450 MW_e sCO_2 Power Cycles for Fossil-based Power Generation – Compressor concepts

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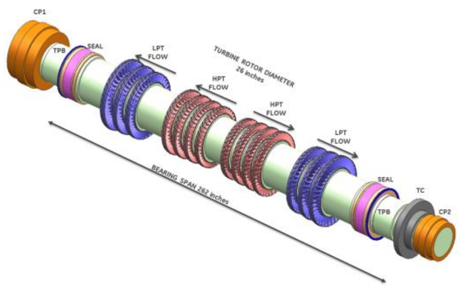
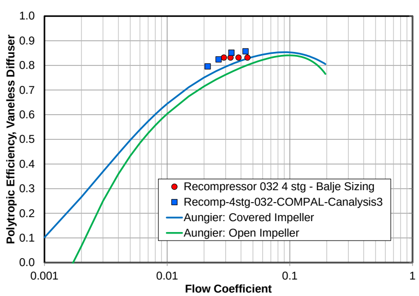
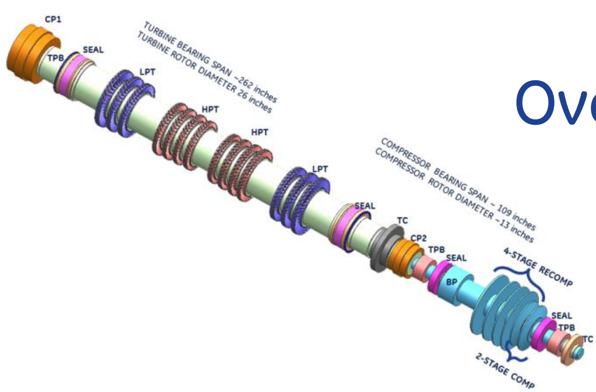
The following slides show the conceptual design method and compares the compressor to literature



Background and design process



Preliminary design and comparisons



Overall layout & comparison with literature

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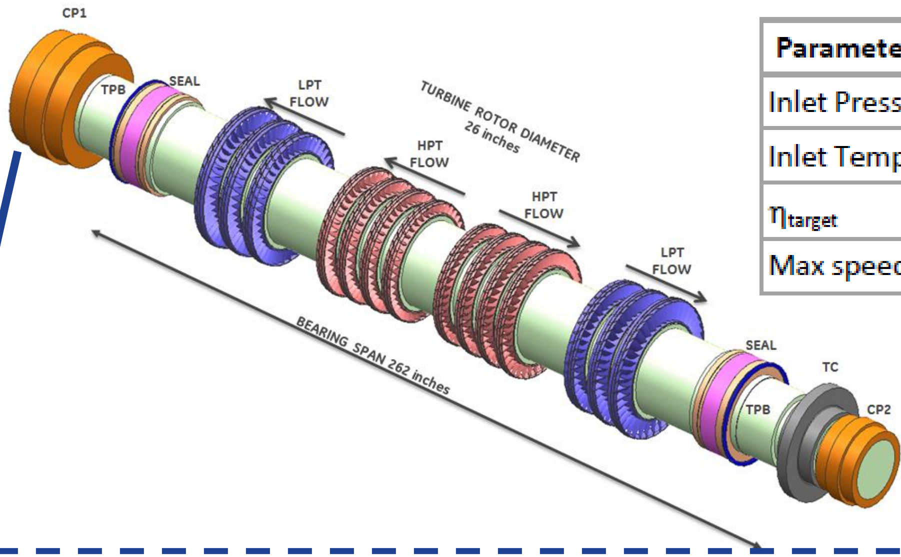
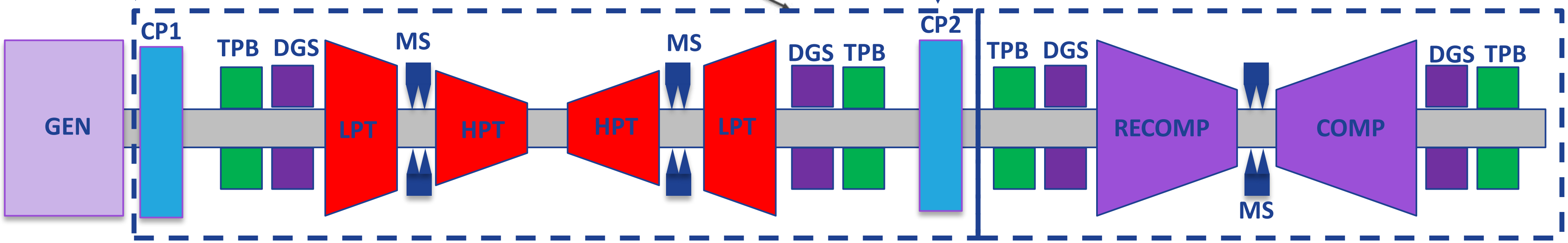
The goal of this work is to conceptually design a compressor to couple with the turbine train

