High Temperature Compressors

Utilizing SMR steam for Industrial Heat

Shane Harvey

Manager – Compressor Technology

sharvey@elliott-turbo.com

EBARA ELLIOTT ENERGY

Vision

Be the **Best Solution Provider** in the energy sector by providing premier equipment and service, while actively leading sustainability efforts worldwide.

Mission

Provide **customer-centric solutions** in the quickest and most efficient manner possible.

Provide **safe working environments** that encourage challenge and change.

Act and **achieve as one team**.

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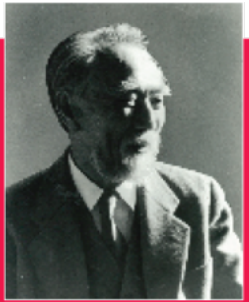
Ebara Elliott Energy History



Issey Hatakeyama, Ebara Founder

Ebara Corporation

1912 Founded Inokuty Type Machinery Office

1920 Established Ebara Corporation

1938 Construction of Haneda Plant in Japan

1961 Entry into the waste treatment plant business

1965 Construction of Fujisawa Plant

1985 Entry into precision machinery business

2010 Establishment of new Futtsu Plant in Chiba Prefecture, Japan, as global pump production base and transfer of functions of the Haneda Plant

2023 Ebara announces a market-driven reorganization to align with customer needs and enhance value creation: Energy, Building Service & Industrial, Infrastructure, Environmental Plants and Precision Machinery.

William Swan Elliott, Founder of Elliott

Elliott Company

1910 Founded by W.S. Elliott in Pittsburgh, Pennsylvania USA with boiler tube cleaners as first product

1920s-1940s Product expansion and acquisitions to include centrifugal compressors, steam turbines, motors, superchargers

1957-1987 Carrier Corporation ownership lead to global compression technology leadership for LNG and ethylene plants using refrigeration

1968 Entered technical cooperation with Elliott Company for compressors, steam turbines

1975 Sodegaura, Japan plant built to produce compressors, turbines

2002 Established Elliott Ebara Turbomachinery Corporation

Sodegaura, Japan

Jeannette, PA, USA

Futtsu, Japan

Compressor, Turbine, and Custom Pump Business of Ebara and Elliott

2000 Following years of initial collaboration based on licensing, Elliott Company was acquired by Ebara as a wholly owned subsidiary.

2011 Elliott Group Holdings Co., Ltd. was established, integrating business management in USA and Japan. Management integration of the compressor and turbine business runs in both countries.

2018 Cryopump business is transferred to Elliott Group

2024 The newly formed Energy Company announces the collective company's new brand Identity – Ebara Elliott Energy (EEE).

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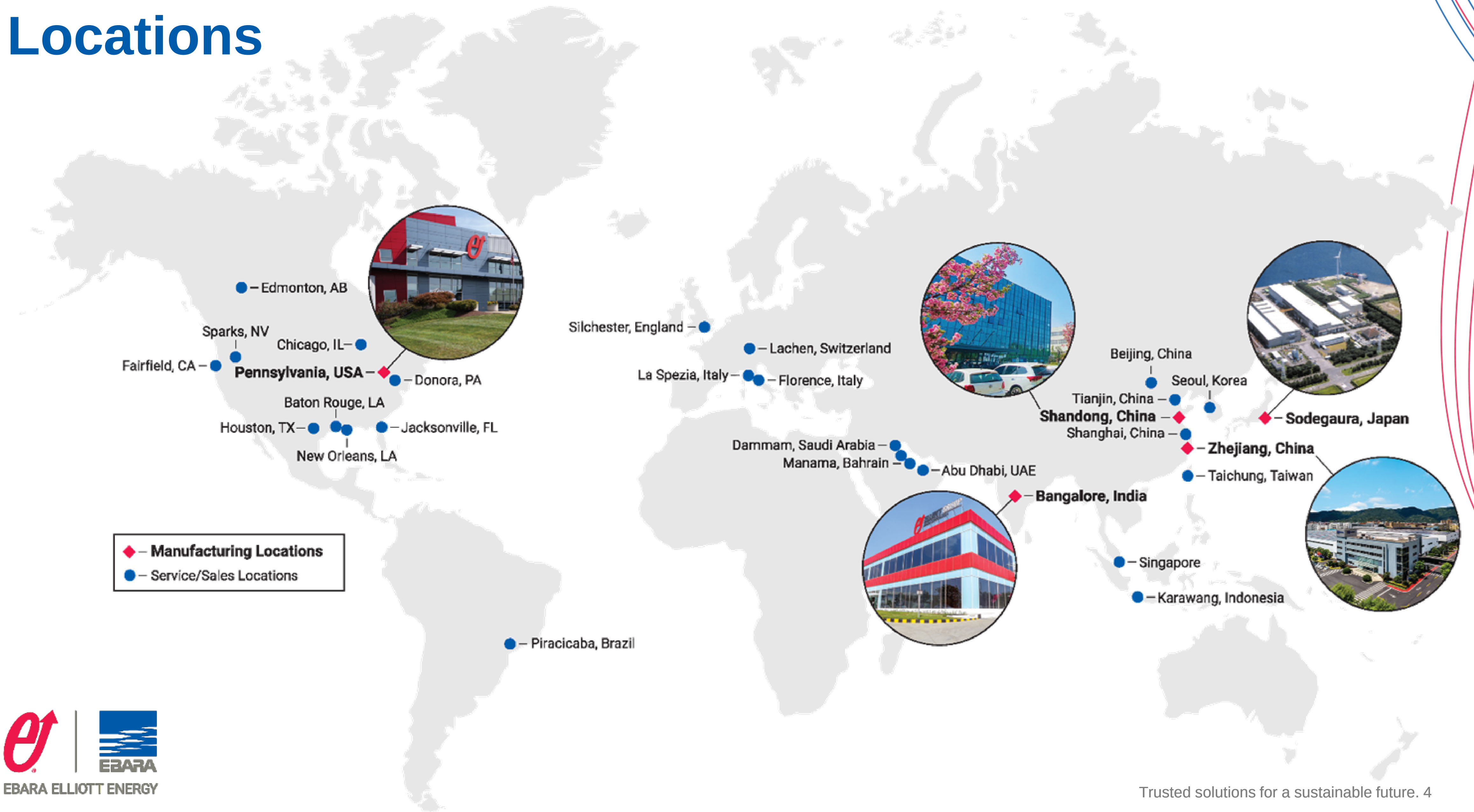
Locations



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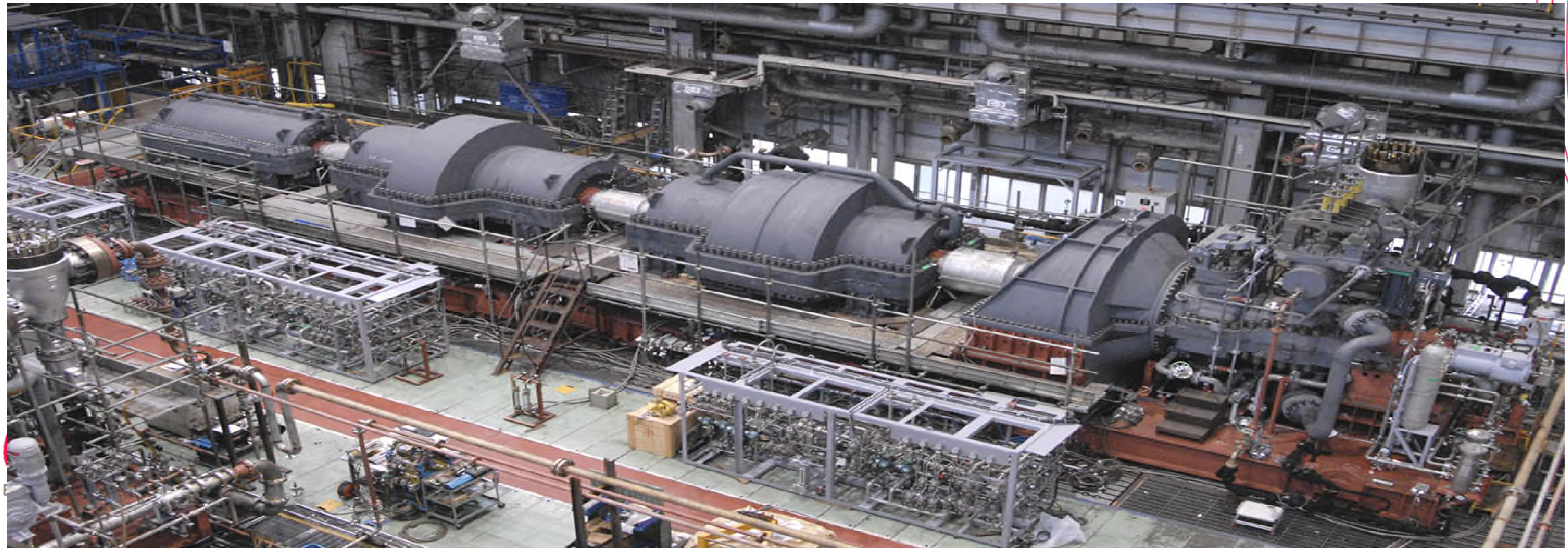
Centrifugal Gas Compressors

