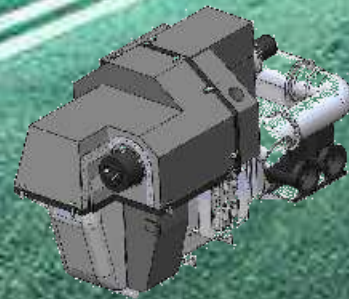
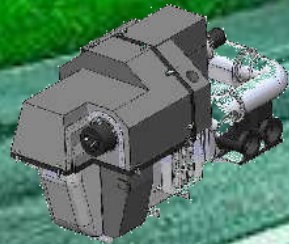


The development of a high efficiency Turbo Generator for series hybrid powertrain in Vehicles



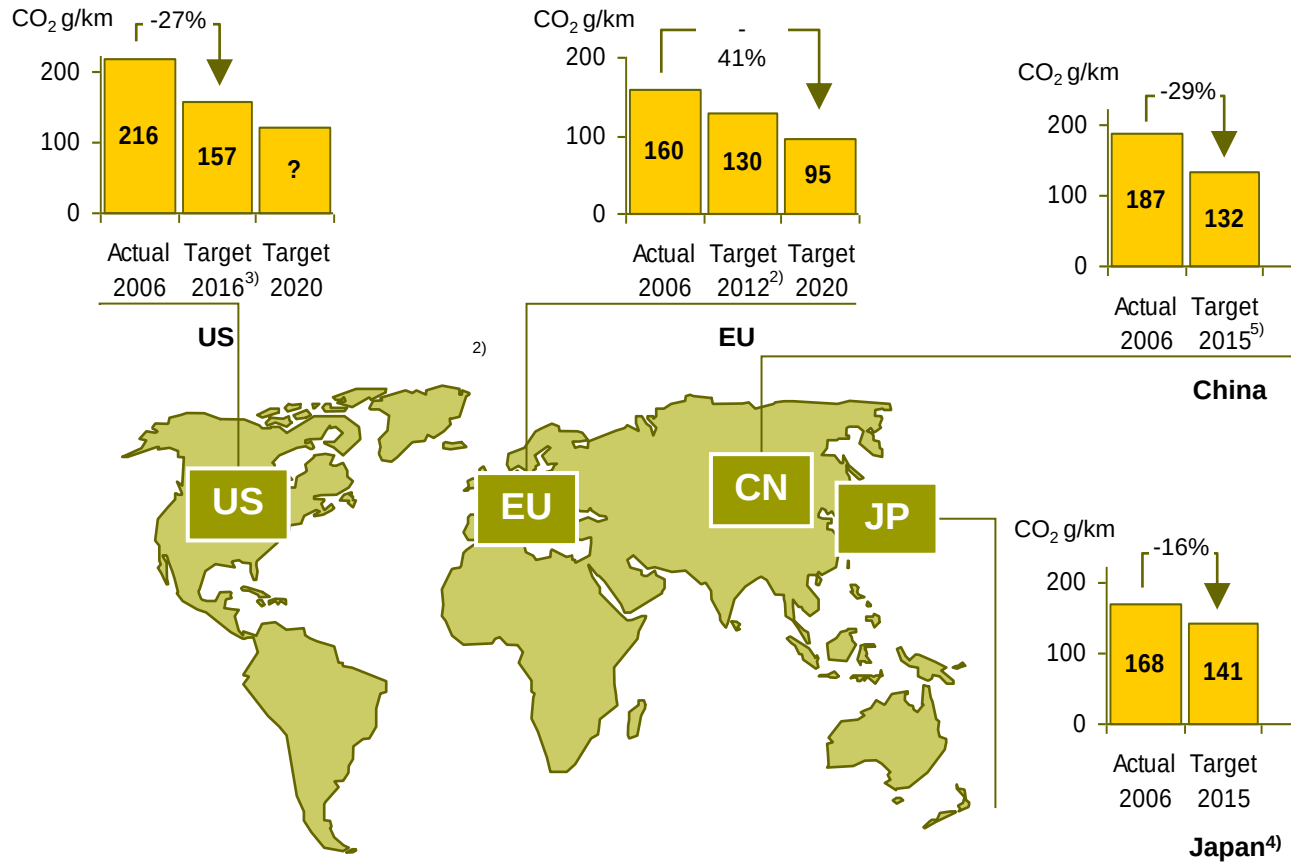
Gery Ordan 13.9.22

Turbine Technology for Series Hybrid

Global Warming

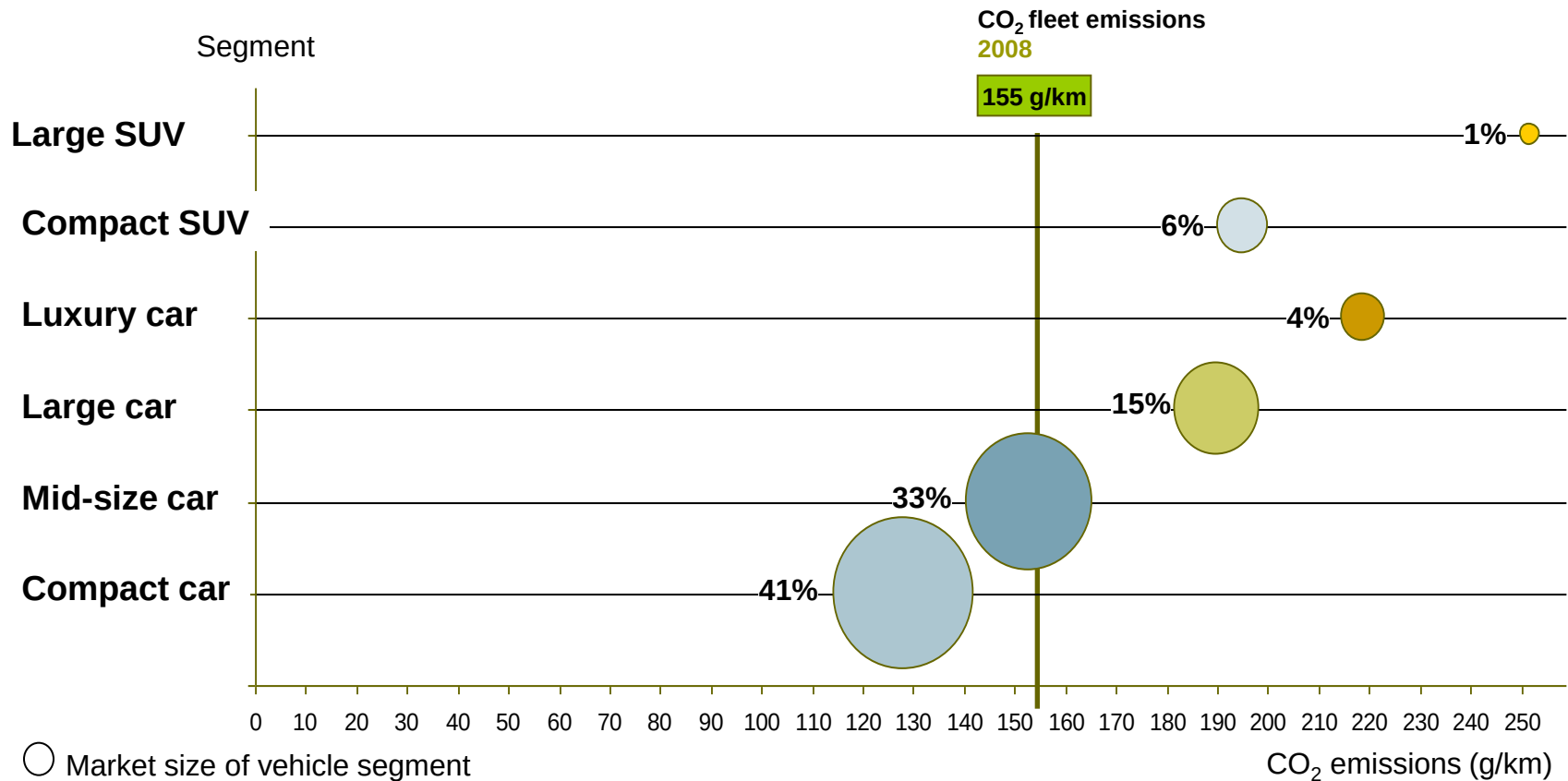
A historical turning point: G8 countries have committed to take the lead in greenhouse gas reduction

CO₂ fleet emission targets of key automotive markets¹⁾



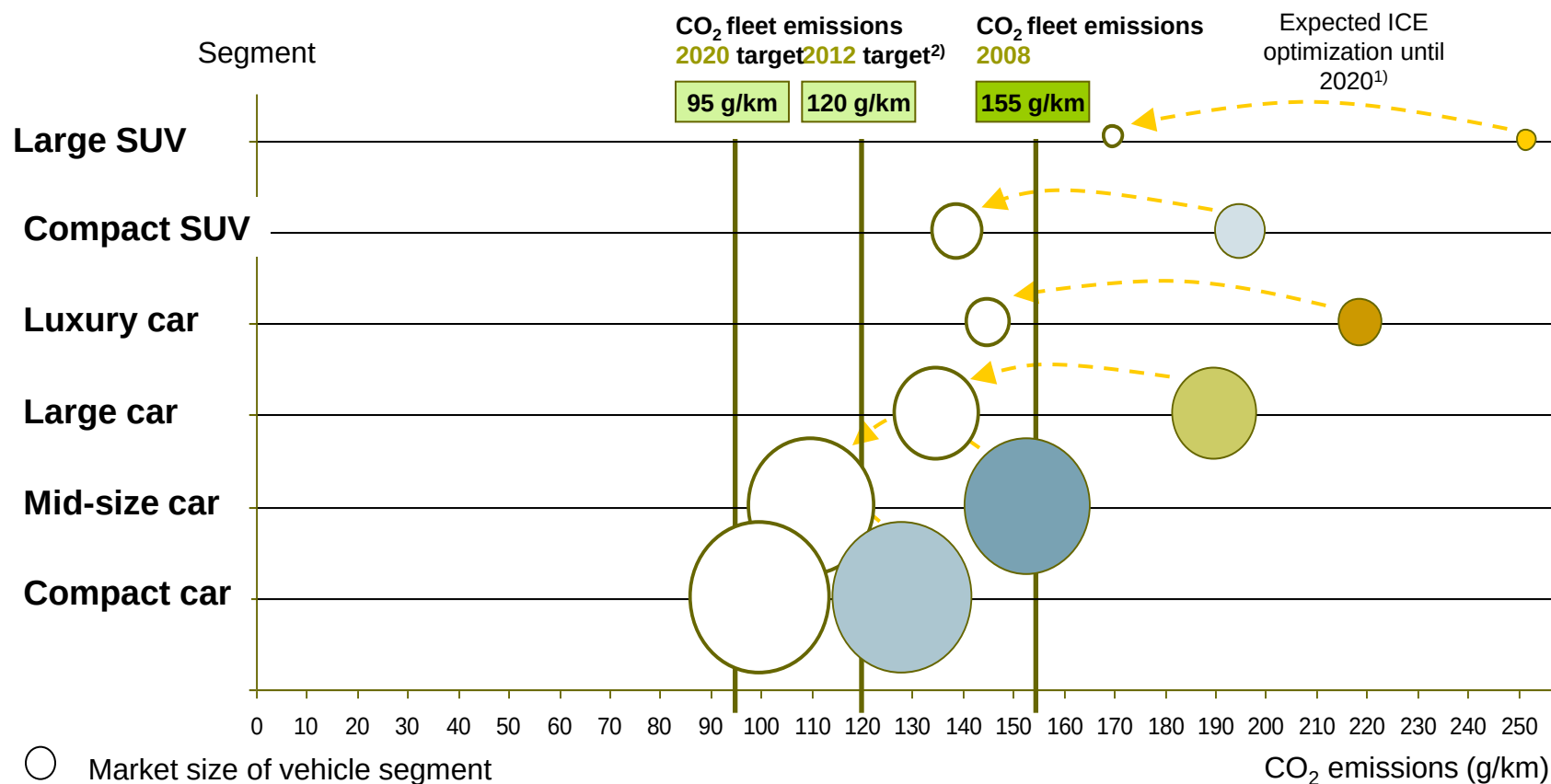
ICE powertrain optimization is not enough to meet EU CO₂ emissions limits of 95 g/km in 2020