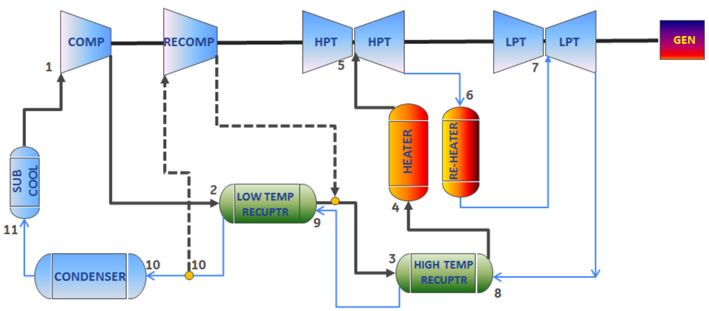


Parameter	Units	Main Compressor	Recompressor
Inlet Pressure P_1	bara	65.9	67.1
Inlet Temperature T_1	°C	21.5	54.8
η_{target}	-	0.79	0.8
Max speed	rpm	3600	3600



Experience charts and a meanline tool are used to design the compressor and recompressor

Thermodynamic cycle modeling



Balje Method

- Experience-based method for 1 stage
- Specific speed + efficiency chart to calculate impeller diameter
- Correlations for hub diameter and axial spacing

Preliminary multi-stage radial compressor/recompressor

- No. of stages
- Impeller & hub diameter
- Axial spacing

COMPAL Design Tool

- Euler turbomachinery equations
- Loss models

Final multi-stage radial compressor/recompressor

- No. of stages
- Impeller & hub diameter
- Axial spacing
- Efficiency
- Off-design performance

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The Balje experience chart is adapted to develop a multi-stage compressor concept design

Inputs:
- P_{t1}
- T_{t1}
- P_{t2}
- Rotation speed
- Number of stages
- Stage inlet Mach number (to estimate static conditions)

↓

Stage Inlet:
- If not first stage, use P_t and T_t from previous stage discharge
- Calculate thermodynamic properties at total conditions
- Use stage inlet Mach number to estimate static conditions
- Calculate inlet density

↓

Balje Calculations
- Enter an ideal enthalpy loading for the stage
- Calculate n_s
- Calculate d_s and h from curve fits to the Baljé chart
- Use D_s to calculate the impeller diameter
- Calculate power from ideal enthalpy and efficiency

$$N_s = \frac{N\sqrt{Q}}{\Delta h^{3/4}}$$

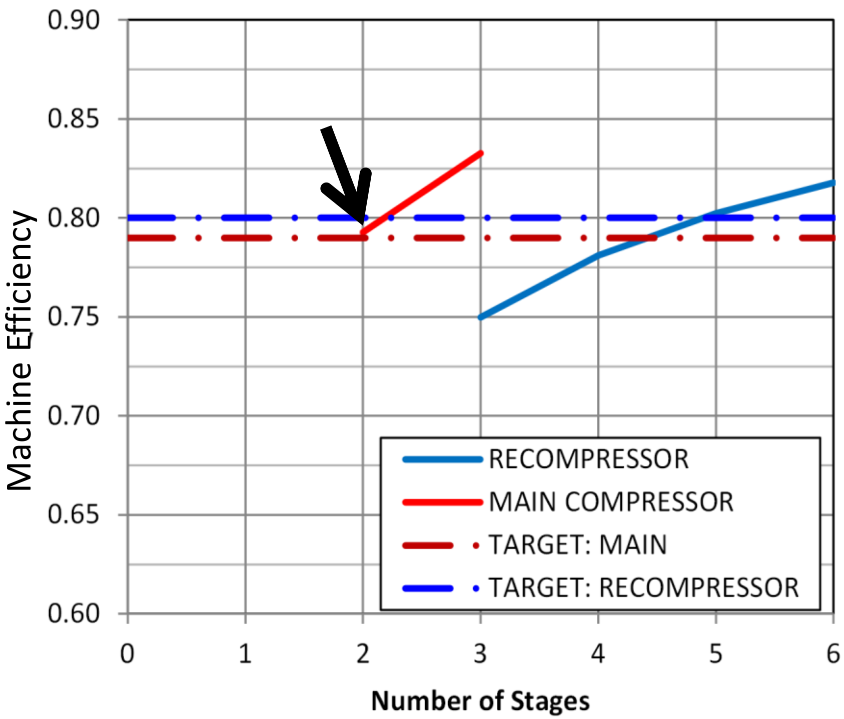
$$D_s = \frac{D\Delta h^{1/4}}{\sqrt{Q}}$$