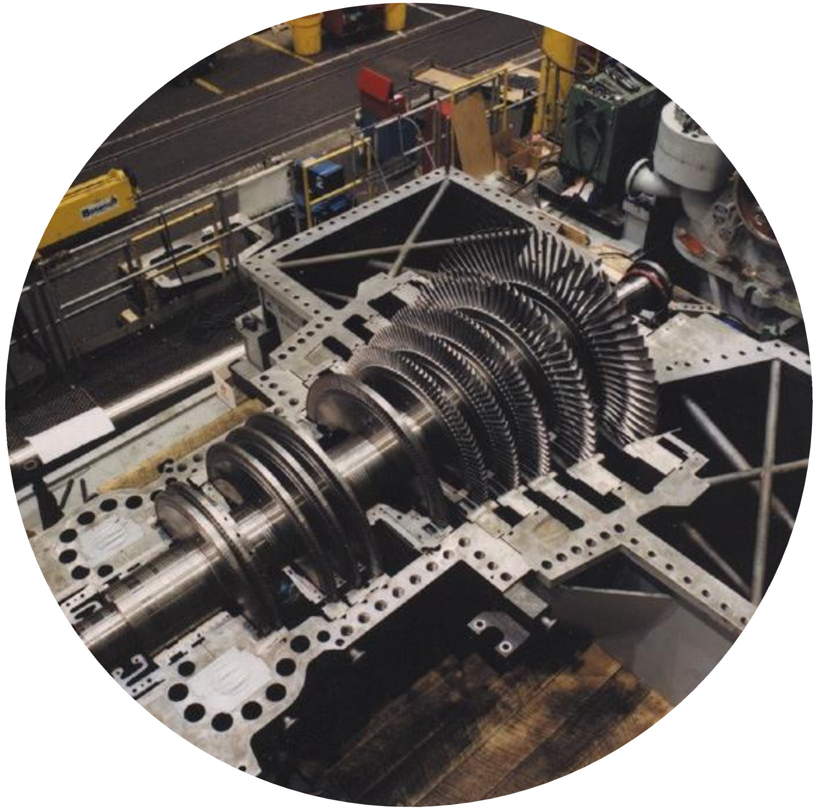
- API 617 Between Bearing Compressors
- Petrochemical, Refining, LNG,
- 15 Frame sizes from ~1,000cfm to >400,000icfm



Steam Turbines Capabilities

For nearly a century, Ebara Elliott Energy steam turbines have earned a reputation as the most rugged, reliable, and versatile drivers in the industry. These powerful workhorses provide exceptional value and performance in a broad range of mechanical and power generation applications, around the clock and around the globe, in environments of every extreme.

Frame:	Process Gas:	Speed Range	Configuration	Power Range
E LINE	Steam	3,500 - 10,000 RPM	Single Valve, Single & Multi Stage	< 7,500 kW
B LINE	Steam	7,000 - 14,000 RPM	Single Valve, Single & Multi Stage	< 4,500 kW
R LINE	Steam	7,000 - 14,000 RPM	Multi Valve, Multi Stage	< 23,000 kW
Q LINE	Steam	3,750 - 8,000 RPM	Multi-Valve, Multi Stage	< 30,000 kW
N LINE	Steam	2,500 - 7,500 RPM	Multi-Valve, Multi Stage	< 100,000 kW



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Power Recovery Expander Capabilities

For over 60 years, our proven design and technology has resulted in a fleet of rugged, reliable machines that recover nearly 0.5 GW of power from waste gas applications.

Frame:	Process Gas:	Capacity Range:	Inlet Temperature Limit:	Power Range
TH85	FCC Flue Gas, Blast Furnace, Coal Gas	< 467,000 lb/hr (< 220,000 kg/hr)	1400 °F (760 °C)	< 11,100 kW
TH100	FCC Flue Gas, Blast Furnace, Coal Gas	< 718,000 lb/hr (< 330,000 kg/hr)	1400 °F (760 °C)	< 18,650 kW
TH120	FCC Flue Gas, Blast Furnace, Coal Gas	< 1,105,000 lb/hr (< 505,000 kg/hr)	1400 °F (760 °C)	< 29,840 kW
TH140	FCC Flue Gas, Blast Furnace, Coal Gas	< 1,700,000 lb/hr (< 772,000 kg/hr)	1400 °F (760 °C)	< 45,000 kW

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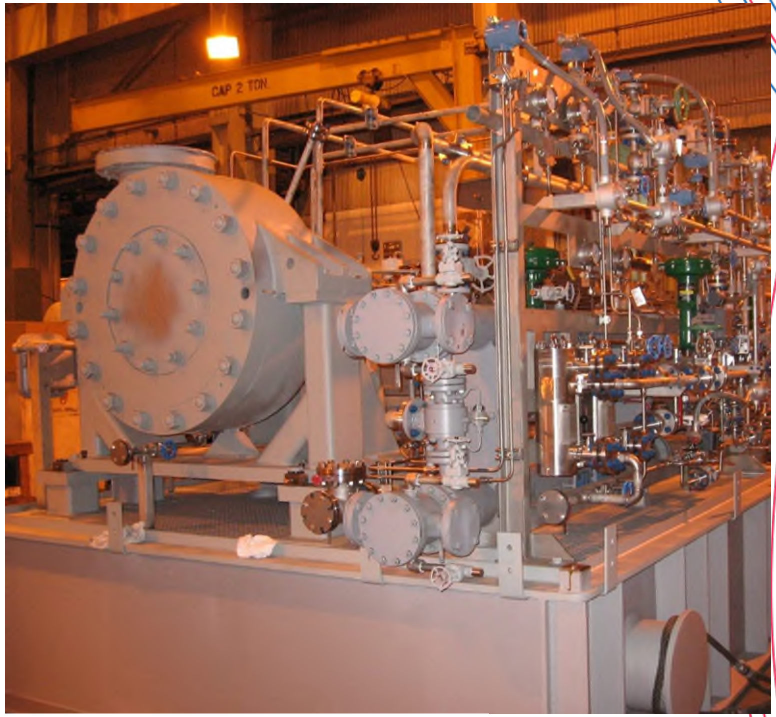
High Temperature Turbomachinery

- Single Stage Compressors (API 617):
  - >50 “P/PH” Compressors > 230ºC (450ºF) , 16 >315ºC (600ºF)
- Multistage Compressors (API 617):
  - >40 “M” compressors > 260ºC (500ºF),
- High Temperature Blower:
  - 700ºC inlet, 724ºC MAWT
  - Blower for Demonstration Molten Carbonate Fuel Cell
- Mechanical Drive Steam Turbines (API 612):
  - Powers >100MW
  - Installations with Steam inlet temperatures to: 535ºC (995ºF)
  - Installations with pressures to 125barg (1800psi)
- Power Recovery Expander:
  - Power >30MW
  - Inlet Temperatures to 760ºC (1400ºF)



