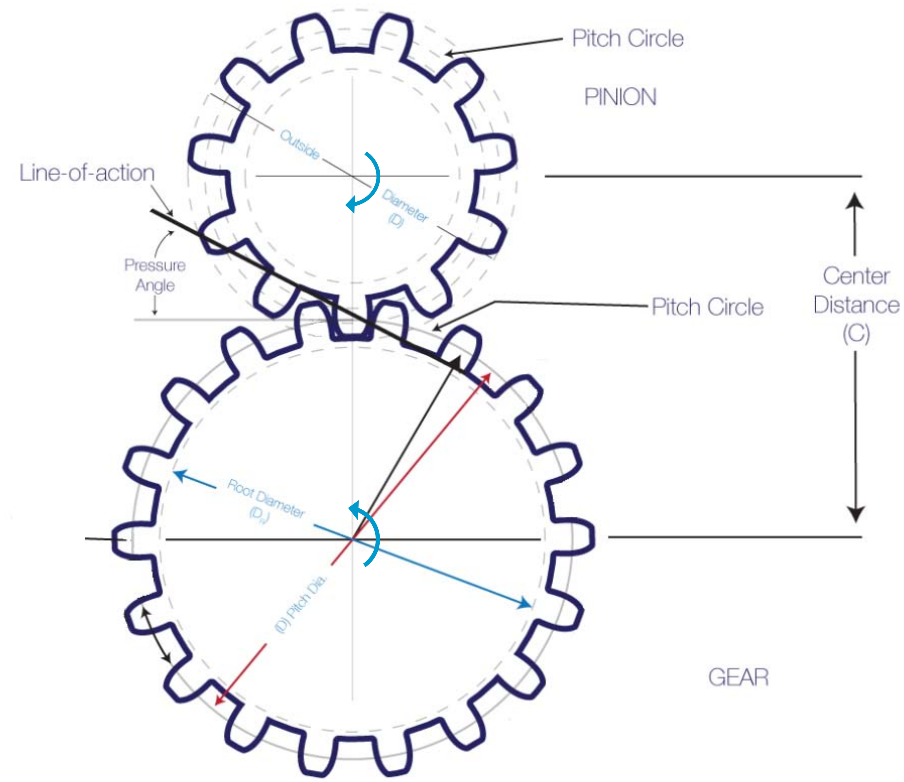
Pitch Line Velocity Limitations

- Physical limitations of the rate at which the loading and unloading of the tooth contact occurs
- API recommends a maximum of 150m/s, while Atlas Copco has experience for up to 185m/s

V: Pitch line velocity (m/s)
d: Gear pitch line diameter (m)
n: Revolutions per minute

$$V(m/s) = (\frac{\pi * d * n}{60})$$

- This therefore means depending on rotational speed there is a given maximum diametrical limit.