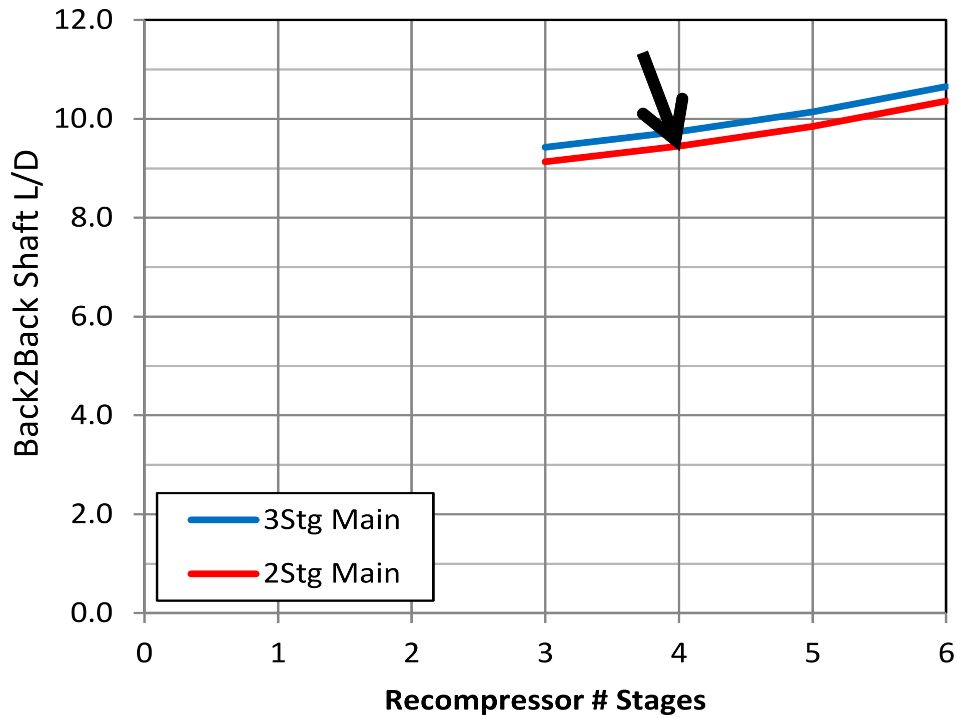
↓

Stage Discharge:
- Calculate P_{t2} with REFPROP from Δh_{ideal} and inlet entropy
- Calculate T_{t2} with REFPROP from Δh_{actual} and total pressure