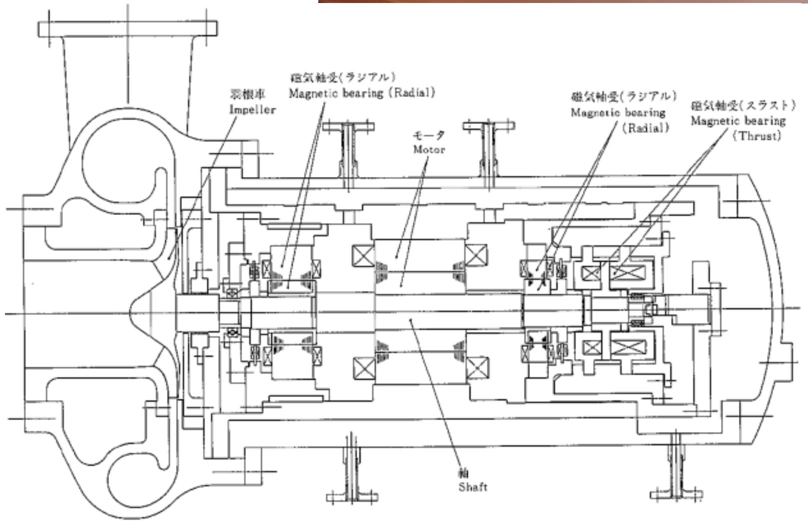


図2 高温ブロワ構造図
Fig. 2 High temperature blower assembly

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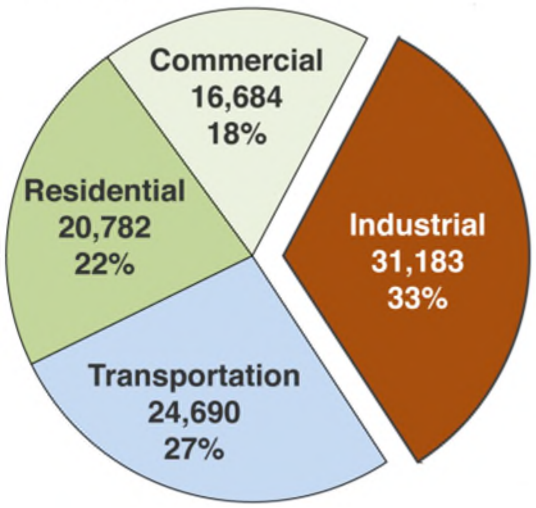
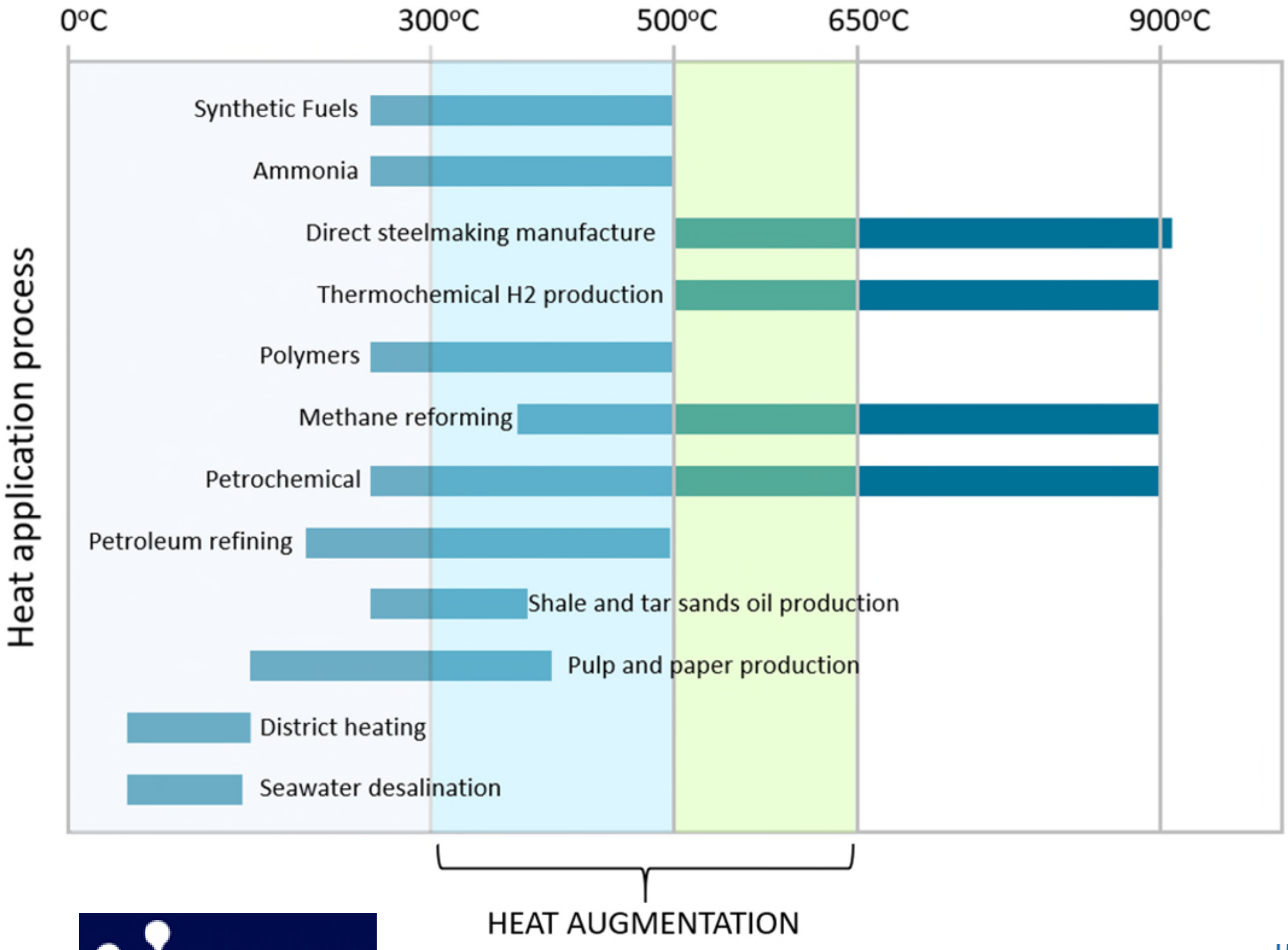
US Industrial Energy Consumption, Process Steam Applications

Total Annual Energy Consumption in US [Tbtu]



Over 50% of industrial energy is used for heat
~510 GW



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Courteous of Nuscale:

Separation of Nuclear and Commercial Requirements

<u>Site Boundary EPZ</u>: Emergency Planning Zone does not extend into the petrochemical plant.

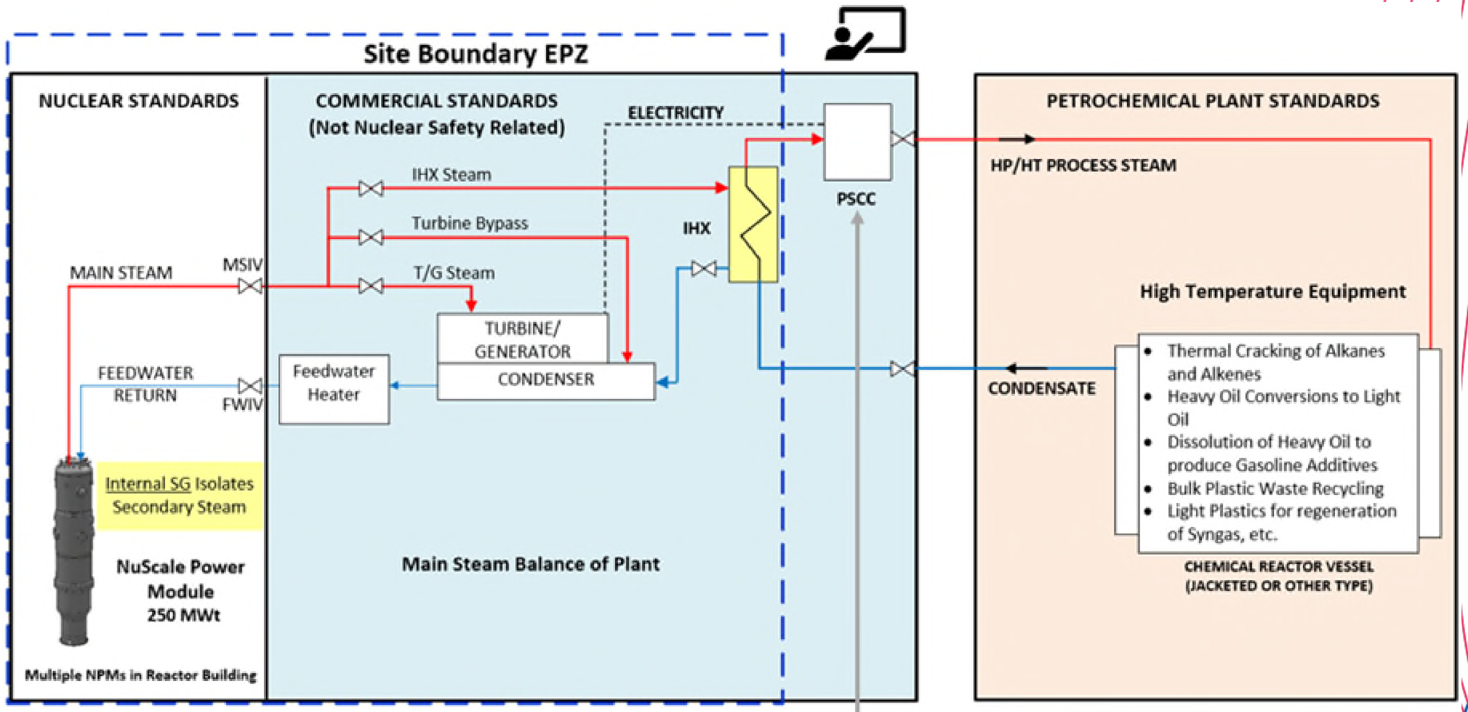
<u>Separation of Nuclear Reactor Coolant and Process Steam</u>

<u>Commercial Grade Balance of Plant</u>: Steam Side of a NuScale Plant is classified and approved as Non-safety related with no risk-significant structures, systems, and components.

- Seismic Category III (non-safety)
- No augmented design requirements
- Commercial Grade Components

<u>Minimizes Higher Temperature-Pressure Piping and Equipment:</u>

- Heat augmentation at the point of use
- Eliminates the need for very high-temperature materials for the full steam pathway
  Reduced cost (compared w/high-temp reactors)



Process Steam Conditioning and Control (Pressure and Heat Augmentation)

US Patent No.: US 12,331,663 B2

<u>Reference</u>: NuScale Final Safety Analysis Report, Chapter 10 Steam and Power Conversion System, Section 10.3 Main Steam System Table 10.3-4: Classification of Structures, Systems and Components. NRC ADAMS Accession # ML20224A499; Codified in 10 CFR 52 Appendix G.

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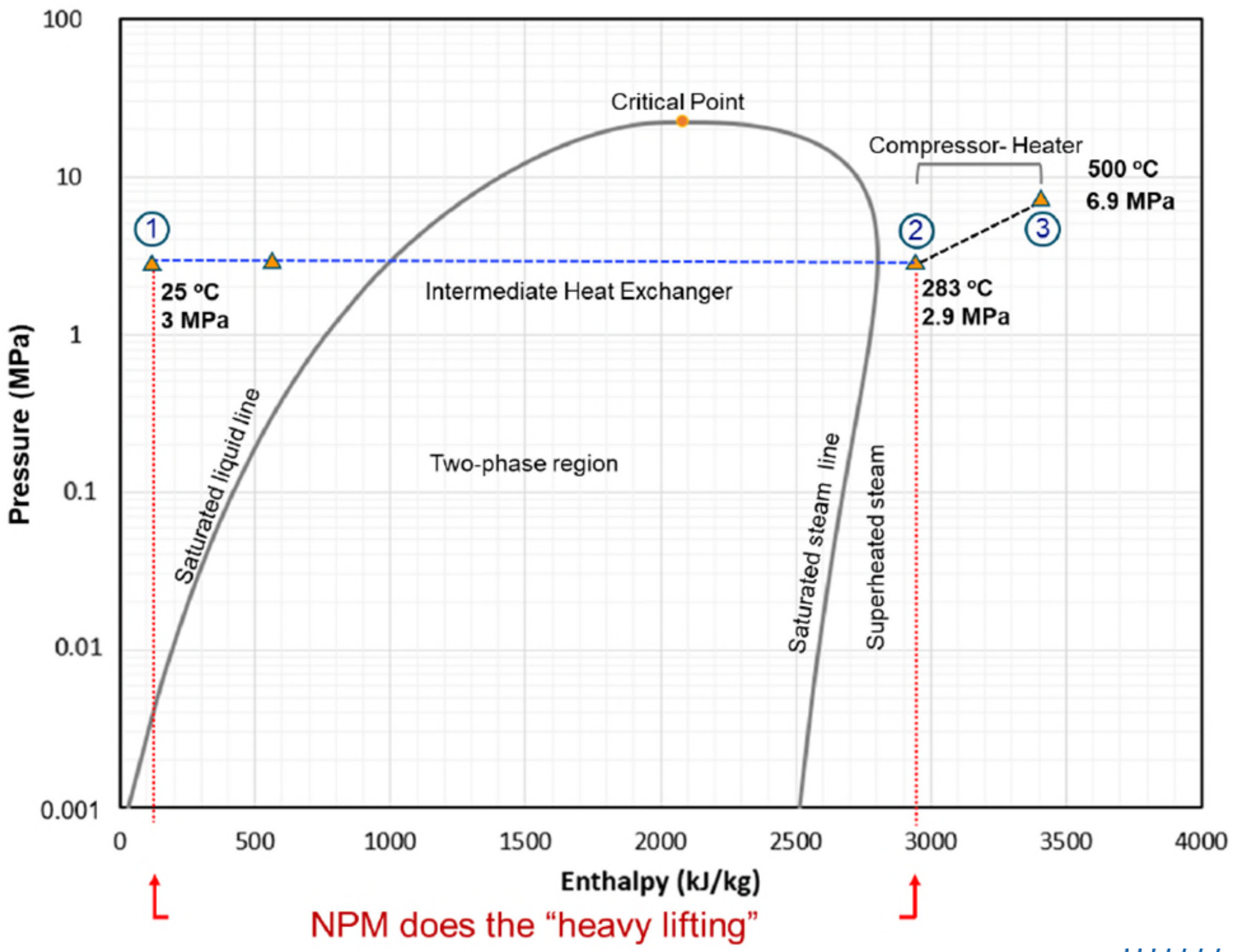
Courteous of Nuscale:

Providing Steam at Pressure and Temperature

- NPM provides the bulk of the thermal energy required to generate the process steam (phase change of liquid water to superheated steam).
- •Further elevating steam temperature and pressure to process conditions only requires an incremental amount of energy addition using steam compression and/or electric heaters
- •Overall thermal efficiency: 67%



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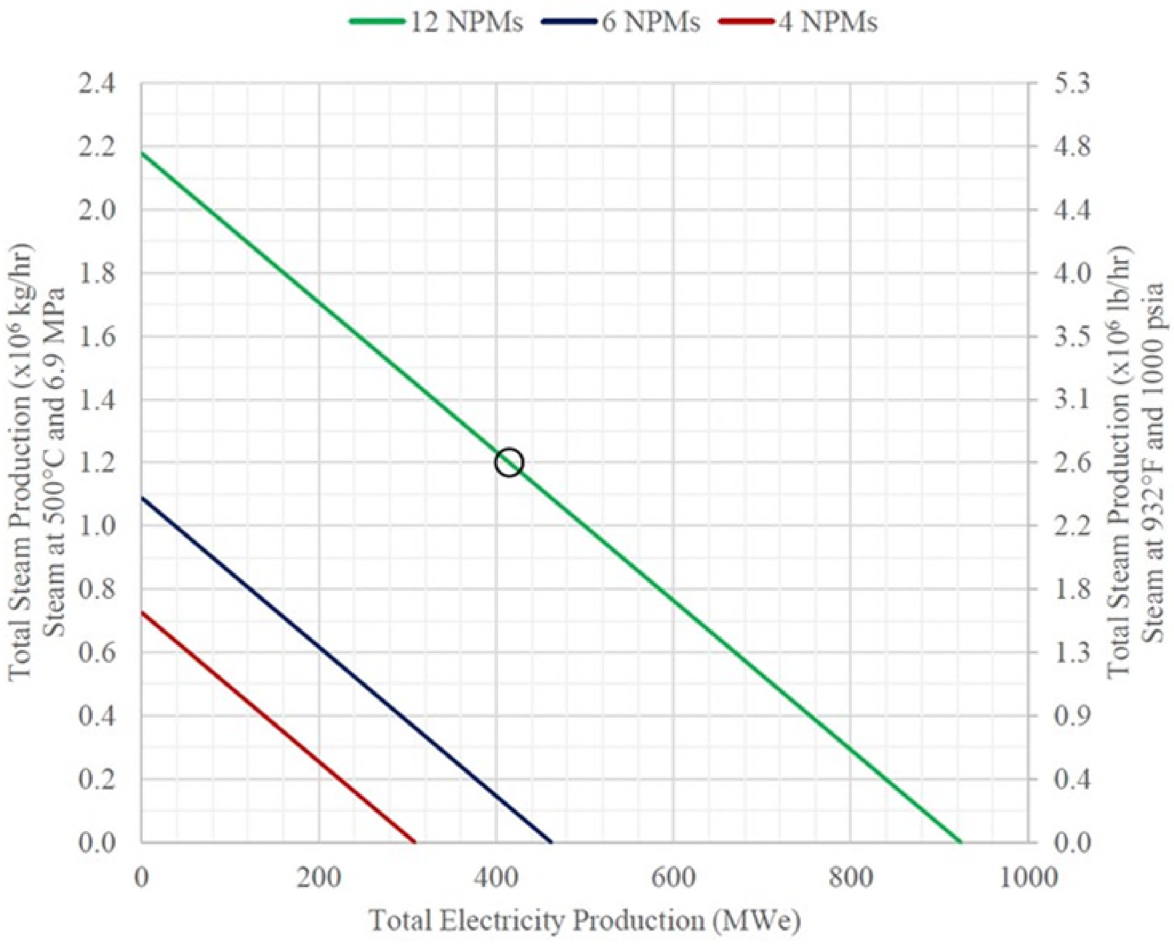
Courteous of Nuscale: NUSCALE

Scalable Architecture

- Plant sized to meet required capacity
- Future expansion enabled by adding modules without interrupting the operation of existing modules
- Simultaneous Steam and Electricity Production
- Example (circle) shows a scenario where a 12 NPM plant produces both 1.2 million kg/hr of steam at 500ºC and 6.9 MPa and 414 MWe of electrical power simultaneously
- 1.2 million kg/hr is sufficient steam to supply a large chemical facility and replace fossil-fueled boilers



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Courteous of Nuscale: NUSCALE

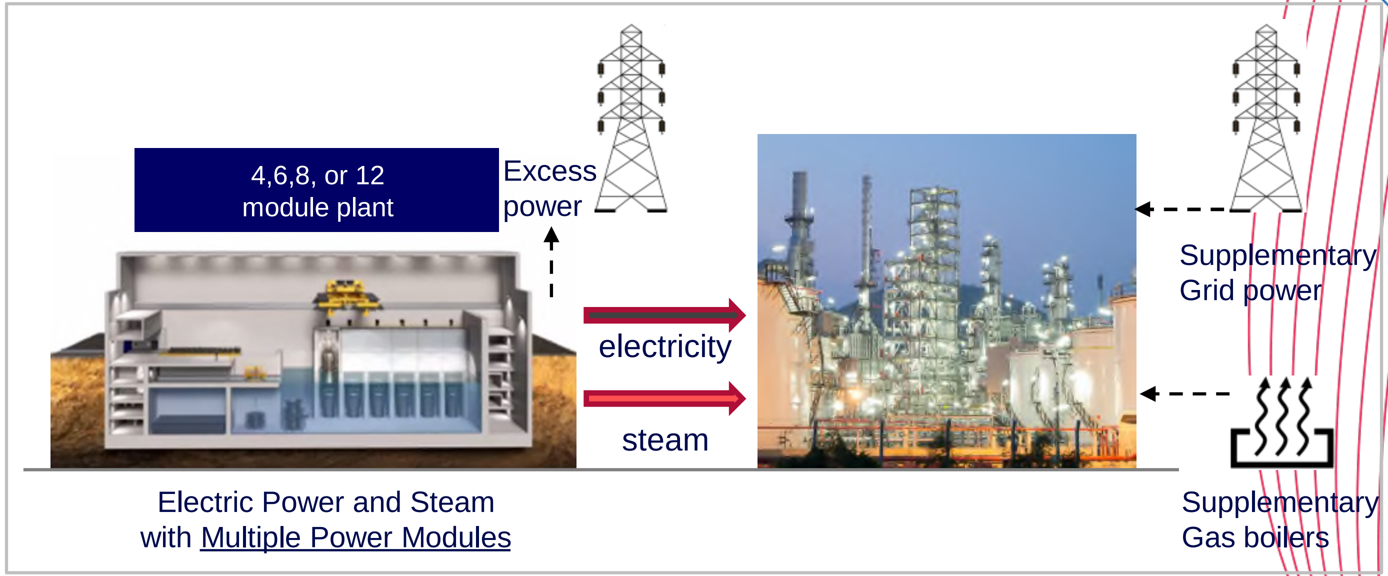
Oak Ridge Study Key Results for Combined Heat and Power

Technoeconomic analysis for a large Chemical facility using real conditions and historical data

- Supply **1.3 million kg/hr**, 400^{o}C, 4.1 MPa and 73 MWe power
- Feasibility of an Integrated Energy System with "*N*" NuScale Power Modules combined with gas-fired boilers to maximize profitability and reduced CO2

<u>Results</u>:

- It is feasible to fully meet the steam and power
- Excess power available to be exported to the grid
- Commercially available equipment
- Scalable architecture, maximum flexibility
    - 12-NPM Plant is the most profitable
    - 4-NPM combined w/boilers is an option
    - 8-NPM allows for N-2 redundancy
- Smooth transition, hybrid: NPM + Gas fired boilers
- 81% - 95% CO2 emissions reduction



<u>2025 Oak Ridge Report ORNL/TM-2025/3938</u>
- Published: December 2025
- Office of Scientific and Technical Information (<u>OSTI</u>) DOE site

- Supersedes ORNL 2020 report
    - Uprated power, heat augmentation, availability, EPZ

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- Courteous of Nuscale:

* 2020 Report (OLD): Integrated Energy System Investigation for the Eastman Chemical Company Kingsport, Tennessee, Facility
2025 Report (NEW): To include power uprate and heat augmentation, expected publication in August 2025