European CO₂ fleet emissions 2008 – 2020E



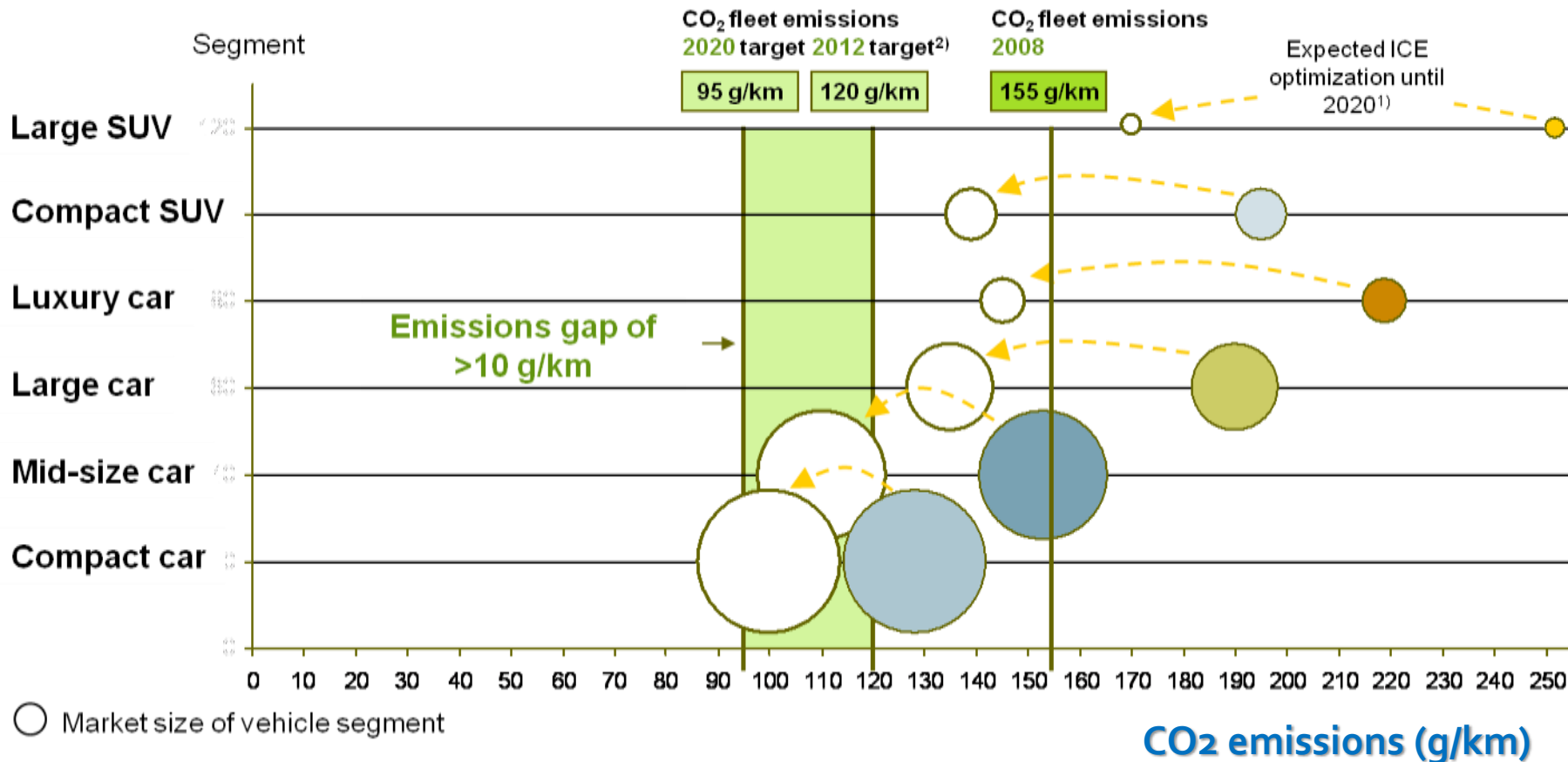
ICE powertrain optimization is not enough to meet EU CO₂ emissions limits of 95 g/km in 2020

European CO₂ fleet emissions 2008 – 2020E



The Challenge

European CO₂ fleet emissions 2008 – 2020E



Today's ICE powertrain technology is not able to meet tomorrow's emission demands.

Turbine Technology for Series Hybrid

We need :

High efficiency

Low emissions

High Power density

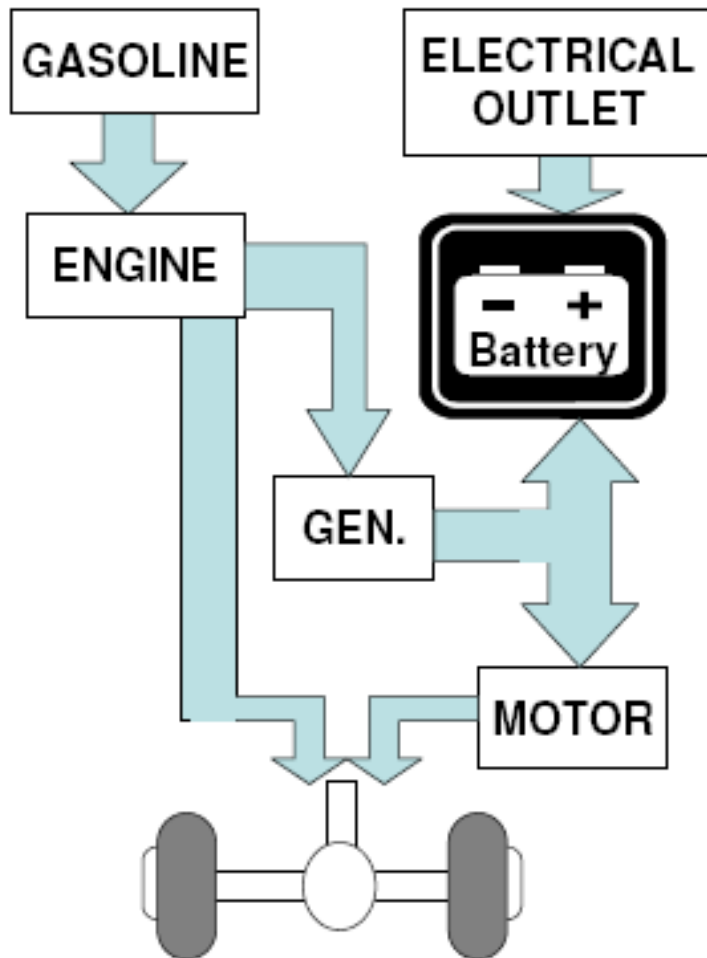
Vehicle Propulsion platform

Turbine Technology for Series Hybrid

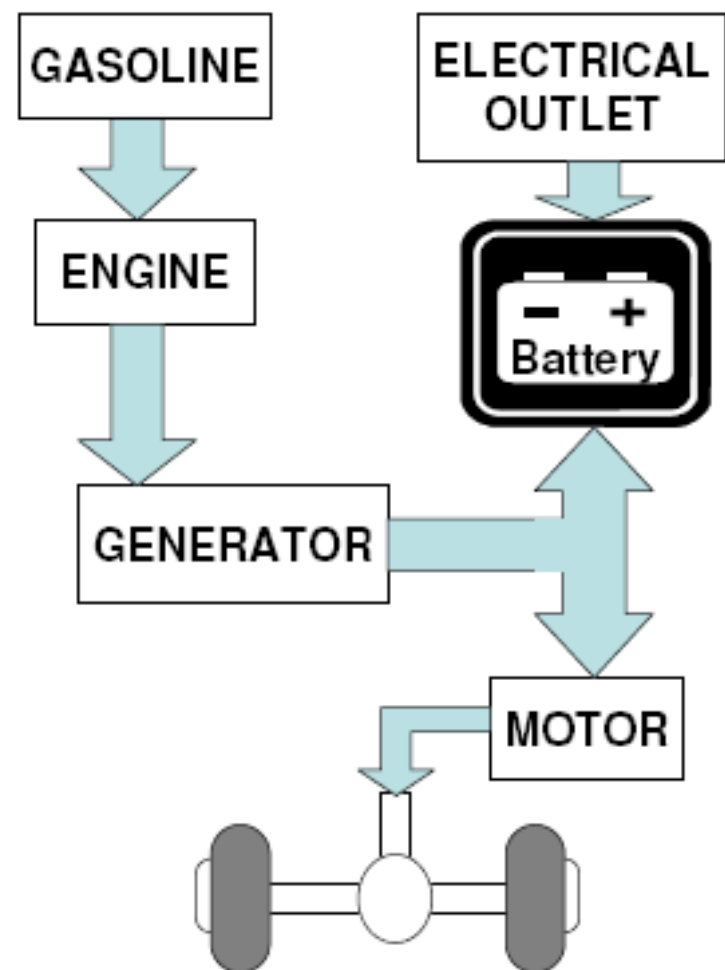
Hybrid Electric Propulsion Concepts

Hybrid Electric Concepts

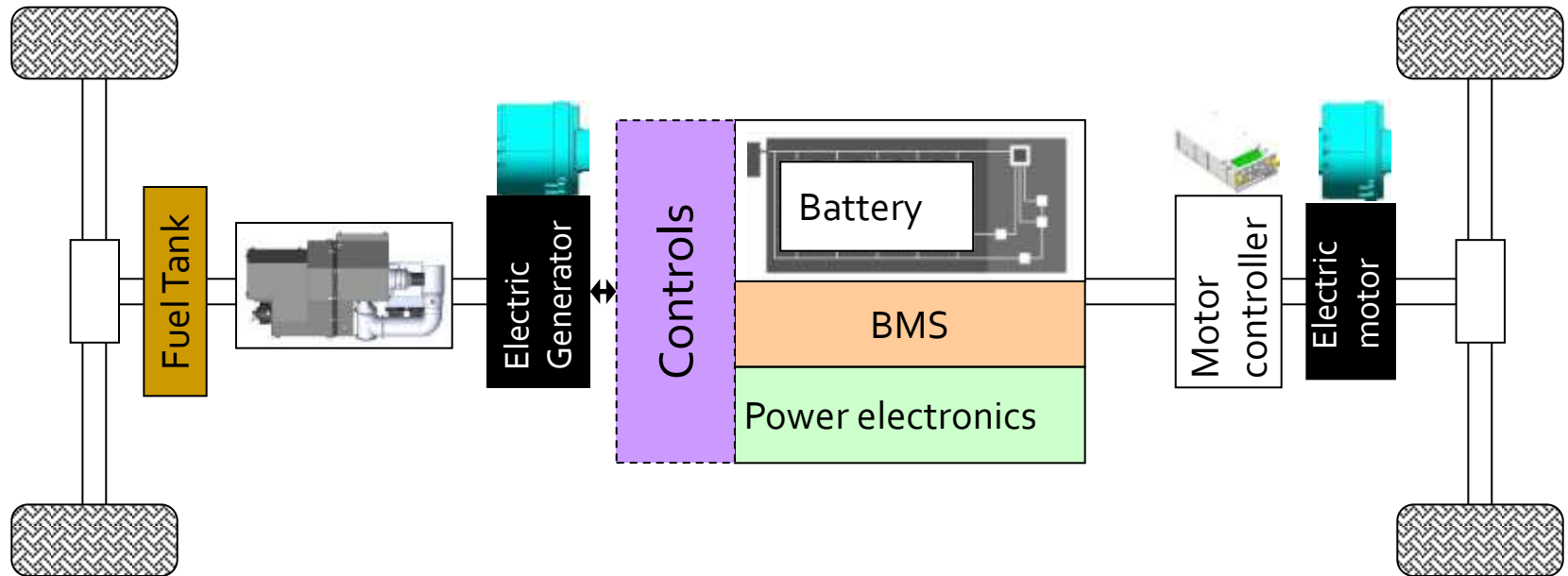
Parallel Hybrid Electric



Series Hybrid Electric



Serial Hybrid – Power Train System



Microturbine Technology - Contents

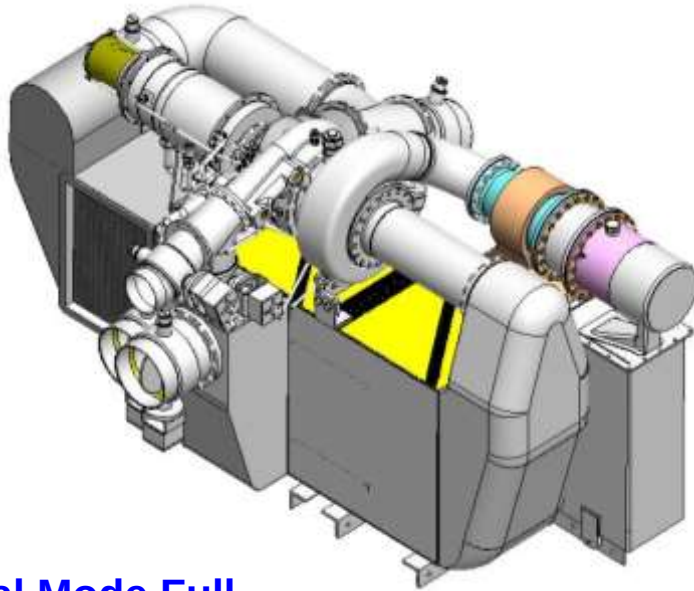
- eTeg 2060 Specifications
- Construction
- Thermal & Acoustic Cover
- Performance
- Model Derivatives
- Power electronics
- Microturbine Development Road Map
- Development of novel heat exchangers
- Toyota Prius Conversion