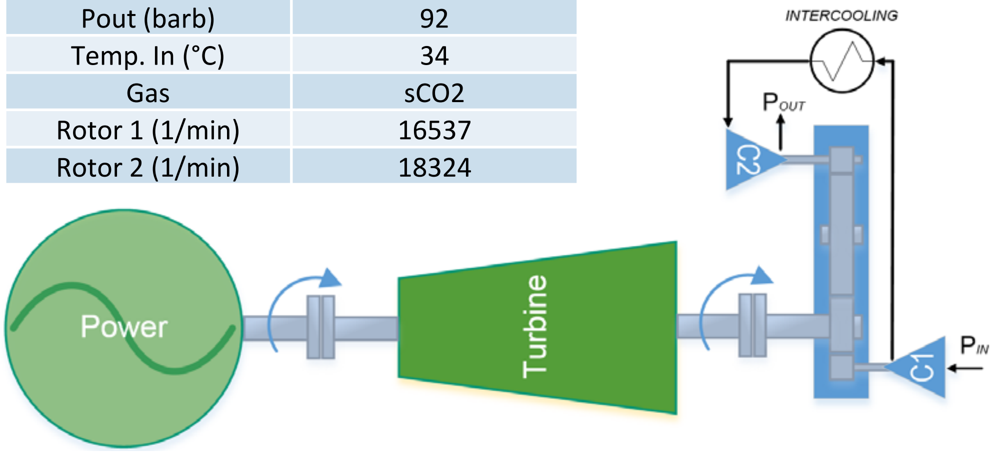


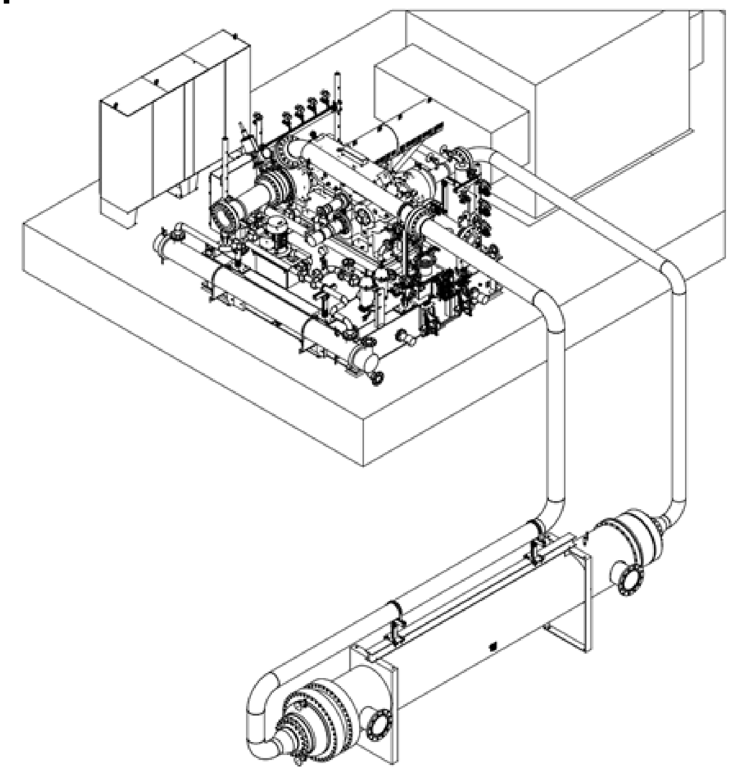
INTEGRALLY GEARED COMPRESSOR SOLUTION

Gas Turbine Driven Atlas Copco Compressor Solution

NET Power Test Plant sCO2 Compressor

At a Glance	
Driver Power (kW)	9650
Driver Speed (1/min)	6000
Suction Volume (m3/h)	6880
Pin (bara)	27
Pout (barb)	92
Temp. In (°C)	34
Gas	sCO2
Rotor 1 (1/min)	16537
Rotor 2 (1/min)	18324