High Temperature Steam Compressor Demonstration and Field Test Program

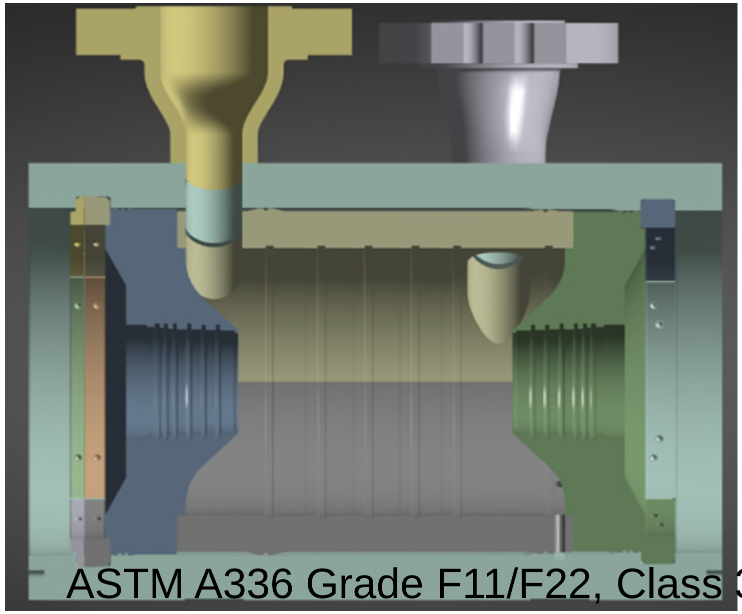
- NuScale and Elliott Ebara have established a collaborative program to demonstrate and field test a high temperature (>500 ^{o}C) steam compression system at commercial scale at a petrochemical plant.
- The compressor will be fabricated by Elliott Ebara and demonstrated at its test facilities in Jeannette, Pennsylvania.
- Subsequently, it is proposed that the system be transported and deployed at an industrial petrochemical site for field testing.
- NuScale and Elliott Ebara are seeking a petrochemical industry partner for this effort.



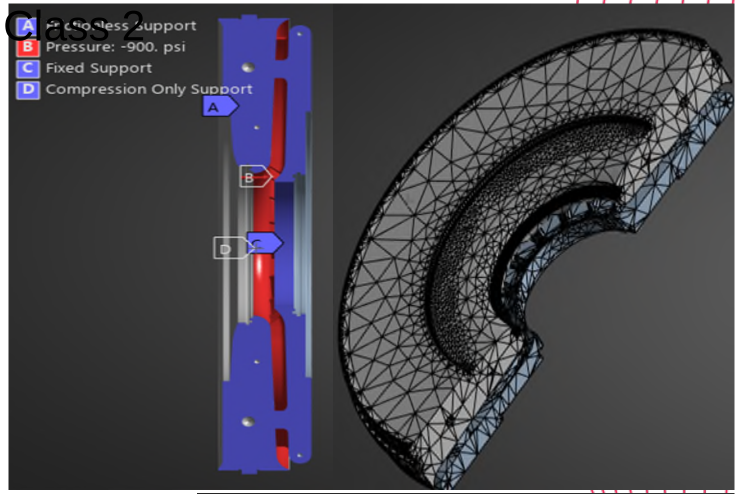
Material Selections

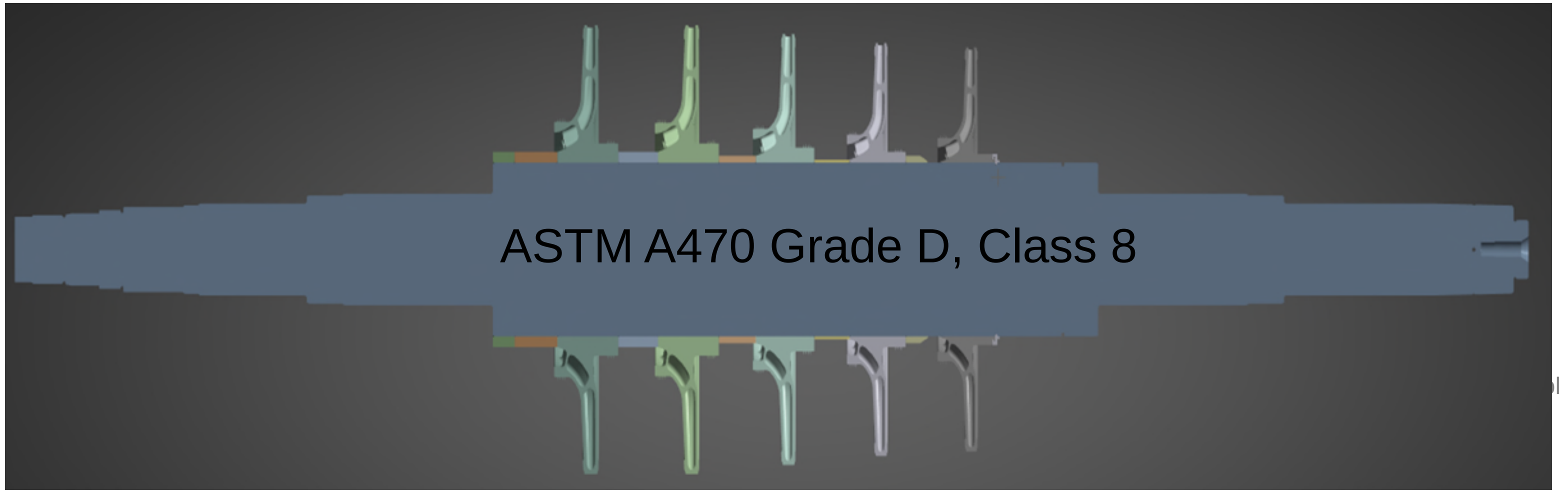
<u>**Materials Utilized for Ansys Analysis**</u>

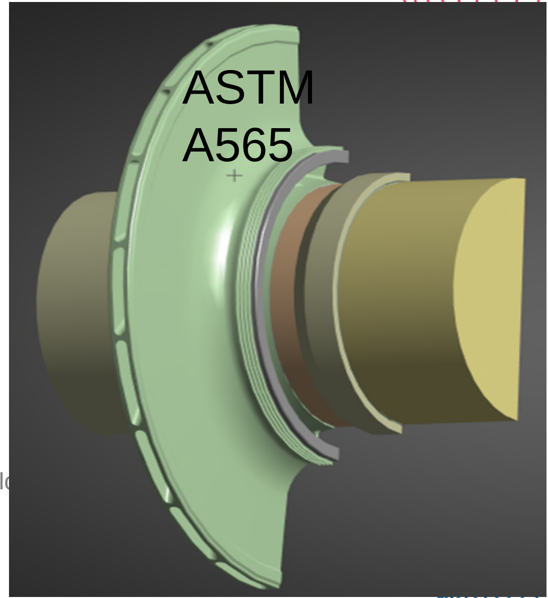
Casing : ASTM A336 Grade F11/22, Class 3
Diaphragms : ASME/ASTM SA/A 387 Grade 11, Class 2
Diaphragm Bolting : Inconel 718
Impellers : ASTM A565
Shaft : ASTM A470 Grade D, Class 8



ASME/ASTM SA/A 387 Grade 11, Class 2







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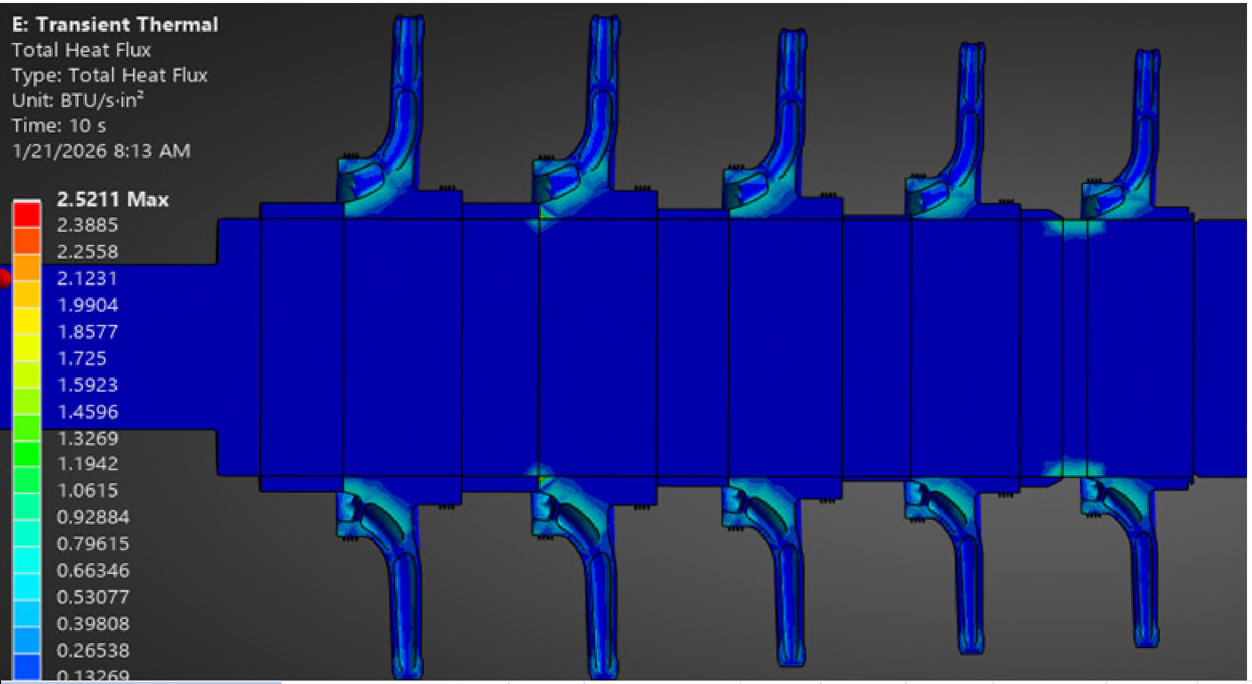
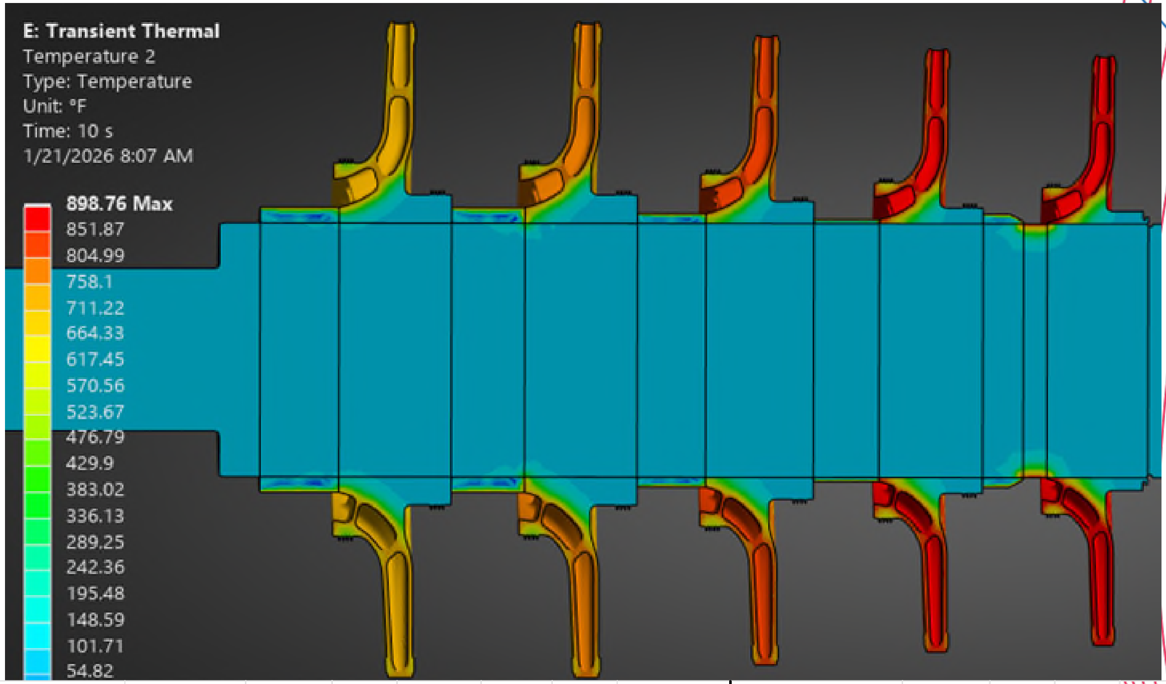
Transient Thermal Results at 500C Discharge