eTeg 2060

Specifications

eTeg 2060 - Dual Mode Full Recuperation

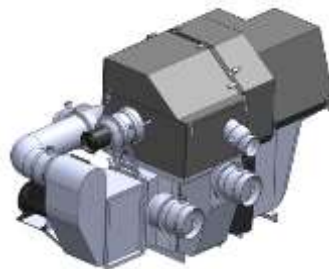
Base Model



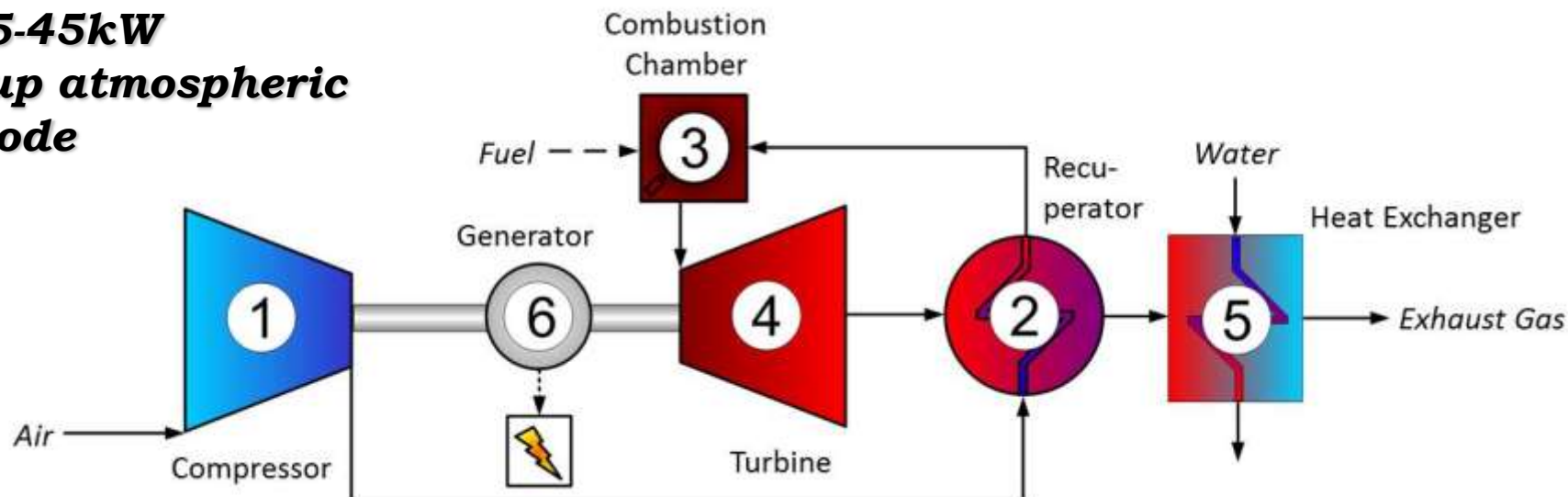
**Dual Mode Full
Recuperation**

**42 KW / 35% / 140 Kg
1349 x 790x 890 mm**

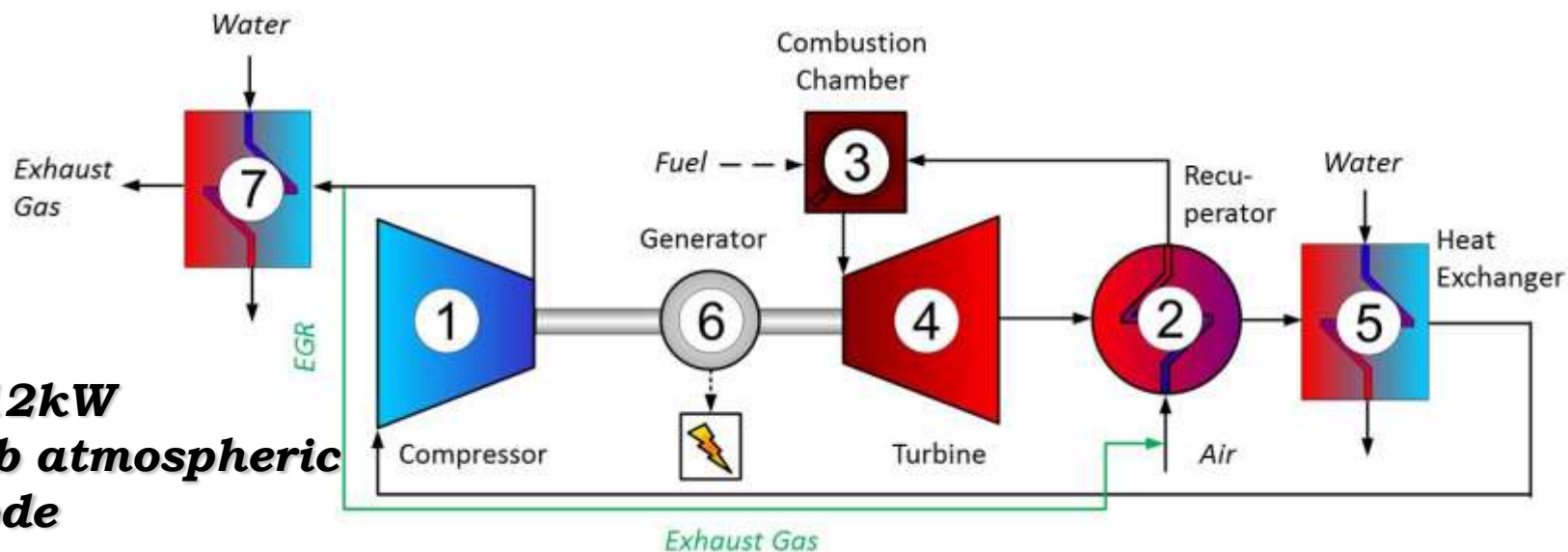
**Efficiency : 36 %
Weight : 120kg**



25-45kW
Sup atmospheric
mode

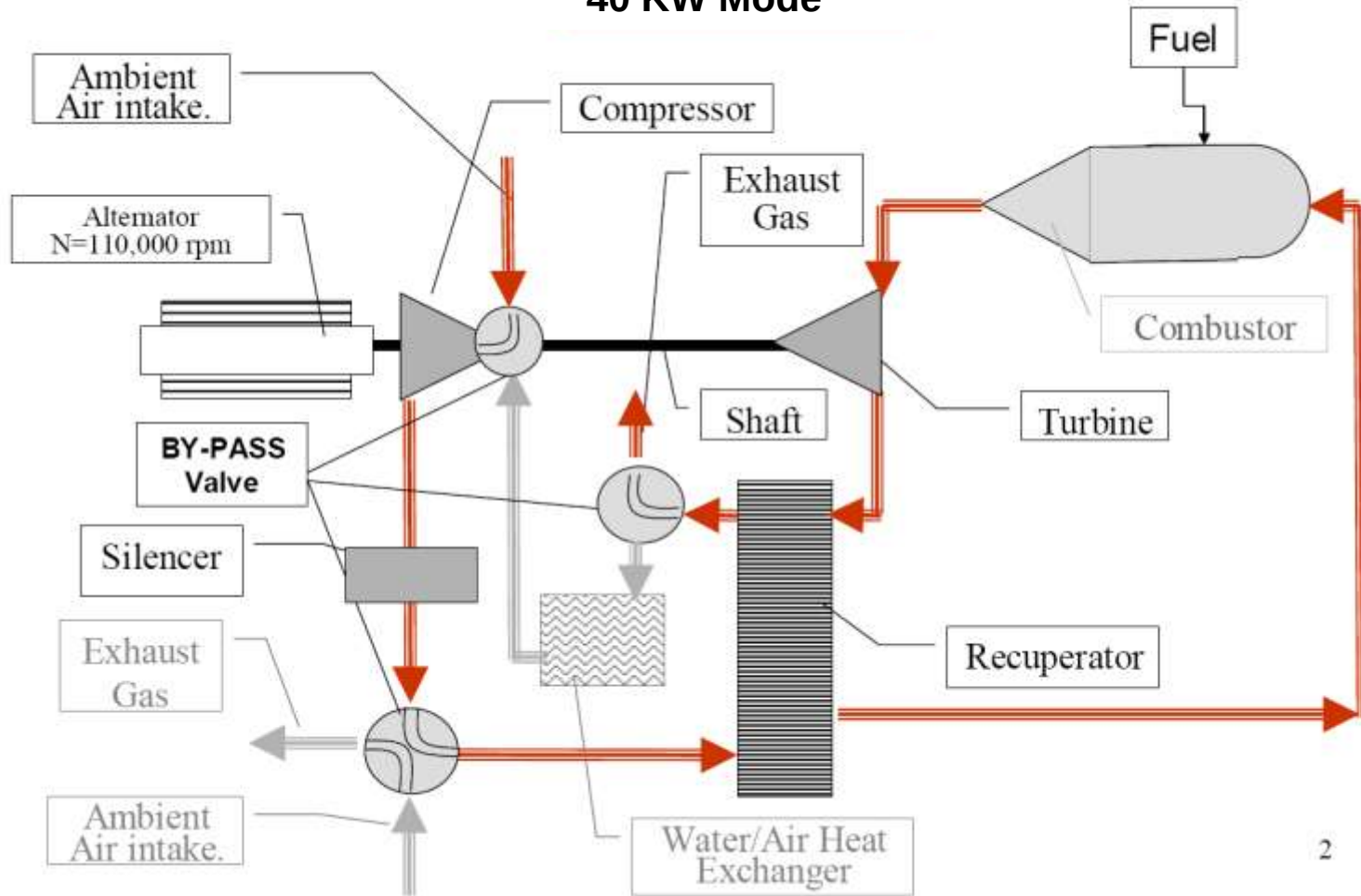


8-12kW
Sub atmospheric
mode



Sup Atmospheric mode

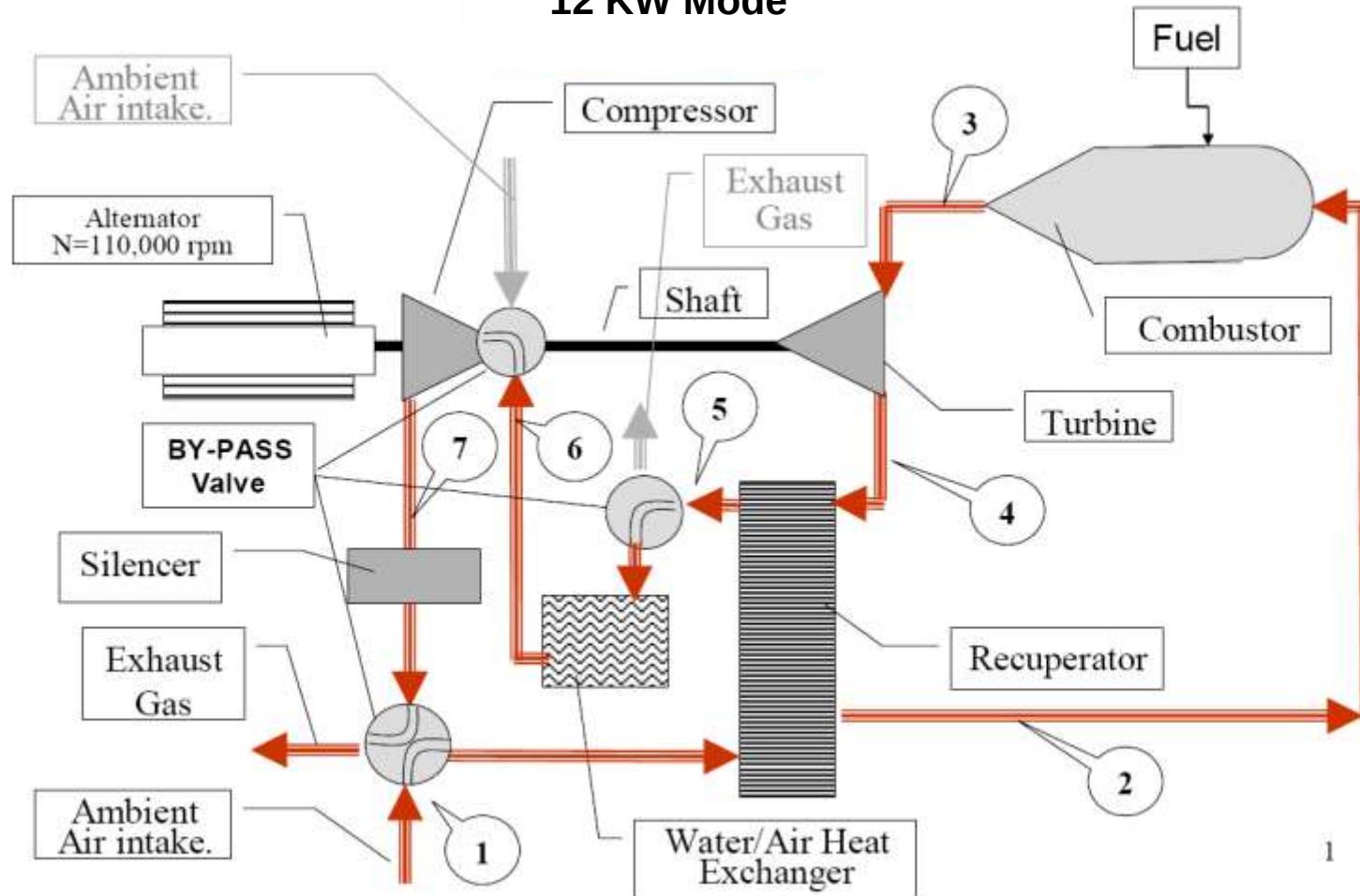
40 KW Mode



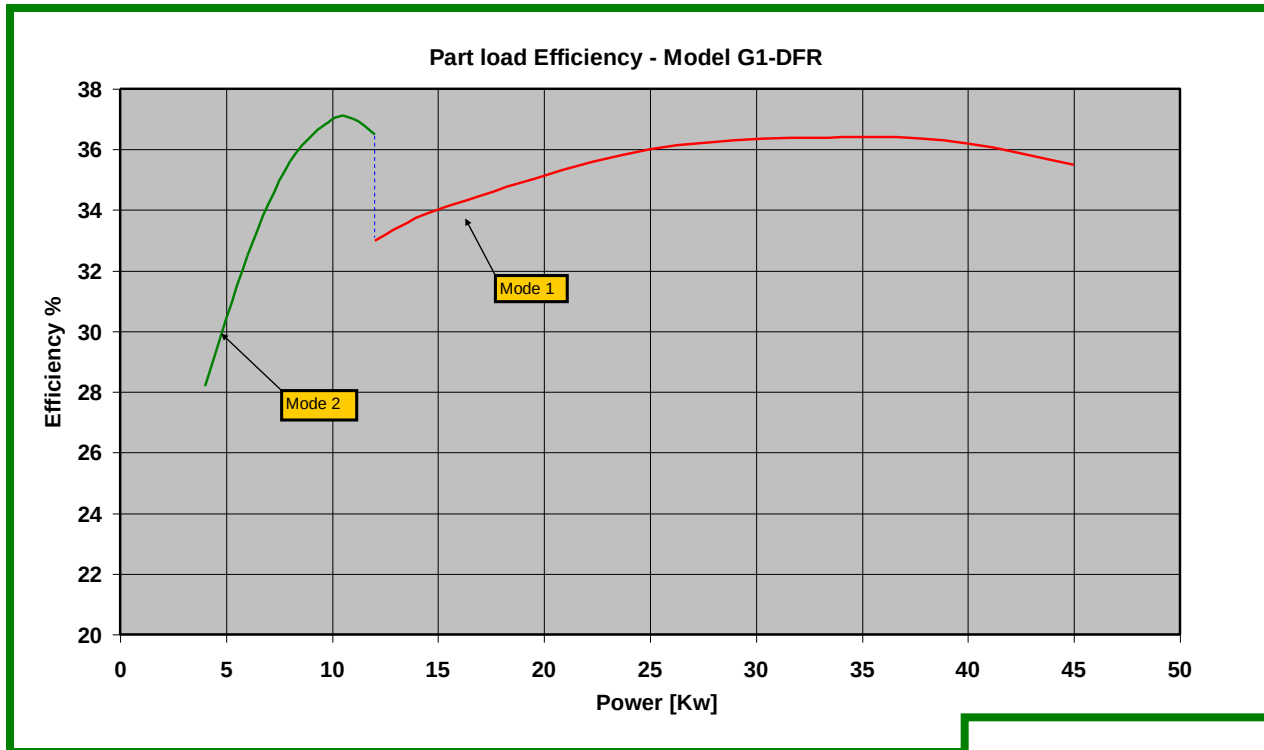
2

Sub Atmospheric mode