March 2018

Atlas Copco

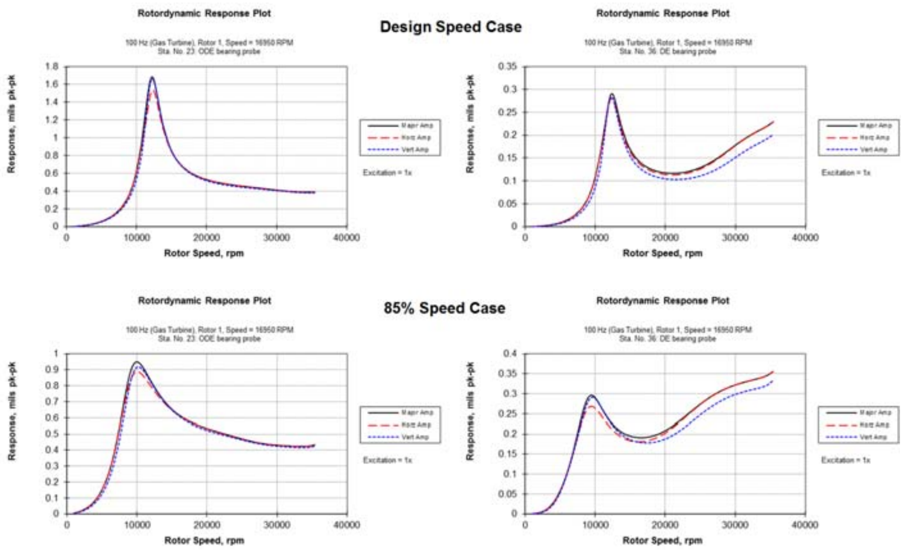
INTEGRALLY GEARED COMPRESSOR SOLUTION

Compressor – Gas Turbine – Generator Train

Challenging Rotordynamic requirements

- In this project the operational speed range of the whole train is from 85% to 100% design speed
- Lateral
  - Enough margin from the natural frequencies (critical speeds) of the rotors, and low speed gearing needs to be designed into the system
  - All operating cases were checked for changes to the rotordynamic response plots
- Torsional
  - When calculating the torsional reactions of the train this also needs to be accounted as the string accelerates under load to the design speed

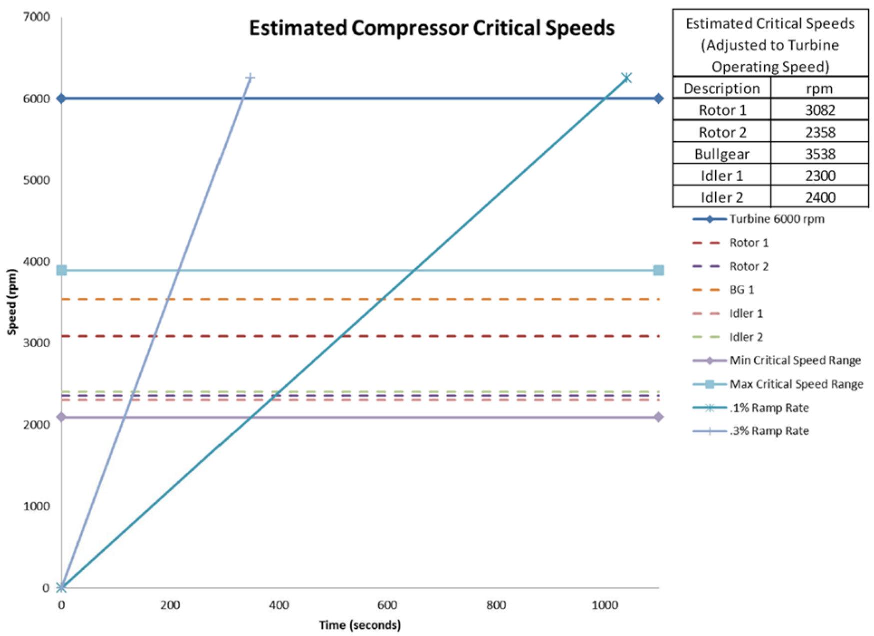
Example of Rotor 1



INTEGRALLY GEARED COMPRESSOR SOLUTION

Compressor – Gas Turbine – Generator Train

Preliminary Critical Speed Map



Estimated Critical Speeds (Adjusted to Turbine Operating Speed)	
Description	rpm
Rotor 1	3082
Rotor 2	2358
Bullgear	3538
Idler 1	2300
Idler 2	2400

Lowest common denominator controls

- During execution, the start, stop and operating controls must constantly be discussed.
- Startup of a intricate train requires many holds and acceleration rates to be discussed with all parties.
  - This delicate balance between multiple parameters such as rotordynamic, aerodynamic, process and mechanical limitations is crucial to an effective solution.
- Stop protocols will also need to be organized depending on equipment hierarchies.