Casing at 400C Inlet to 500C outlet

Location	Temp	Temp	Pres	Specific Volume	Mass Flow m=CFH/v	Flow Area	Hydraulic Diameter	Density	Specific Heat	Thermal Conductivity	Absolute Viscosity
	T	T	P	v	m	A	D_h	ρ	c_p	k	μ
Location	[°R]	[°F]	[psia]	ft^3/lb	[Lb/Hr]	[Ft²]	[Ft]	[lb/ft³]	[BTU/Lb·°F]	[BTU/Hr·Ft·°F]	[Lb/Ft.Sec]
Stage 1	1213	752	460	1.5020	64156	1.569	1.41	0.6658	0.5475	0.0332	1.6380E-05
Stage 2	1249	788	508	1.4014	68758	1.556	1.41	0.7136	0.5491	0.0347	1.6961E-05
Stage 3	1285	824	556	1.31864	73075	1.424	1.35	0.7584	0.5507	0.0362	1.7540E-05
Stage 4	1321	860	604	1.24931	77131	1.299	1.29	0.8004	0.5522	0.0376	1.8110E-05
Stage 5	1357	896	652	1.19041	80947	1.236	1.25	0.8400	0.5537	0.0392	1.8690E-05
Stage 1 Spacer	1213	752	460	1.5020	642	0.156	0.45	0.6658	0.5475	0.0332	1.6380E-05
Stage 2 Spacer	1249	788	508	1.4014	688	0.144	0.43	0.7136	0.5491	0.0347	1.6961E-05
Stage 3 Spacer	1285	824	556	1.31864	731	0.130	0.41	0.7584	0.5507	0.0362	1.7540E-05
Stage 4 Spacer	1321	860	604	1.24931	771	0.119	0.39	0.8004	0.5522	0.0376	1.8110E-05
Stage 5 Spacer	1357	896	652	1.19041	809	0.080	0.32	0.8400	0.5537	0.0392	1.8690E-05

Location	Kinematic Viscosity	Prandtl Number	Flow Rate	Reynolds Number	Nusselt Number	Heat Trans Coefficient	h	CFH= M*v	Velocity	Speci-fic Volume		ID
	υ	Pr	Q	R_{eD}	Nu	h	BTU/	CFH	V	v	ID	Area
Location	[Ft²/Sec]	-	[Ft³/Min]	-	-	[BTU/Hr·In²·°F]	in²*Sec*°F	[Ft³/Hr]	ft/sec	[Ft³/lb]	in	in^2
Stage 1	2.4602E-05	0.9722	1606.0	9.799E+05	1411.88	0.2303	6.3977E-05	96360	17	1.50197	16.96326	226
Stage 2	2.3770E-05	0.9671	1606.0	1.019E+06	1453.36	0.2486	6.9067E-05	96360	17	1.40143	16.88803	224
Stage 3	2.3129E-05	0.9618	1606.0	1.094E+06	1535.78	0.2864	7.9547E-05	96360	19	1.31864	16.15593	205
Stage 4	2.2625E-05	0.9564	1606.0	1.171E+06	1617.96	0.3289	9.1361E-05	96360	21	1.24931	15.43035	187
Stage 5	2.2249E-05	0.9513	1606.0	1.221E+06	1668.89	0.3618	1.0049E-04	96360	22	1.19041	15.05446	178.0
Stage 1 Spacer	2.4602E-05	0.9722	16.1	3.106E+04	89.24	0.0461	1.2816E-05	963.6	2	1.50197	5.352372	22.5
Stage 2 Spacer	2.3770E-05	0.9671	16.1	3.343E+04	94.46	0.0530	1.4731E-05	963.6	2	1.40143	5.146201	20.8
Stage 3 Spacer	2.3129E-05	0.9618	16.1	3.624E+04	100.53	0.0621	1.7240E-05	963.6	2	1.31864	4.879506	18.7
Stage 4 Spacer	2.2625E-05	0.9564	16.1	3.874E+04	105.81	0.0711	1.9757E-05	963.6	2	1.24931	4.66609	17.1
Stage 5 Spacer	2.2249E-05	0.9513	16.1	4.804E+04	125.41	0.1070	2.9709E-05	963.6	3	1.19041	3.82652	11.5

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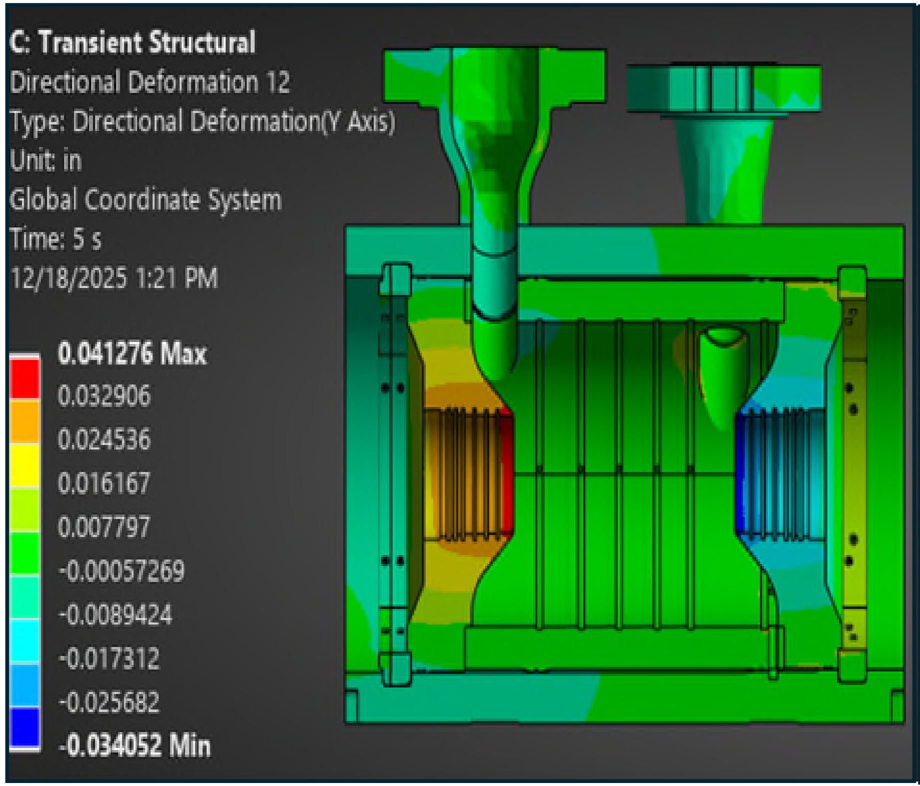
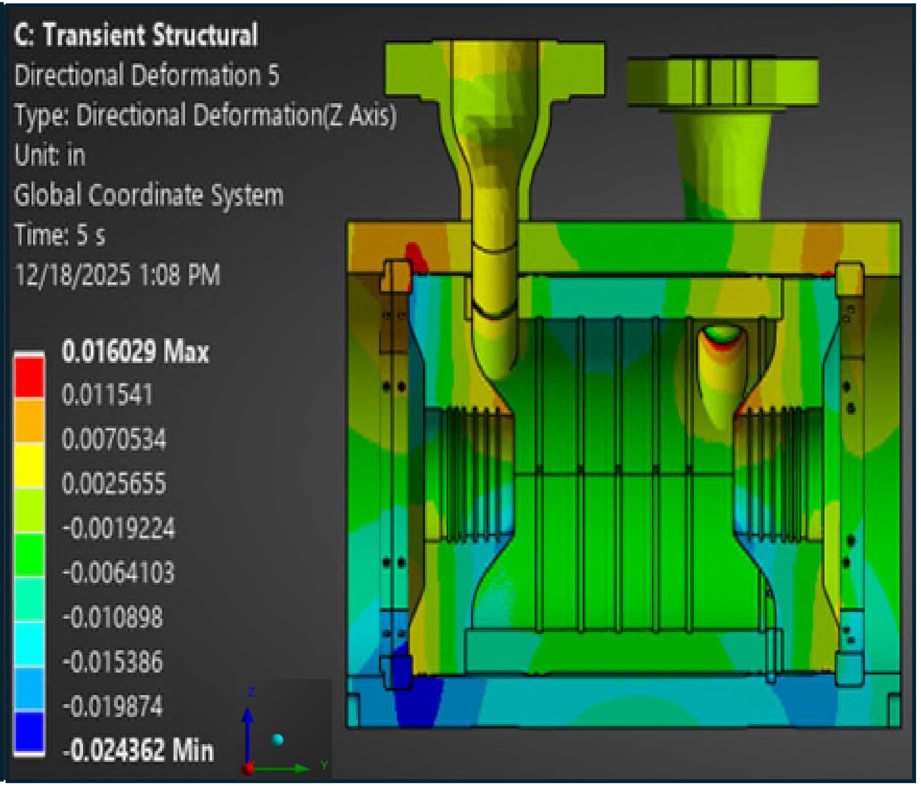
Transient Structural Conditions at 500 C Outlet