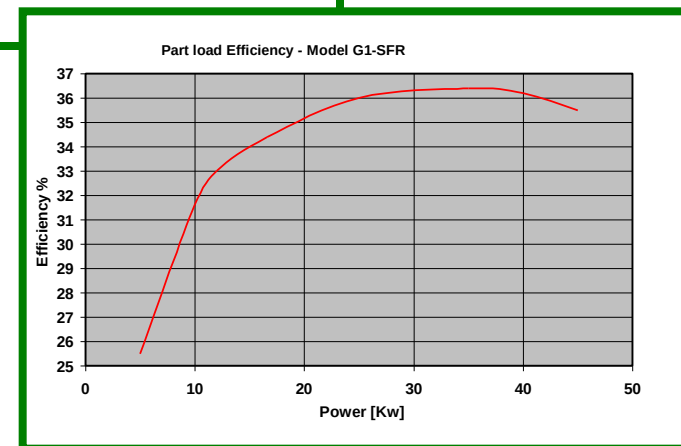
12 KW Mode



eTeg 2060- Dual Mode Performance

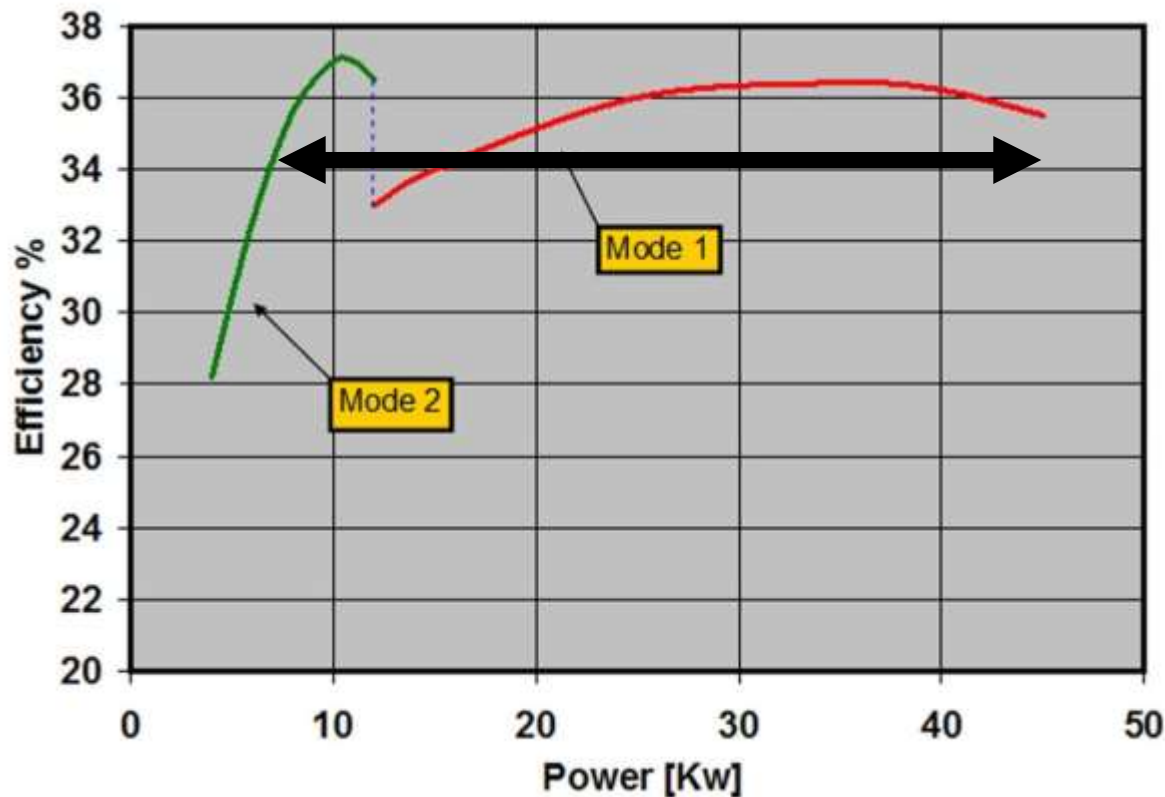


“Dual mode” allows to operate the turbine at two operating ranges while maintaining high thermal efficiency

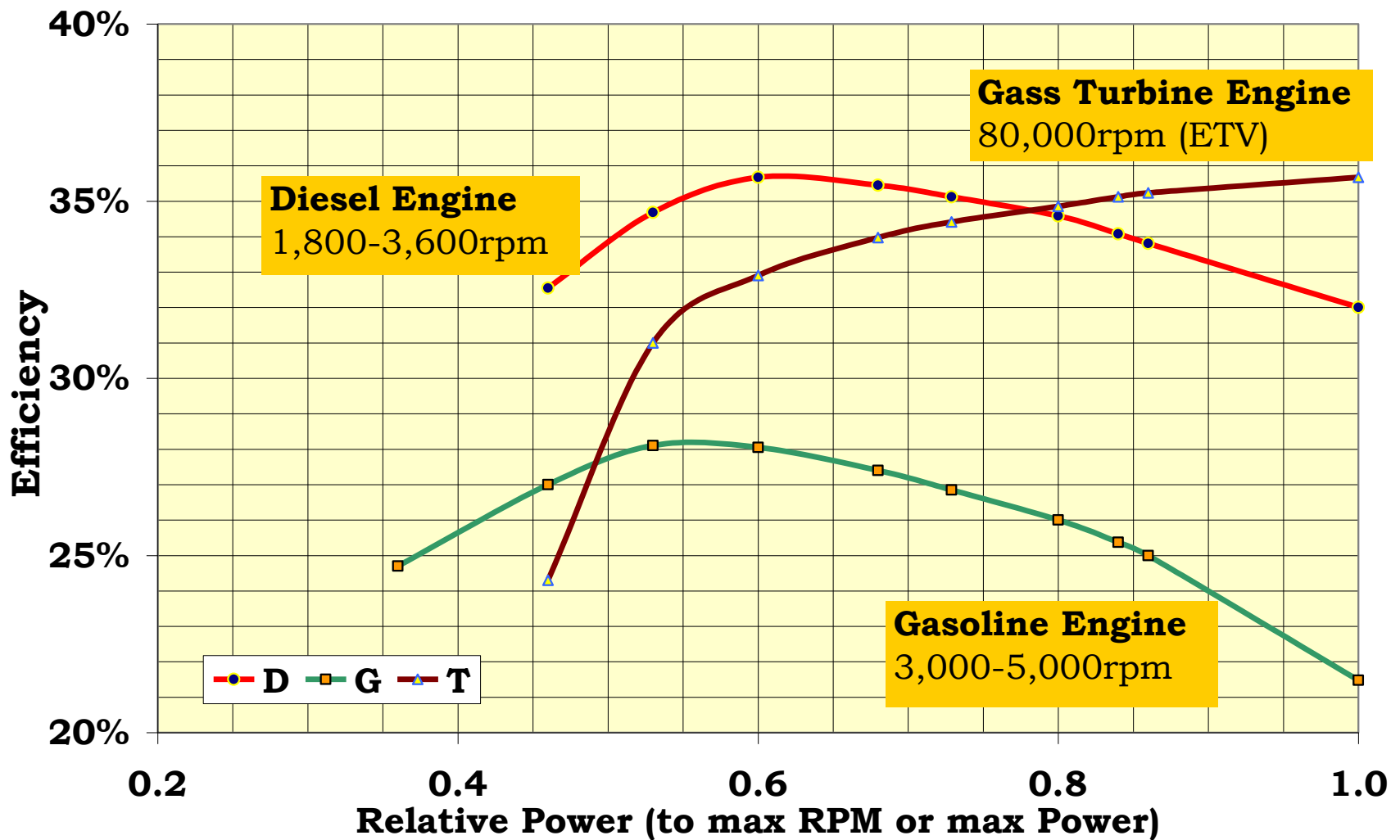


eTeg 2060– Dual Mode Performance

- The TEG system will have a very wide range of power at high efficiency ($>35\%$)



Diesel, Gasoline & Gas turbine Engine Efficiency vs. rpm



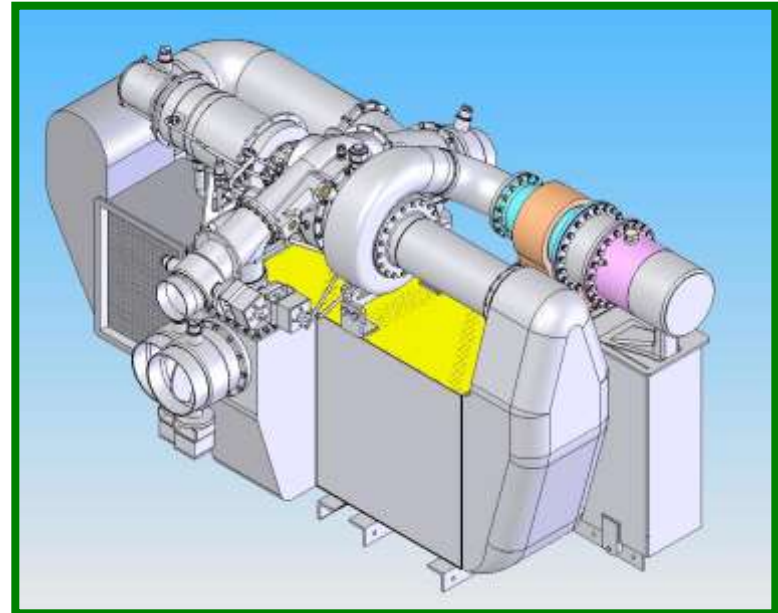
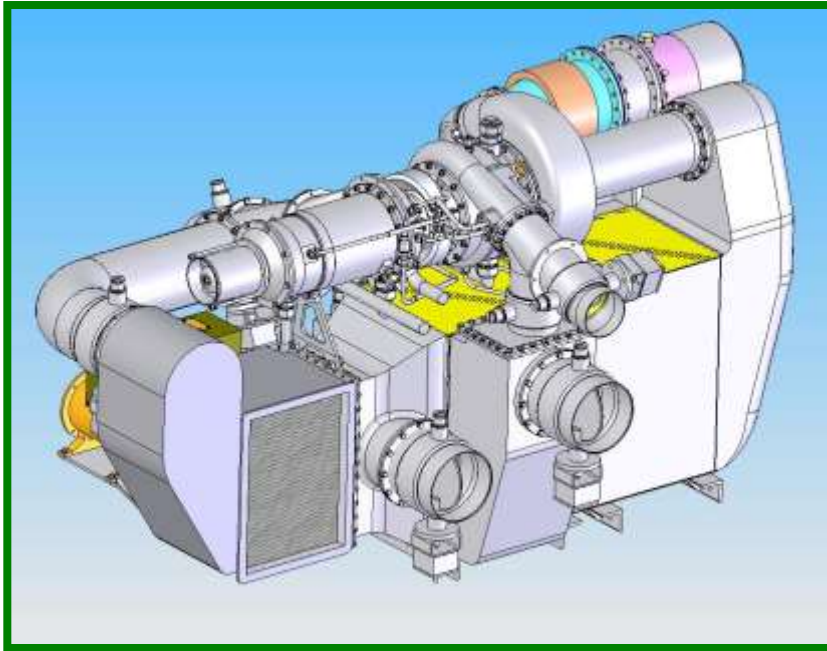
eTeg 2060 – main specifications