Last stage? NO → back to Stage Inlet; YES → STOP

The number of compressor stages was selected by both efficiency and shaft L/D





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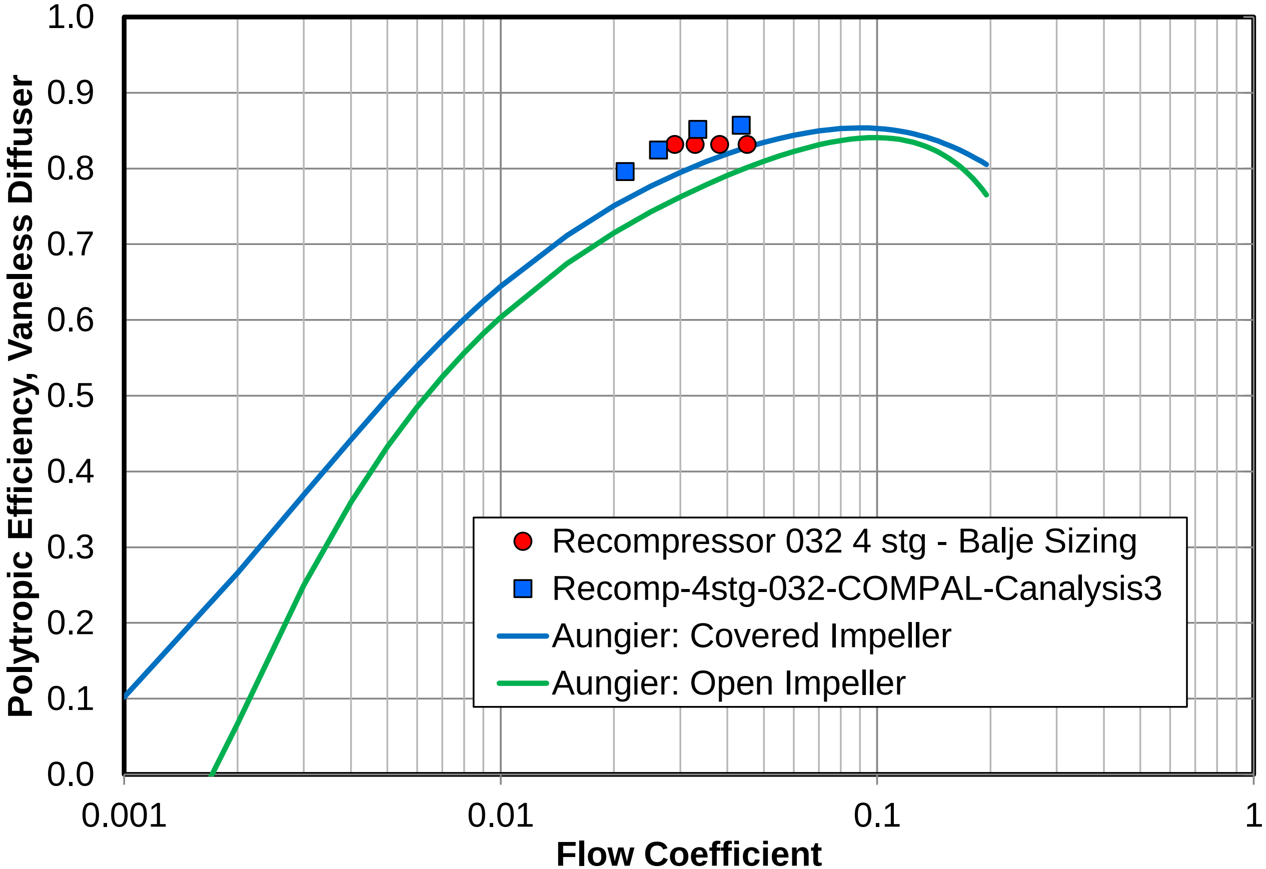
The polytropic efficiency from the meanline tool agreed with the Balje method and experience