Environment:

- Imported Thermal Load
- Pressure(psia):
  - 460psia – 700psia
- Temp (F):
  - 752F – 932F
- CFH: 96,360



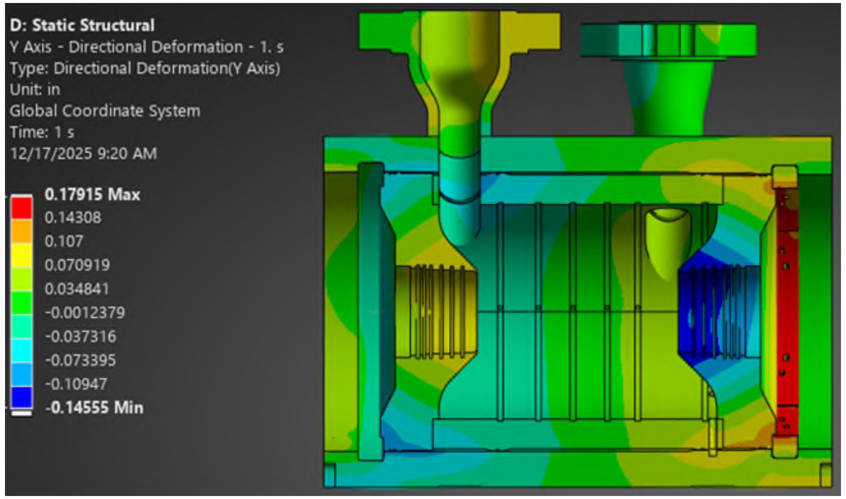


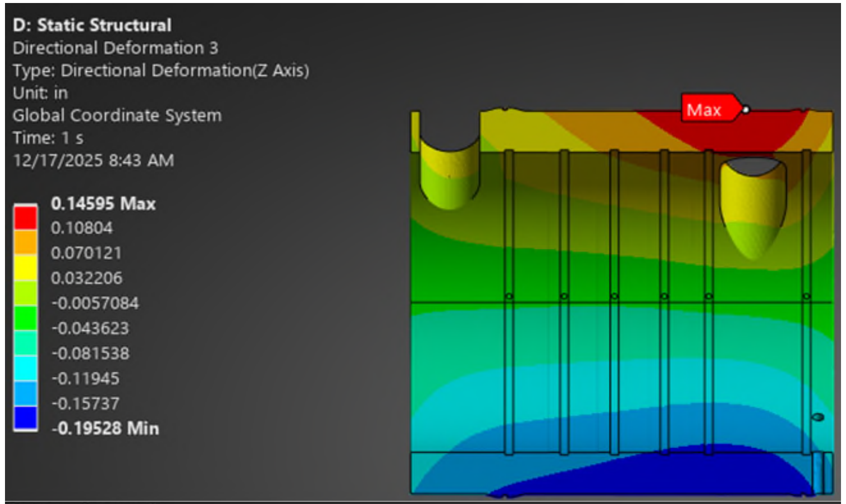
Casing at 400C Inlet to 500C outlet

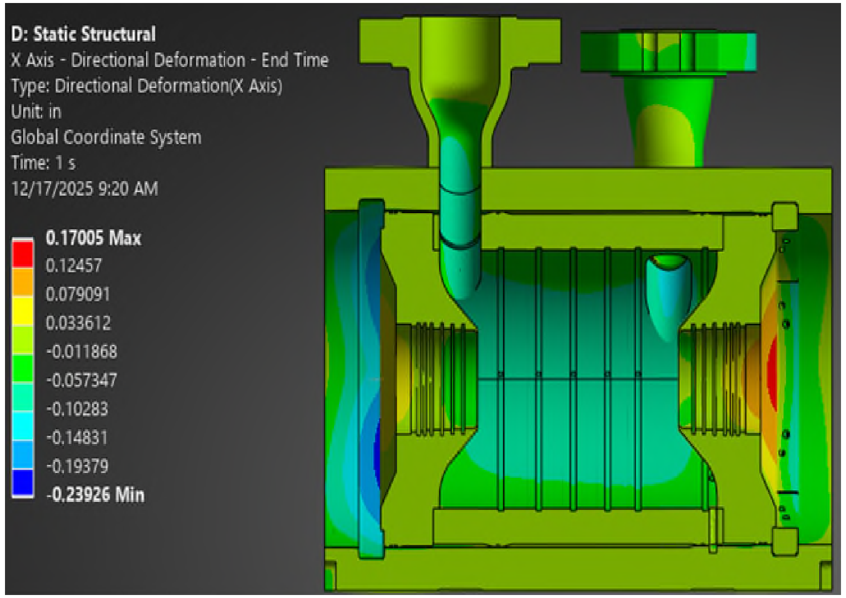
Location	Temp	Temp	Pres	Specific Volume	Mass Flow m=CFH/v	Flow Area	Hydraulic Diameter	Density	Specific Heat	Thermal Conductivity	Absolute Viscosity	Kinematic Viscosity	Prandtl Number	Flow Rate	Reynolds Number	Nusselt Number	Heat Trans Coefficient
	T	T	P	v	m	A	D_h	ρ	c_p	k	μ	υ	Pr	Q	R_{eD}	Nu	h
Location	[°R]	[°F]	[psia]	ft^3/lb	[Lb/Hr]	[Ft²]	[Ft]	[lb/ft³]	[BTU/Lb·°F]	[BTU/Hr·Ft·°F]	[Lb/Ft.Sec]	[Ft²/Sec]	-	[Ft³/Min]	-	-	[BTU/Hr·In²·°F]
Entry Plenum	1213	752	460	1.5020	64156	0.778	1.00	0.6658	0.5475	0.0332	1.6380E-05	2.4602E-05	0.9722	1606.0	1.392E+06	1869.63	0.4332
Entry Pipe	1213	752	460	1.5020	64156	0.313	0.63	0.6658	0.5475	0.0332	1.6380E-05	2.4602E-05	0.9722	1606.0	2.196E+06	2692.51	0.9843
Inner Casing before stage	1213	752	460	1.5020	64156	2.125	1.64	0.6658	0.5475	0.0332	1.6380E-05	2.4602E-05	0.9722	1606.0	8.422E+05	1250.70	0.1753
Stage 1	1249	788	508	1.4014	68758	1.285	1.28	0.7136	0.5491	0.0347	1.6961E-05	2.3770E-05	0.9671	1606.0	1.121E+06	1568.93	0.2954
Stage 2	1285	824	556	1.31864	73075	1.146	1.21	0.7584	0.5507	0.0362	1.7540E-05	2.3129E-05	0.9618	1606.0	1.220E+06	1675.08	0.3482
Stage 3	1321	860	604	1.24931	77131	1.139	1.20	0.8004	0.5522	0.0376	1.8110E-05	2.2625E-05	0.9564	1606.0	1.251E+06	1705.17	0.3701
Stage 4	1357	896	652	1.19041	80947	0.986	1.12	0.8400	0.5537	0.0392	1.8690E-05	2.2249E-05	0.9513	1606.0	1.367E+06	1826.76	0.4434
Inner Casing Guide Van to exit	1393	932	700	1.1398	84543	1.965	1.58	0.8774	0.5554	0.0407	1.9268E-05	2.1961E-05	0.9467	1606.0	9.810E+05	1398.15	0.2498
Exit Pipe	1393	932	700	1.1398	84543	0.389	0.70	0.8774	0.5554	0.0407	1.9268E-05	2.1961E-05	0.9467	1606.0	2.205E+06	2672.96	1.0734
Exit Plenum	1393	932	700	1.1398	84543	0.951	1.10	0.8774	0.5554	0.0407	1.9268E-05	2.1961E-05	0.9467	1606.0	1.410E+06	1868.87	0.4798
Outer To Inner Casing Leakage Path	1213	752	460	1.5020	64	14.979	4.37	0.6658	0.5475	0.0332	1.6380E-05	2.4603E-05	0.9724	1.6	3.172E+02	2.28	0.0001