- Net electric power : 9-12 / 12-42 KW
- Output : 400 VAC, 1300 Hz (full speed), 3 phase
- 300-700 VDC bus voltage (optional with IPE)
- Thermal efficiency : 34-37 %
- Max Turbine inlet temperature : 1300 K
- Airflow : 105/304 gr/sec
- Preessure ratio : 3
- Recuperator Effectiveness : 91%/89
- Multi fuel capability
- Modular design
- Low emissions (15 PPM Nox, 25 PPM CO)

eTeg 2060

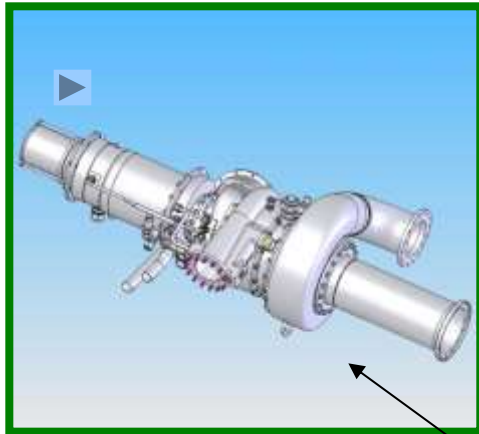
Construction

eTeg 2060 MicroTurbine Generator

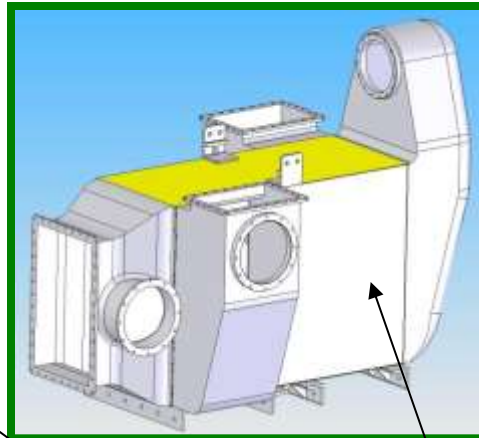


eTeg 2060 Main Assemblies

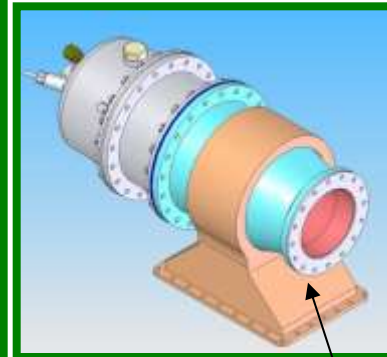
Power Unit



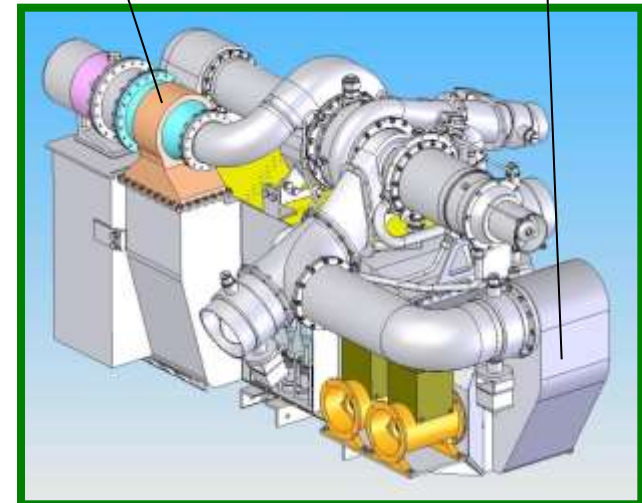
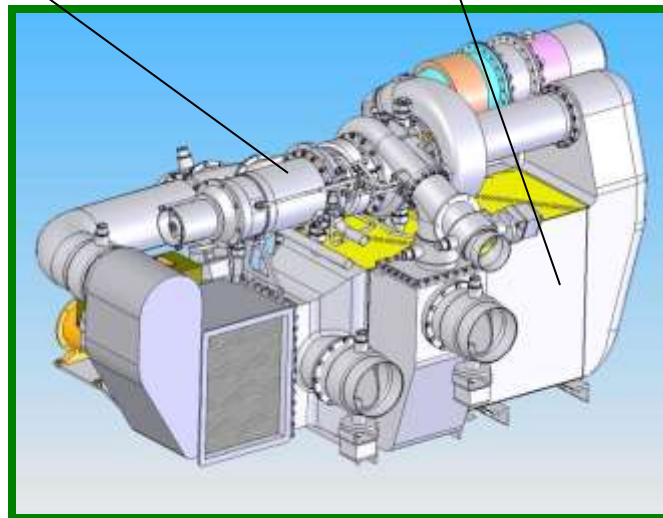
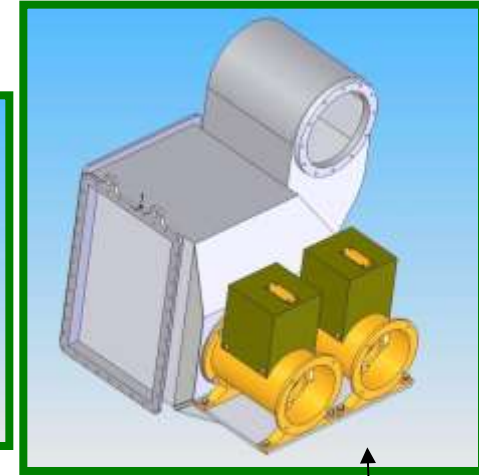
Recuperator