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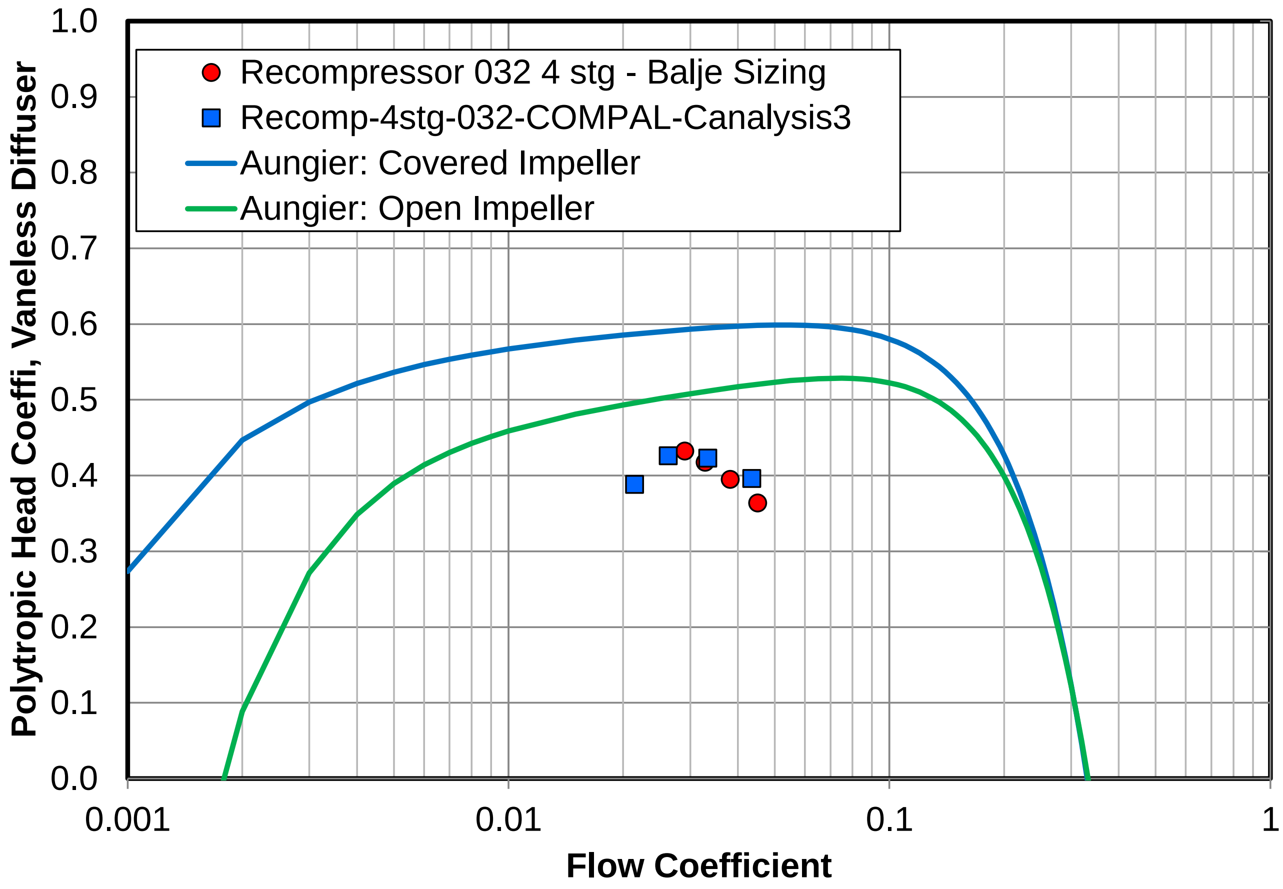
The polytropic head from the meanline tool and the Balje method were less than experience