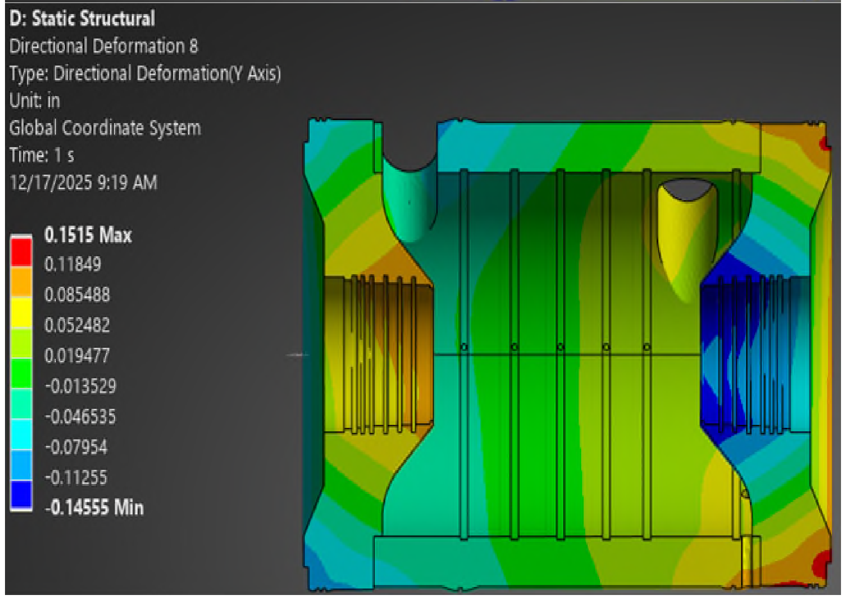
Location	h	CFH= M*v	Velocity	Speci-fic Volume		ID	h
	BTU/	CFH	V	v	ID	Area	BTU/
Location	in²*Sec*°F	[Ft³/Hr]	ft/sec	[Ft³/lb]	in	in^2	in2*Sec*oF
Entry Plenum	1.2034E-04	96360	34	1.50197	11.94164	112	1.2034E-04
Entry Pipe	2.7342E-04	96360	86	1.50197	7.569398	45	2.7342E-04
Inner Casing before stage	4.8705E-05	96360	13	1.50197	19.73857	306	4.8705E-05
Stage 1	8.2042E-05	96360	21	1.40143	15.34762	185	8.2042E-05
Stage 2	9.6708E-05	96360	23	1.31864	14.49429	165	9.6708E-05
Stage 3	1.0282E-04	96360	24	1.24931	14.4503	164	1.0282E-04
Stage 4	1.2316E-04	96360	27	1.19041	13.44619	142.0	1.2316E-04
Inner Casing Guide Van to exit	6.9381E-05	96360	14	1.13978	13.98228	283.0	6.9381E-05
Exit Pipe	2.9818E-04	96360	69	1.13978	8.444016	56.0	2.9818E-04
Exit Plenum	1.3329E-04	96360	28	1.13978	13.20734	137.0	1.3329E-04
Outer To Inner Casing Leakage Path	3.3435E-08	96.36	0	1.502	52.40589	2157.0	3.3435E-08

Casing Interaction both tolerance and shear ring evaluation



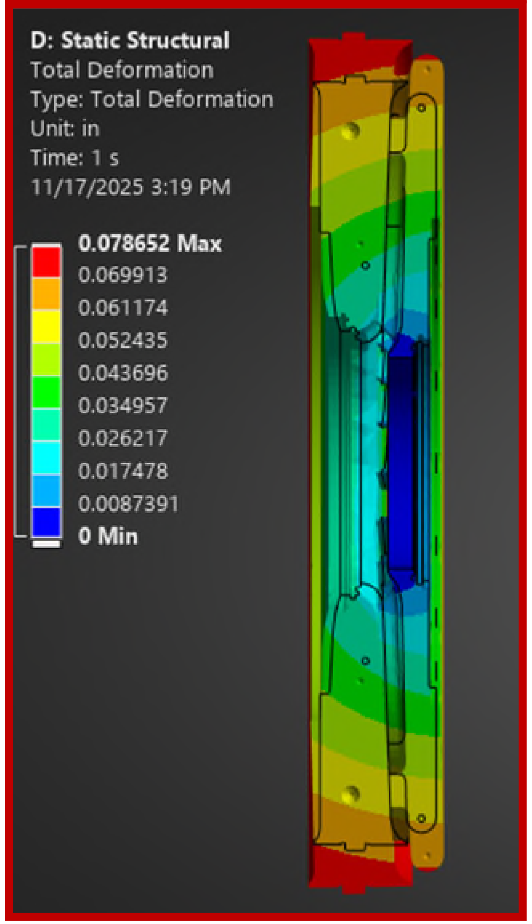




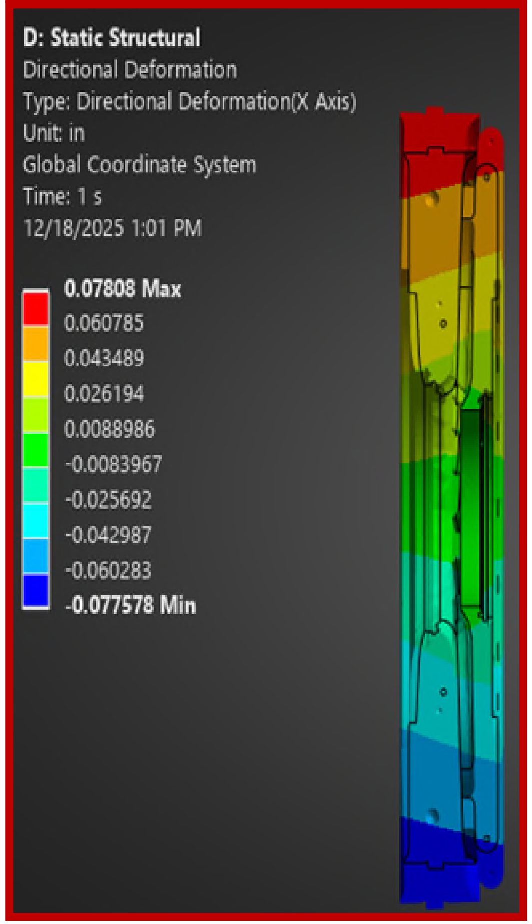


Diaphragm Findings at Steady State Thermal 932F

Total Deformation



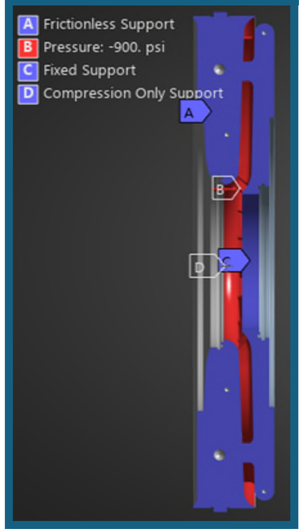
Direct Def (X axis)



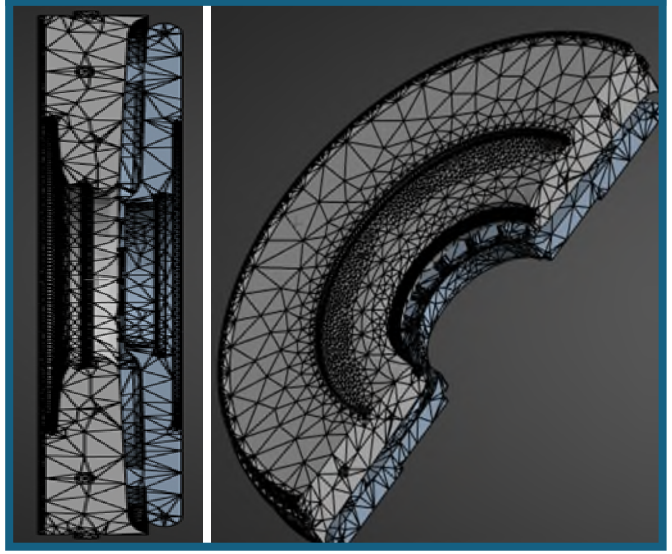
Environment:

- Pressure(psia): 700
- Temp (F): 932 F (500 C)
- CFH: 96,932
- Convection Coeff: 1.2316E-04 Btu/in2*s*F
- Max Displacement (X axis): 0.07808”
- Material Selection: MS 446

Boundary Conditions



Mesh Environment



Location	Temp	Temp	Pres	Specific Volume	Mass Flow m=CFH/v	Flow Area	Hydraulic Diameter	Density	Specific Heat	Thermal Conductivity	Absolute Viscosity	Kinematic Viscosity	Prandtl Number	Flow Rate	Reynolds Number
	T	T	P	v	m	A	D_h	ρ	c_p	k	μ	υ	Pr	Q	R_{eD}
Location	[°R]	[°F]	[psia]	ft^3/lb	[Lb/Hr]	[Ft²]	[Ft]	[lb/ft³]	[BTU/Lb·°F]	[BTU/Hr·Ft°F]	[Lb/Ft.Sec]	[Ft²/Sec]	-	[Ft³/Min]	-
Diaphragm	1393	**932**	**900**	**0.8762**	140453	3.667	2.16	1.1413	**0.5704**	**0.0414**	**1.9302E-05**	1.6913E-05	0.9578	2051.1	1.191E+06

Location	Nusselt Number	Heat Trans Coefficient	h	CFH= M*v	Velocity	Speci-fic Volume		ID	h	Temp	Pres	Location	Radiation hr
	Nu	h	BTU/	CFH	V	v	ID	Area	BTU/	T	P		BTU/
Location	-	[BTU/Hr·In²·°F]	in²*Sec*°F	[Ft³/Hr]	ft/sec	[Ft³/lb]	in	in^2	in2*Sec*oF	[oF]	[psia]		in2*Sec*oF
Diaphragm	1640.62	0.2182	6.0614E-05	**123068**	9	0.87622	25.92818	**528**	6.0614E-05	932	900	Diaphragm	