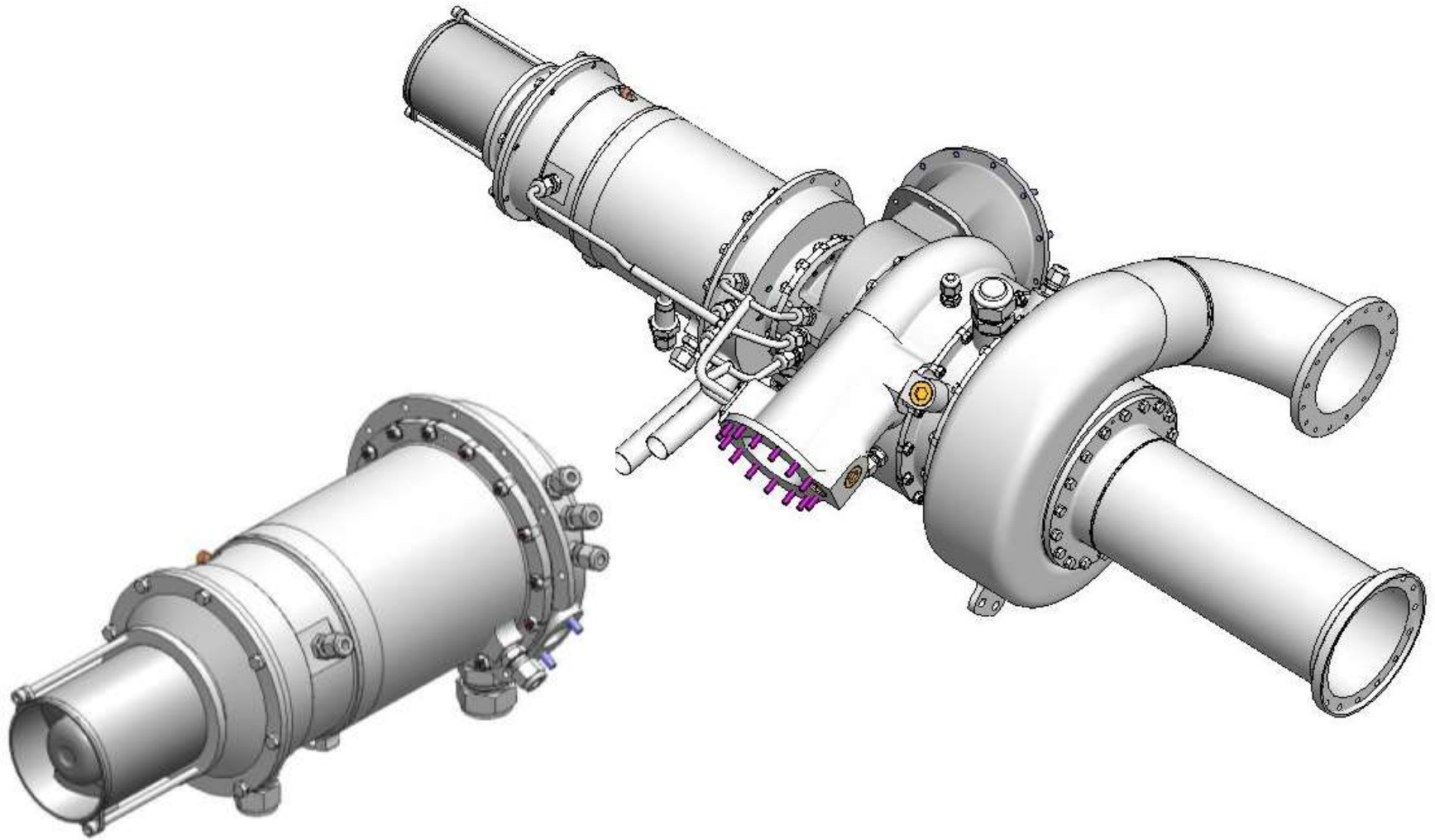
Combustion Chamber



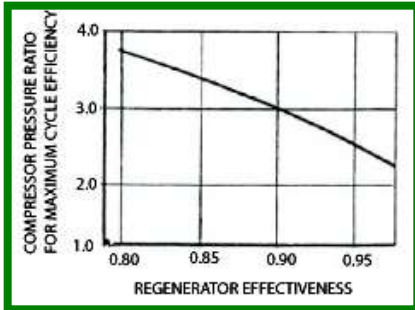
Heat Exchanger



The Turbo-Power Unit

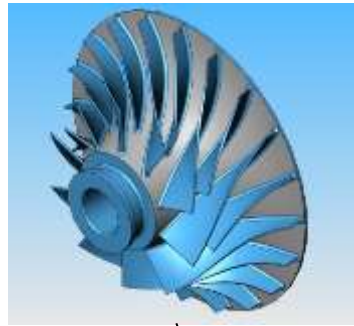


TPU Cut View

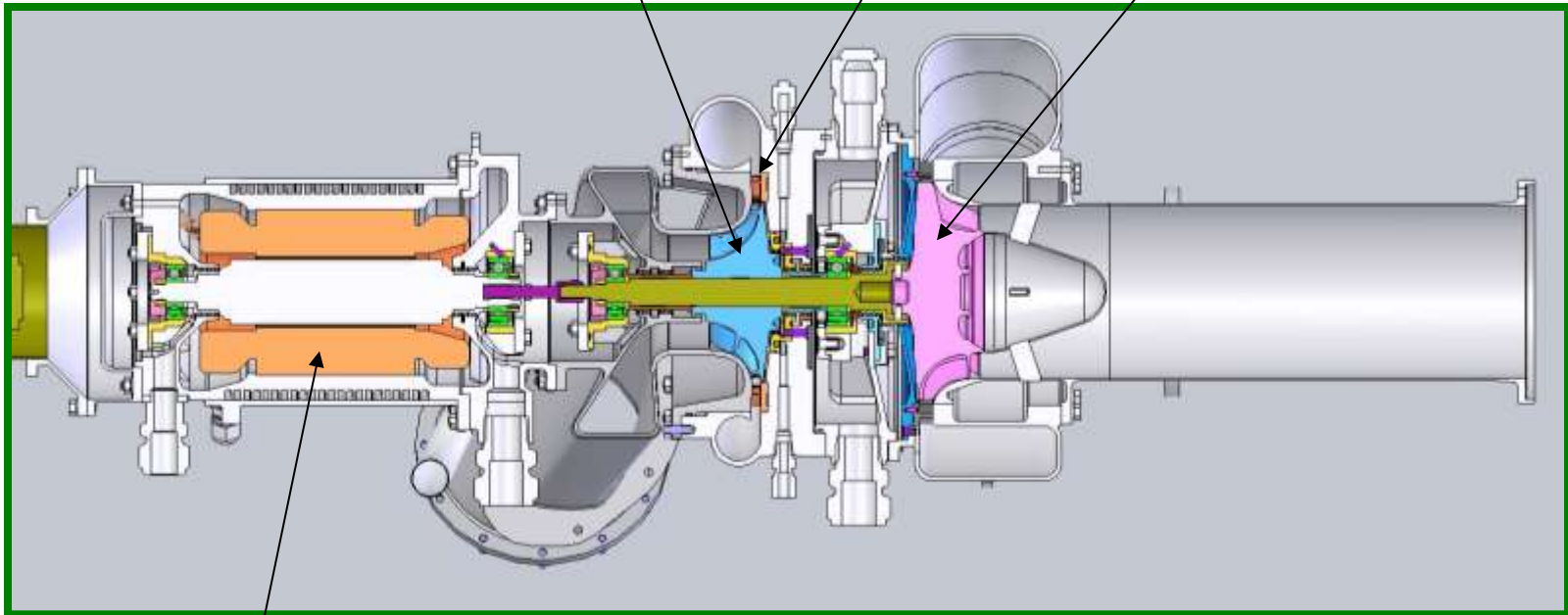


Compressor

P.R = 3 Efficiency : 0.785

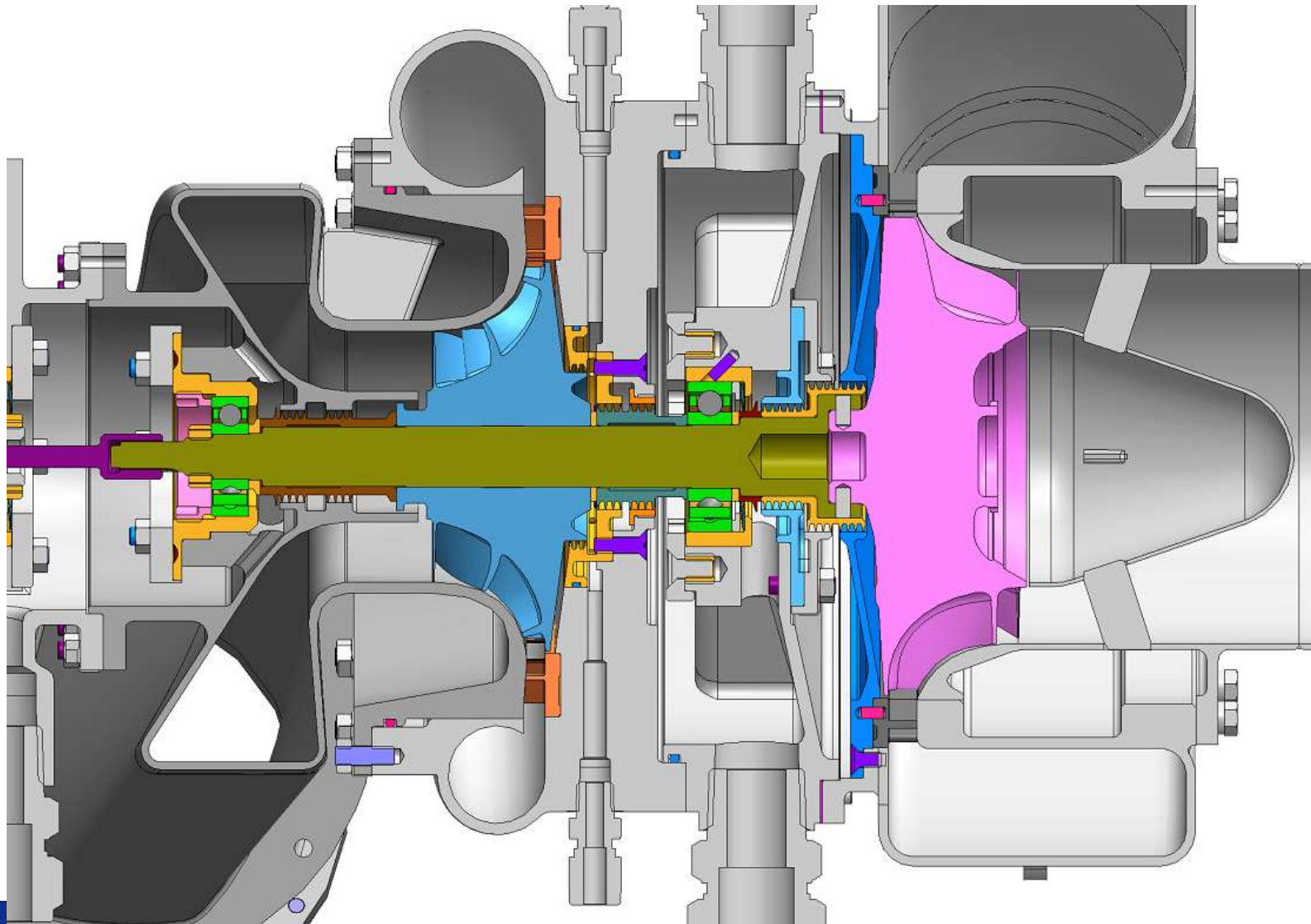


**Turbine
Efficiency :
0.852**

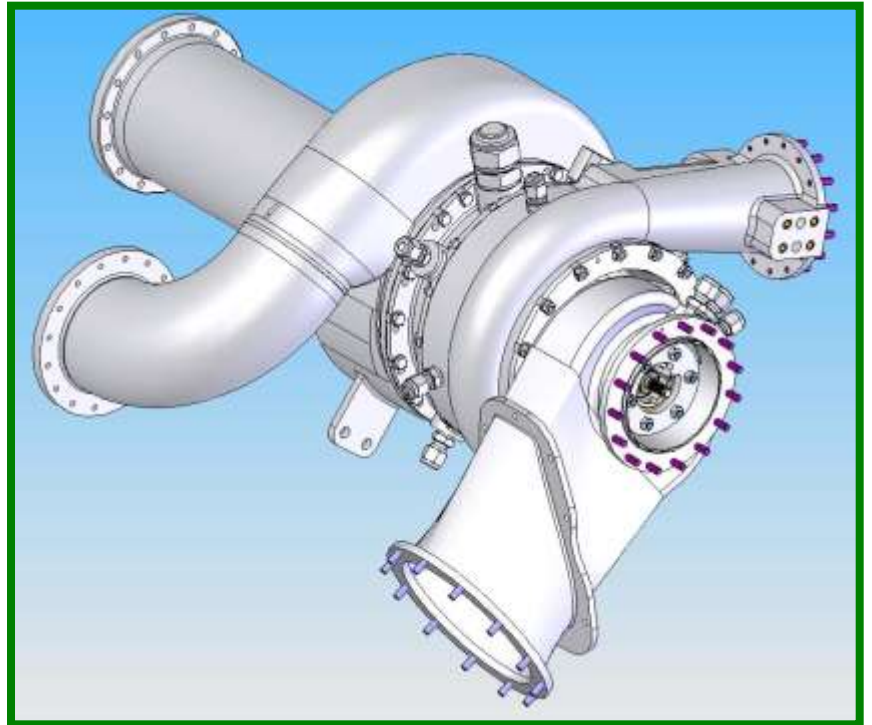
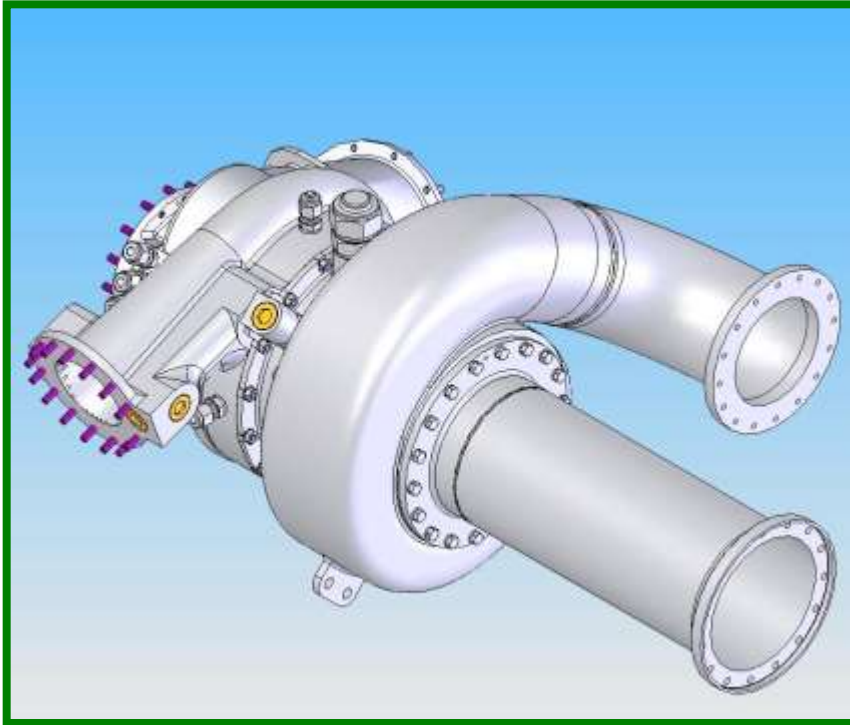


Generator

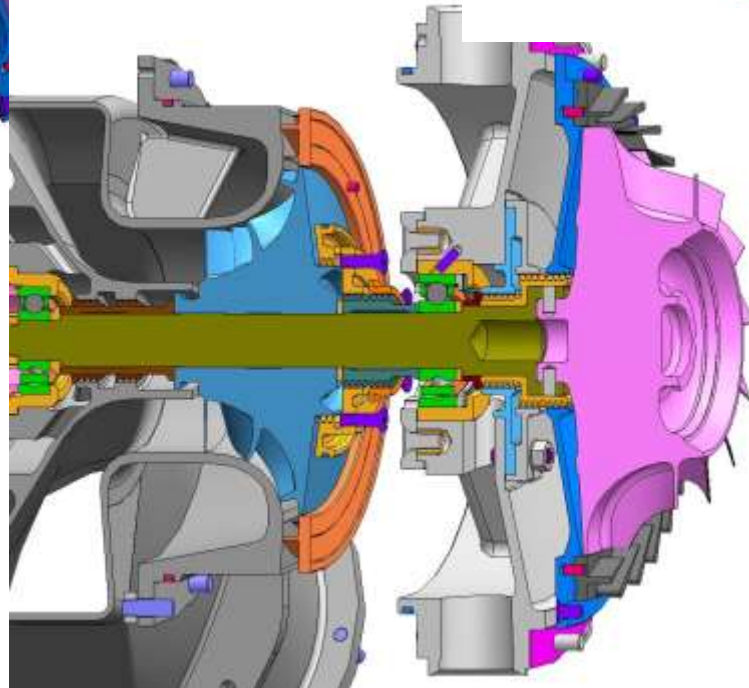
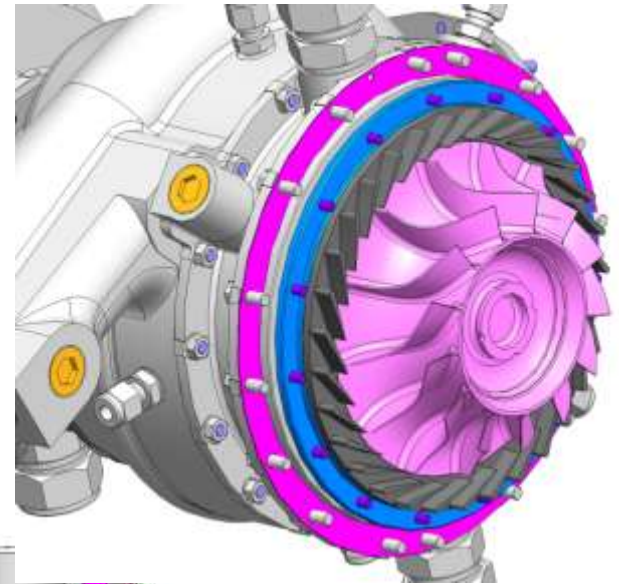
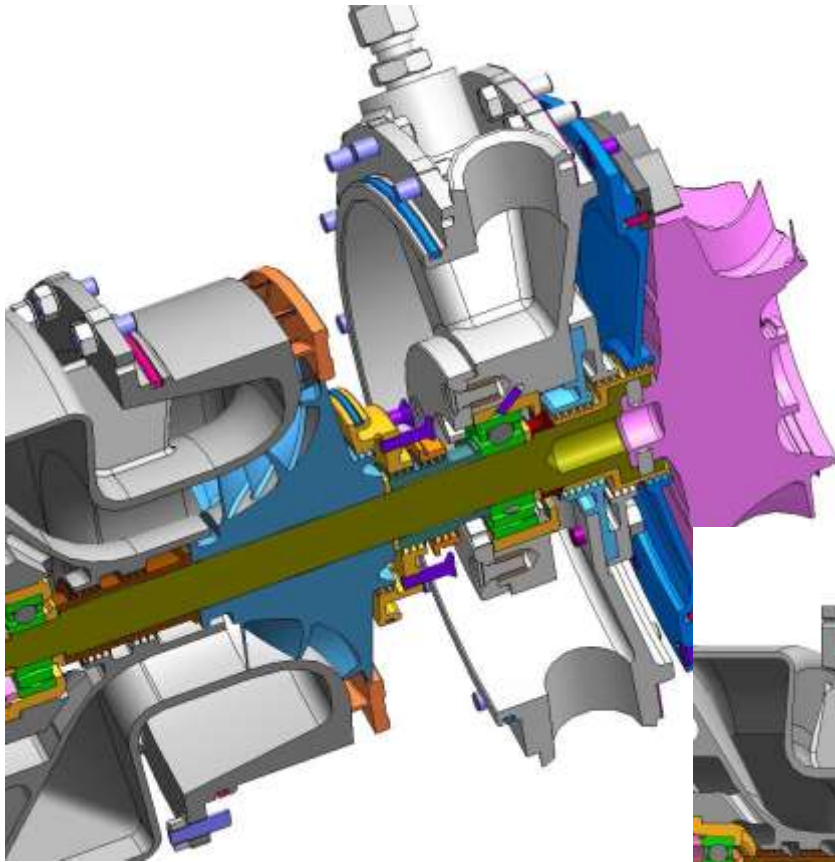
Basic details and units of Turbo-compressor