INTEGRALLY GEARED COMPRESSOR SOLUTION

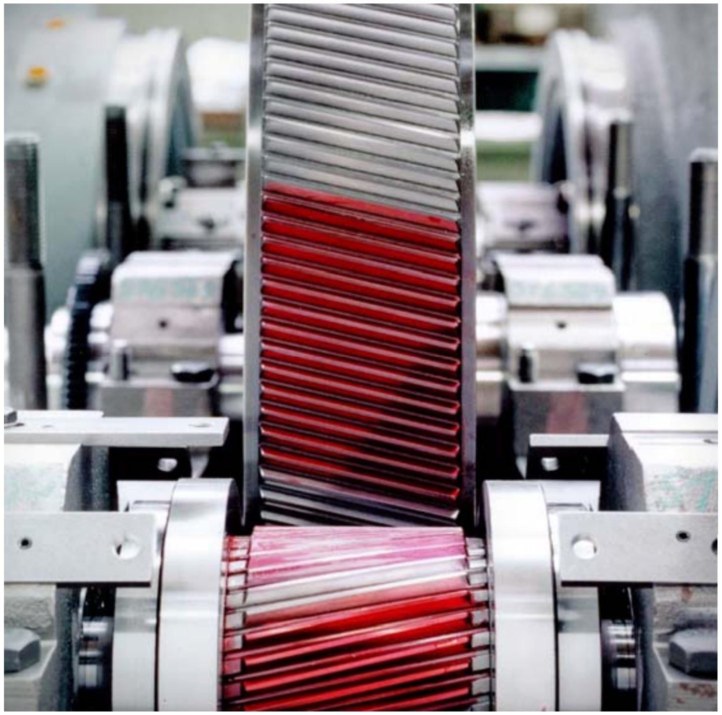
High pressure sCO2

- Rotordynamic cross coupling must be investigated
  - This is different than many other compressor projects due to the high density found in sCO2
- Seal components require special attention
  - Dry Gas Seals are sensitive to fluid and simulations should be produced to ensure the process remains stable as it moves across the seal face
  - Seal lines can be mounted with either heat tracing or seal gas heaters to ensure proper temperatures (phases) remain as intended.
  - Seal feeds and drains should be sloped to avoid liquid retention
  - Explosive decompression!

INTEGRALLY GEARED COMPRESSOR SOLUTION

Conclusion

- Employing a integrally geared compressor in a sCO_2 application presents many challenges. The complexity of the application is only increased when operating in a Compressor – Gas Turbine – Generator train.
- Proper planning and experience helps to mitigate the risk and allows for a robust design.
- Like a well designed gear mesh, clearly defined requirements and good inter-team communication helps produce the best outcome during execution.



IN PLANNING FOR FIRST COMMERCIAL PROJECT

NET POWER IS READY TO ENGAGE IN DETAILED SITE PLANNING WITH POTENTIAL PROJECT PARTNERS.

COMPLETED DETAILED PRE-FEED IN 2017 FOR A 303 MWE SINGLE TRAIN SYSTEM, 120 BAR CO_2 CAPTURE.

TARGETING ONLINE DATE IN 2021. SEEKING TO ISSUE A NOTICE-TO-PROCEED IN 2018.

Plant outputs	
Electric Output	303MW
CO_2 Output	• 890,000 ton/year • 40 million scf/day
N_2 Output	4.2 MM ton/year
Ar Output	70,000 ton/year
ASU O_2	4,200 ton/day
Site Area	13 acres

FOAK Commercial Plant Performance*		
Thermal Heat Input (MW)	**549.1**	**100%**
Turbine Shaft Power (MW)	**453.0**	**-18%**
Shaft-mounted CO_2 compressor and generator	-47.9	-8%
Gross Electrical Output (MW)	**405.1**	
ASU auxiliary load	-65.1	-12%
BOP parasitics (pumps, cooling tower, etc.)	-37.5	-7%
Net Electrical Output (MW)	**302.5**	**55.1%**
Net Plant Efficiency (% on LHV)*	55.1%	55.1%
Net Plant Heat Rate (LHV)*	6,193	6,193

* Efficiency optimized for US economics. For countries with high gas prices, 58.9% efficiency is achievable at higher capital cost.

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Sustainable Productivity