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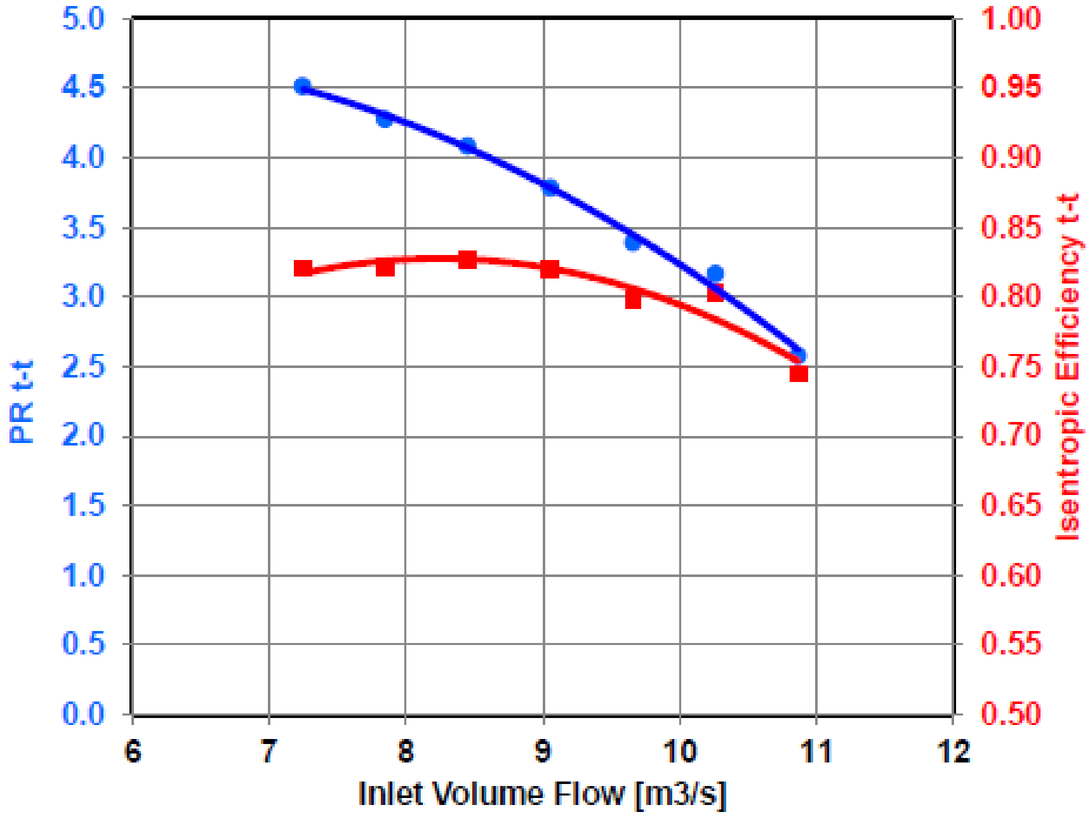
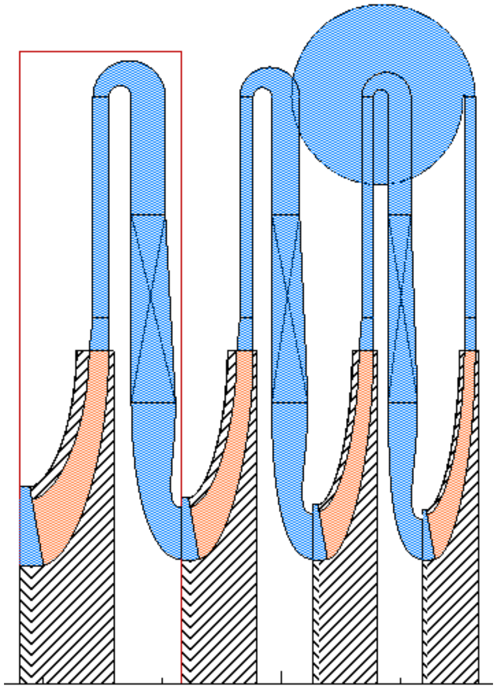
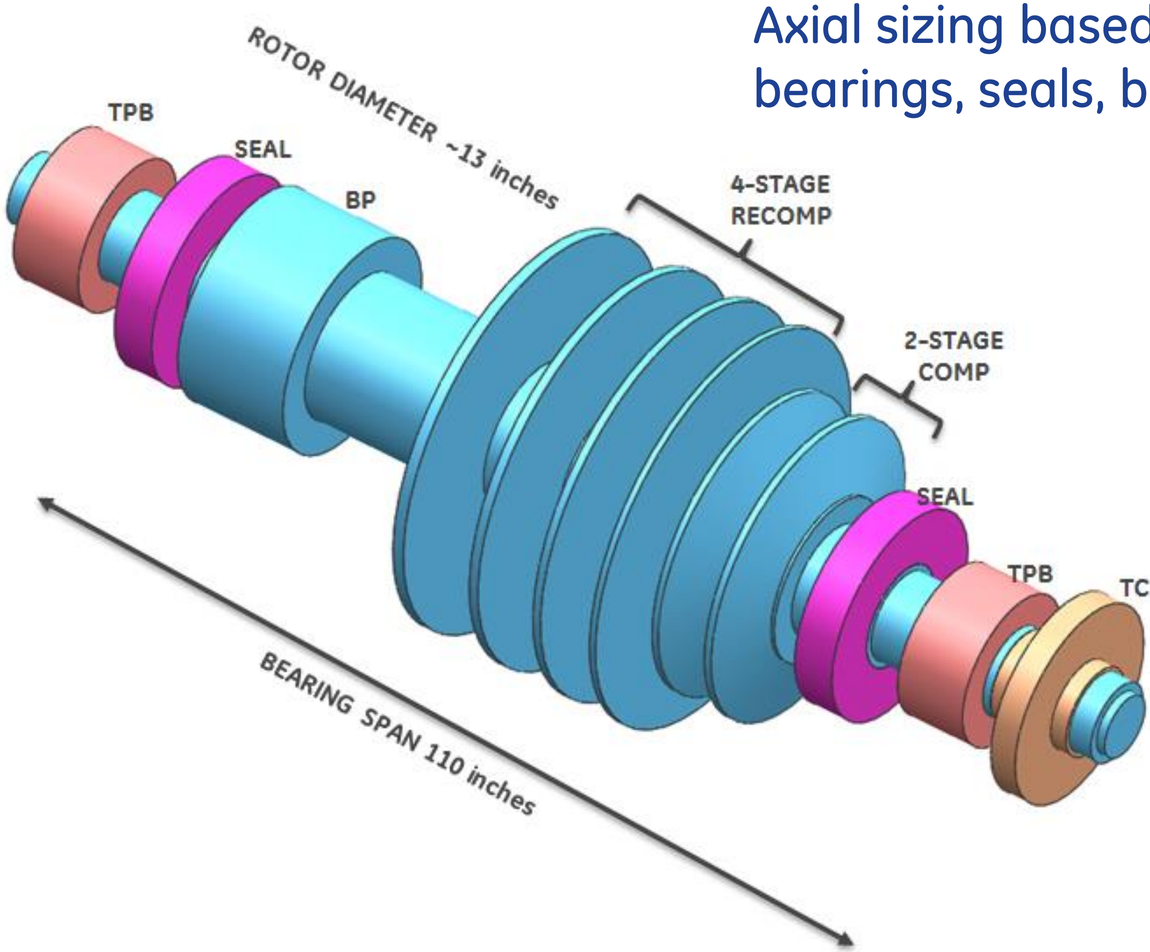
The meanline tool was used to generate off-design estimates of the compressor performance