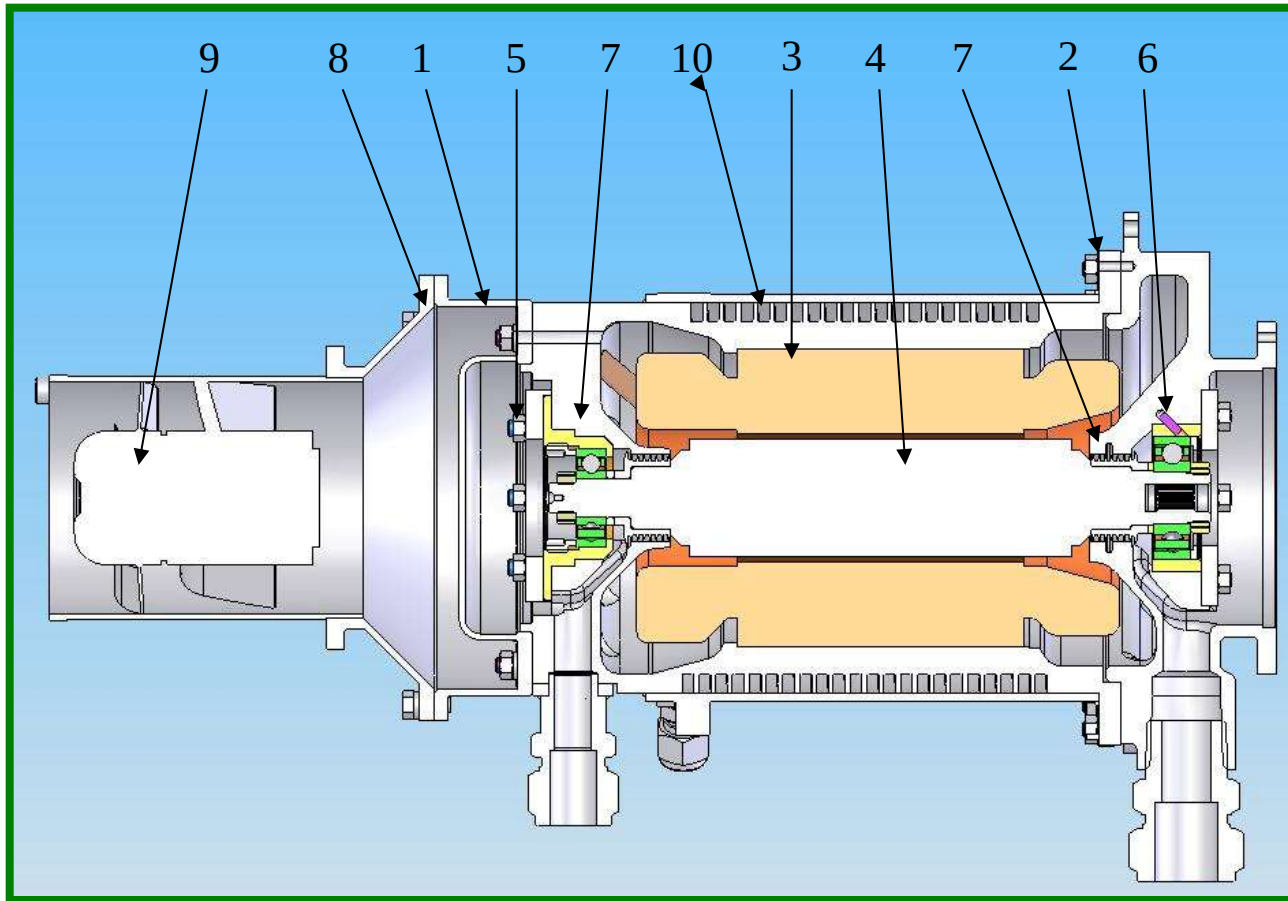
Turbo-compressor



Turbo-compressor



Generator design



- 1- Outer housing;
- 2- Rear housing;
- 3- Electric stator part;
- 4- Generator shaft;
- 5- Front bearings;
- 6- Rear bearing;
- 7- Labyrinth seals;
- 8- Cover;
- 9- Fan "MELBA" for air cooling;
- 10- Channels of oil cooling.



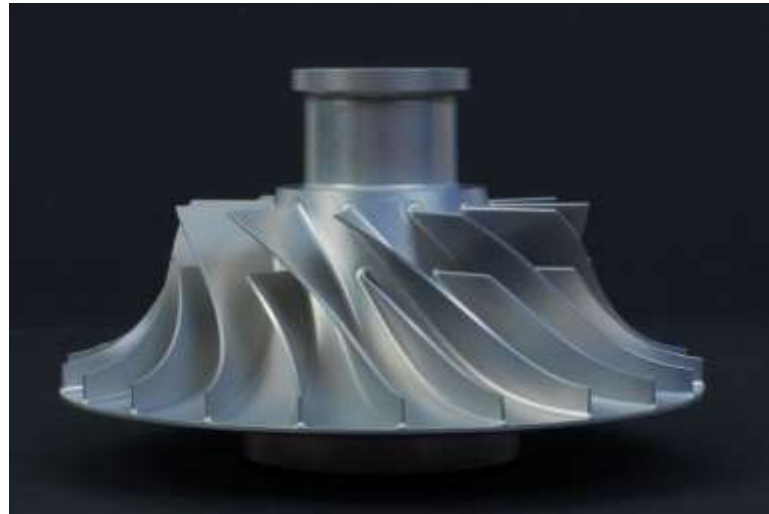
eTeg 2060- Parts



JET WAVE
Engineering Consultant
Gery Ordan



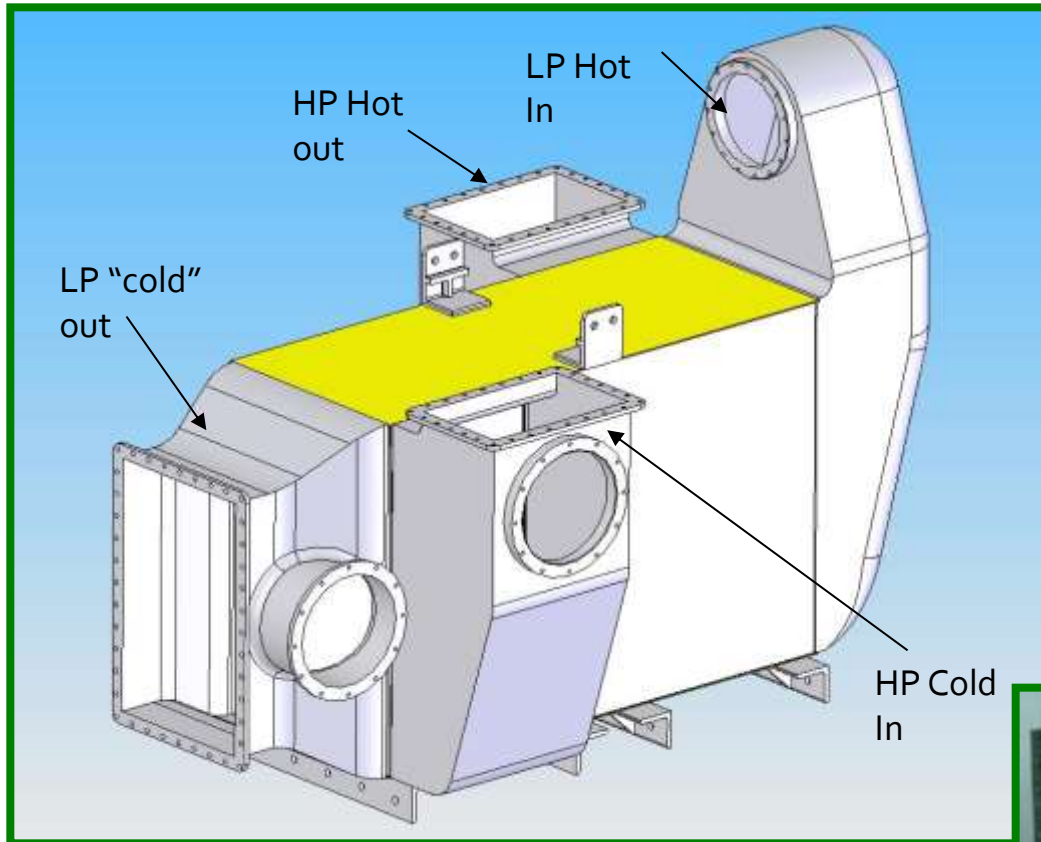
eTeg 2060- Parts



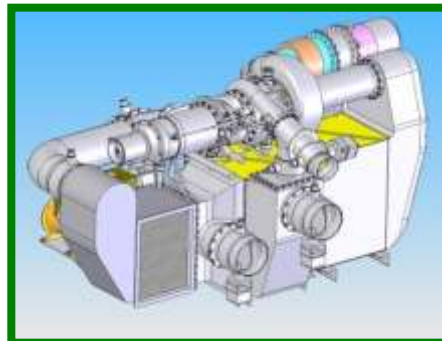
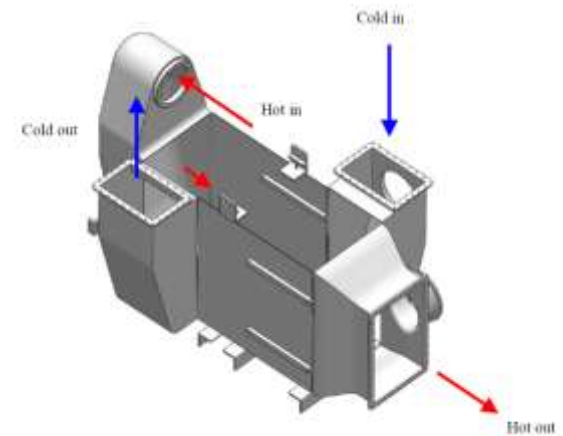
eTeg 2060- Parts



Recuperator Shell @ Headers

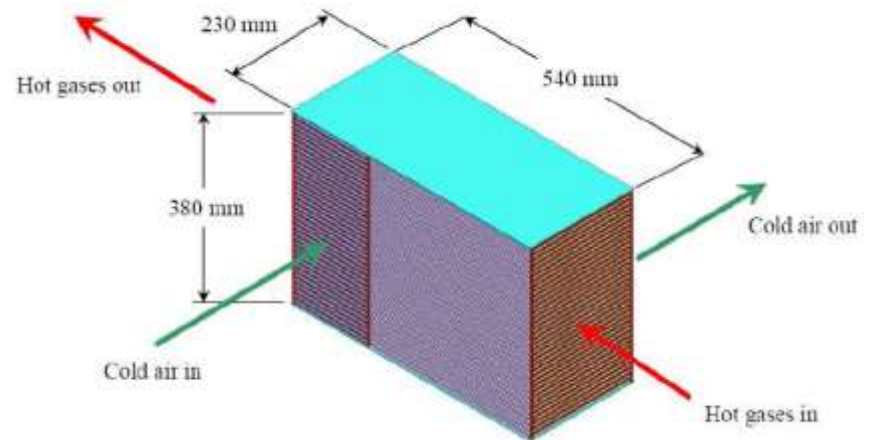
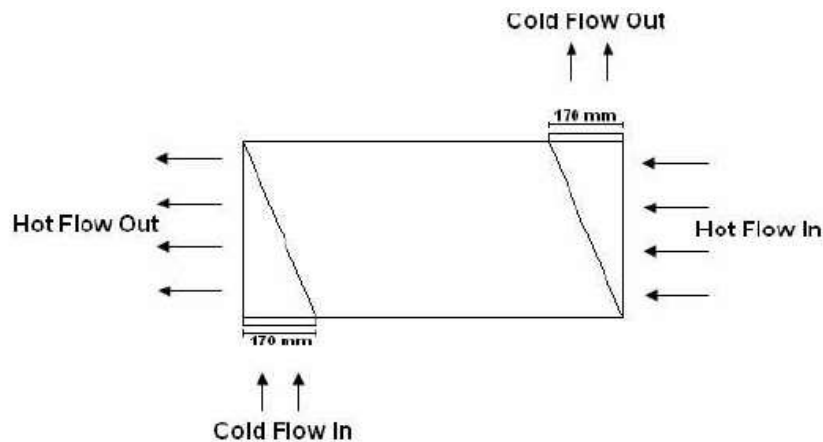