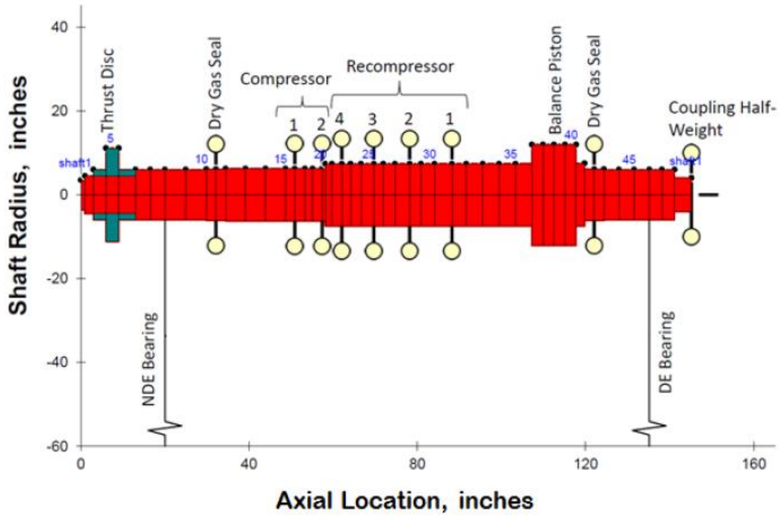


The conceptual layout is back-to-back with a 4 stage recompressor and 2 stage main compressor

Axial sizing based on impeller stages size, bearings, seals, balance piston



Compressor rotordynamic analysis



- Analysis performed using XLTRC code on two rotor lengths: nominal and 15% longer, and two bearing configurations
- Nominal rotor, stiff bearings – unacceptable configuration due to insufficient separation margins
- Long rotor, stiff bearings – acceptable configuration
- Nominal rotor, soft-mounted bearings – acceptable rotordynamics

Soft-mounted bearings, squeeze film damper and hole-pattern balance piston is the recommended configuration

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Literature Review: Compressors

Reference/Cycle	Dostal et al. [9]	Gong et al. [10]	Johnson et al. [11]	Moullec [1]	Mcdowell et al. [12]	Compressor Designs Present Work
Operating Speed [rpm]	3600	3600	-	3600	6000	3600
Length / Diameter [-]	8.6	-	-	6.6	10.2	8.4
Compressor Configuration	Axial	Radial, back to back	Radial, back to back	Axial	Radial, back to back	Radial, back to back
Compressor / Recompressor Power [MW]	- / -	41 / 81	- / -	250/370	131 / 220	65/123
Compressor Inlet / Outlet Pressure [bara]		77/ 200		74/320	77/282	67/ 257
Compressor Inlet / Outlet Temperature [°C]	42 / -	32 / 62	- / -	30/ 104	32 / 72	27 / 60
Compressor Mass Flow [kg/s]	2604	1915	-	5510	2653	2134
Compressor Specific Speed / Diameter (First Stage) [-]	- / -	0.38 / 6.01	- / -	1.06 / 2.95	0.25 / -	0.52 / 5.28
Compressor Efficiency [%]	96	85	-	90	81	83
Recompressor Inlet / Outlet Pressure [bara]	- / -	80 / 208	-	76 / 319	79 / 280	68 / 255
Recompressor Inlet / Outlet Temperature [°C]	- / -	73 / 164	- / -	95/ 275	77 / 205	65/ 198
Recompressor Mass Flow [kg/s]	1146	1331	-	3240	1398	1282
Recompressor Specific Speed / Diameter (First Stage) [-]	- / -	0.62/ 5.13	- / -	1.70/ 2.10	0.08/ -	0.66 / 4.46
Recompressor Efficiency [%]	94.8	89.8	-	90.0	79.9	80.1

Literature Review: Turbines

Reference/Cycle	Dostal et al. [9]	Gong et al. [10]	Johnson et al. [11]	Moullec [1]	Mcdowell et al. [12]	50 MW_e turbine present work [2]	450 MW_e turbine present work [2]
Speed [rpm]	3600	3600	-	3600	6000	9500	3600
Turbine configuration	-	-	Double flow	-	Double flow	Single flow	Double Flow
Turbine Power [MW]			1000	1677	220	14	360
Turbine inlet / outlet pressure [bara]	- / -	- / -	- / -	310.7 / 81.5	275.8 / 81	250.6 / 61.6	250.6 / 131.8
Turbine inlet / outlet temperature [°C]	- / -	- / -	- / -	620/565	704/543	700/ 518	700 / 612
Turbine mass flow [kg/s]	3750	-	-	8750	1150	343	3413
Turbine efficiency	92.9	-	-	93	90.1	90.3	90.6

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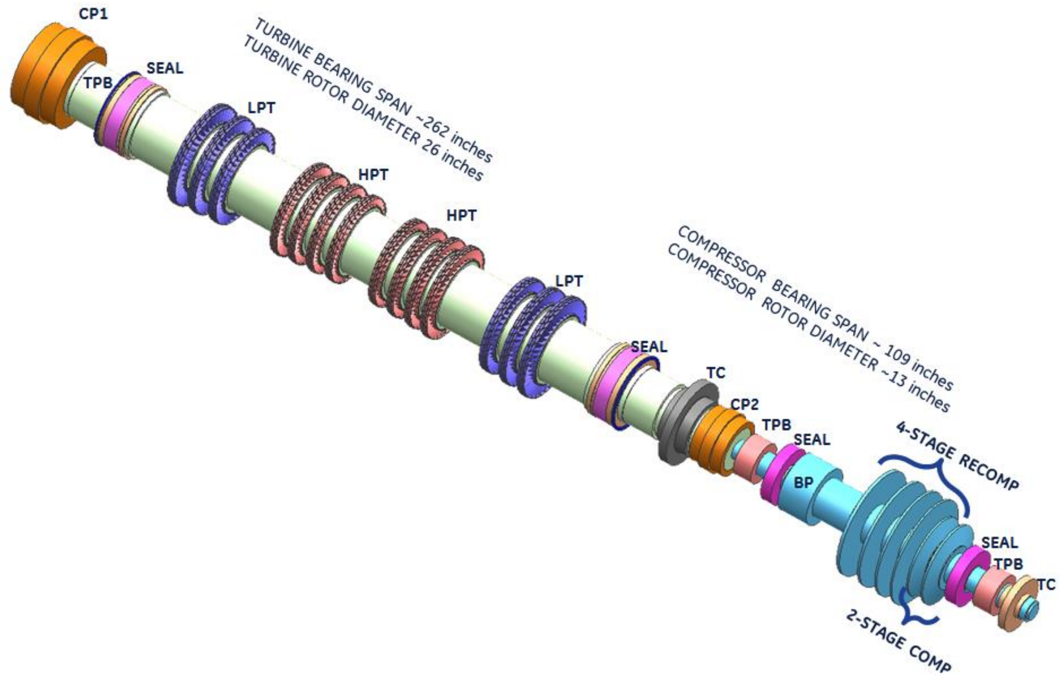
Summary and Conclusions



Compressor/Recompressor

- 2-stage main compressor, 4-stage recompressor, 3600 rpm
- Single casing, back-to-back configuration is feasible

Overall, a thermodynamic cycle with 51.9% cycle efficiency

- Reheat cycle with recompression for 450 MW net electric output
- Concept designs for turbines
- Concept designs for compressor/recompressor

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