Recuperator Packaging Shell @ headers

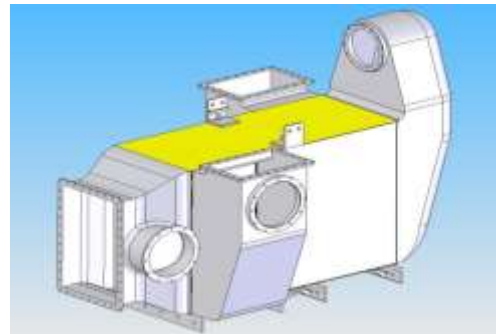


Recuperator Specifications

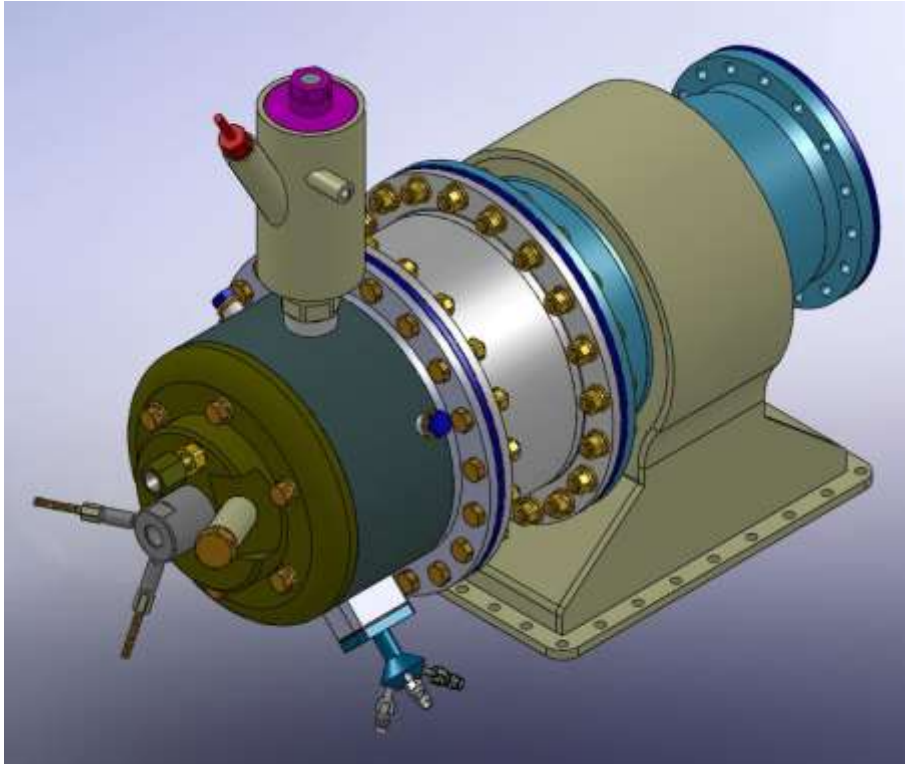
Parameter	12 KW		40KW	
	Hot	Cold	Hot	Cold
Inlet temperature, [°C]	761	30	757	175
Outlet temperature, [°C]	71.8	731.3	249.7	695.2
Thermal effectiveness	0.943		0.891	
Inlet pressure, [kPa]	38	100.3	110	304
Pressure drop, [kPa]	2.29	2.90	2.80	3.20
Mass flow rate, [kg/s]	0.108	0.107	0.304	0.301



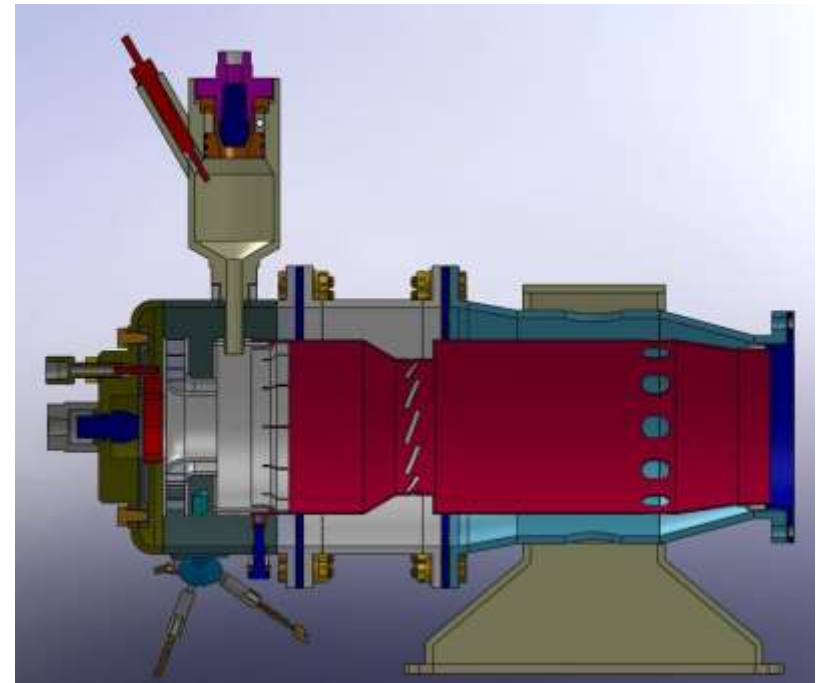
eTeg 2060- Parts



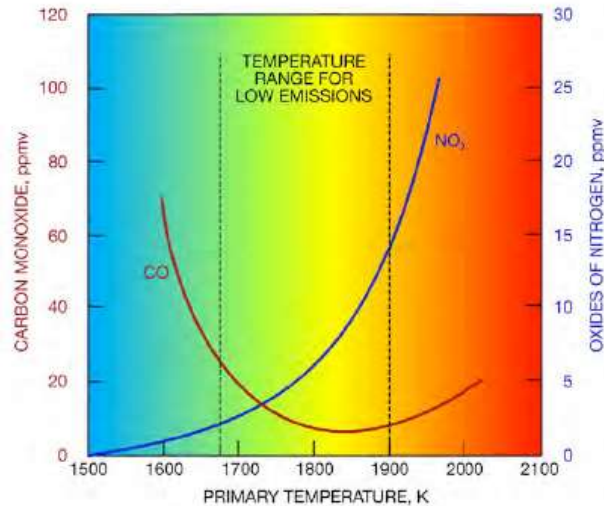
Combustion Chamber



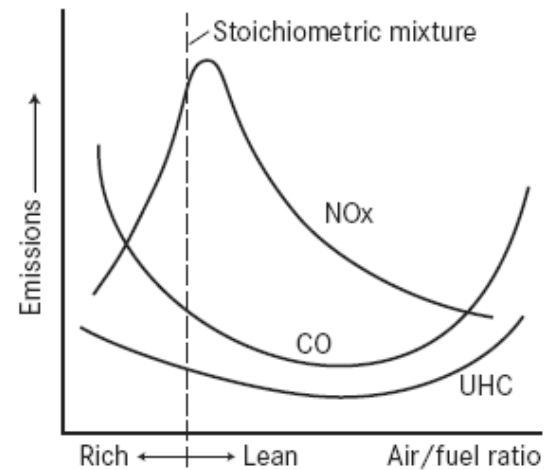
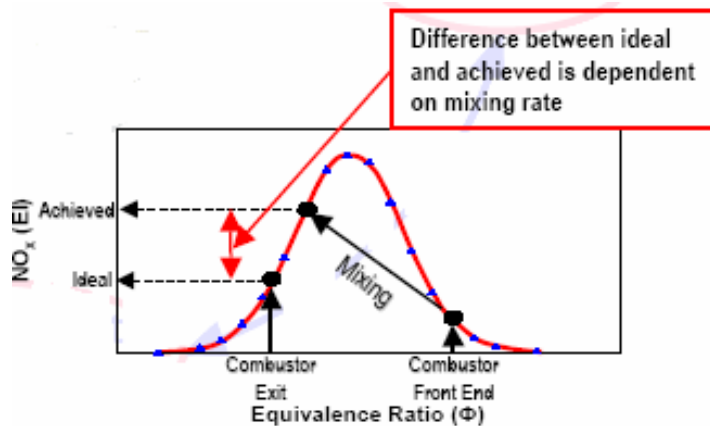
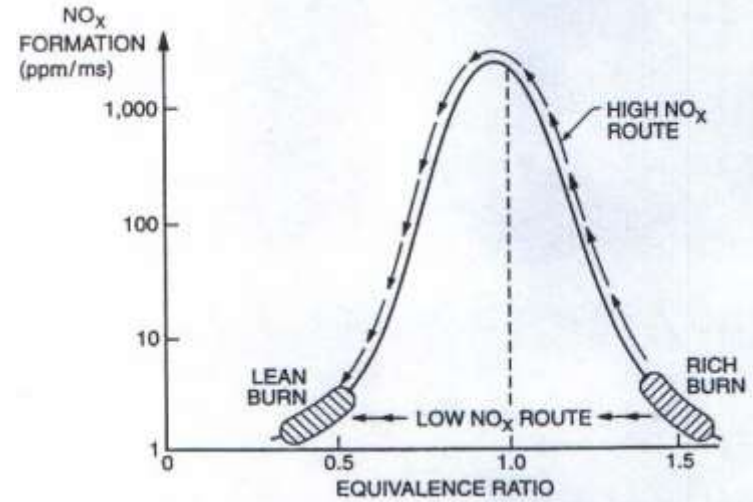
RQL Concept



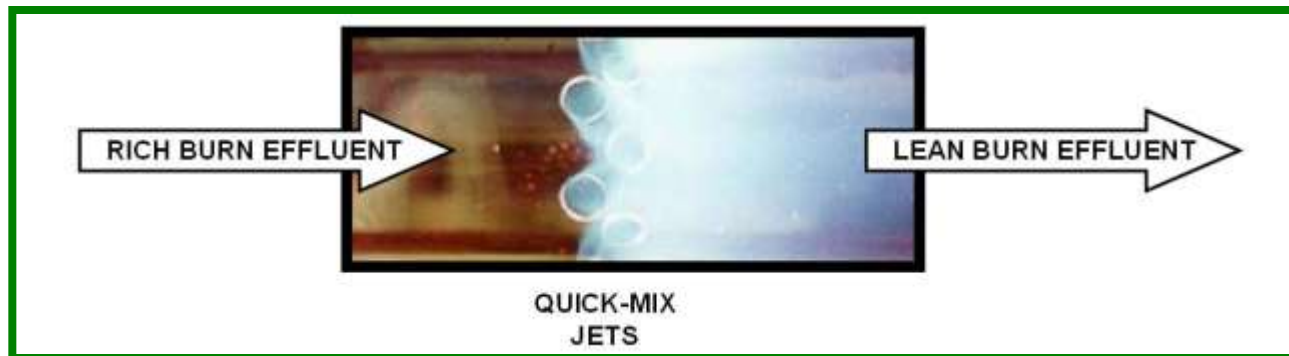
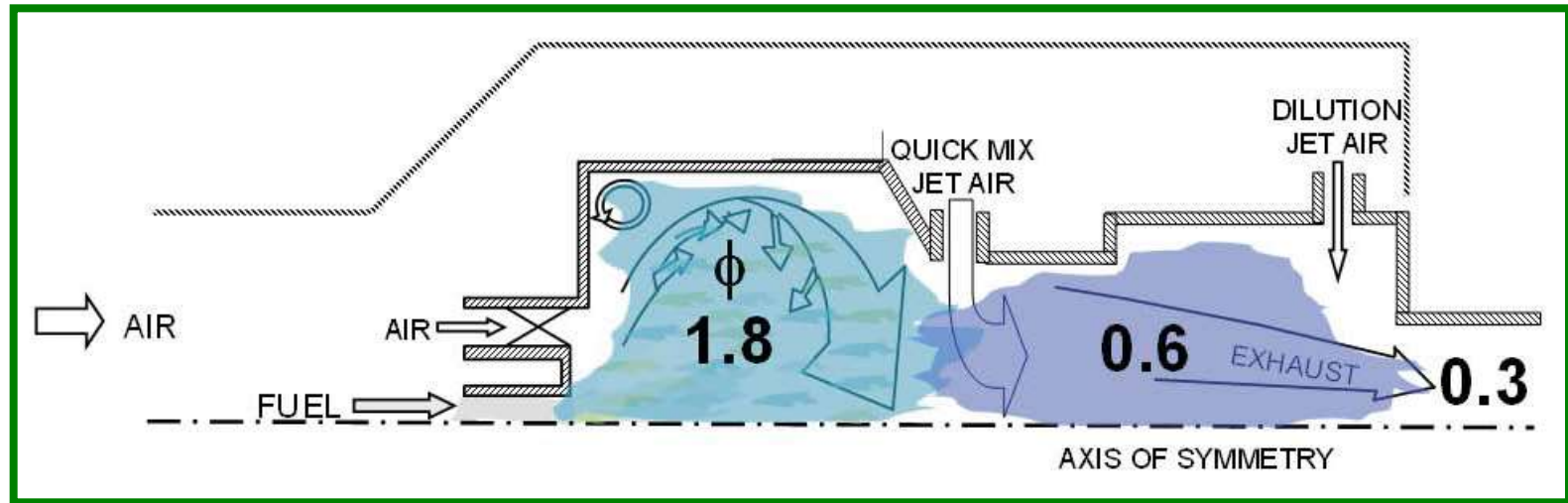
Combustion Chamber – RQL Technology



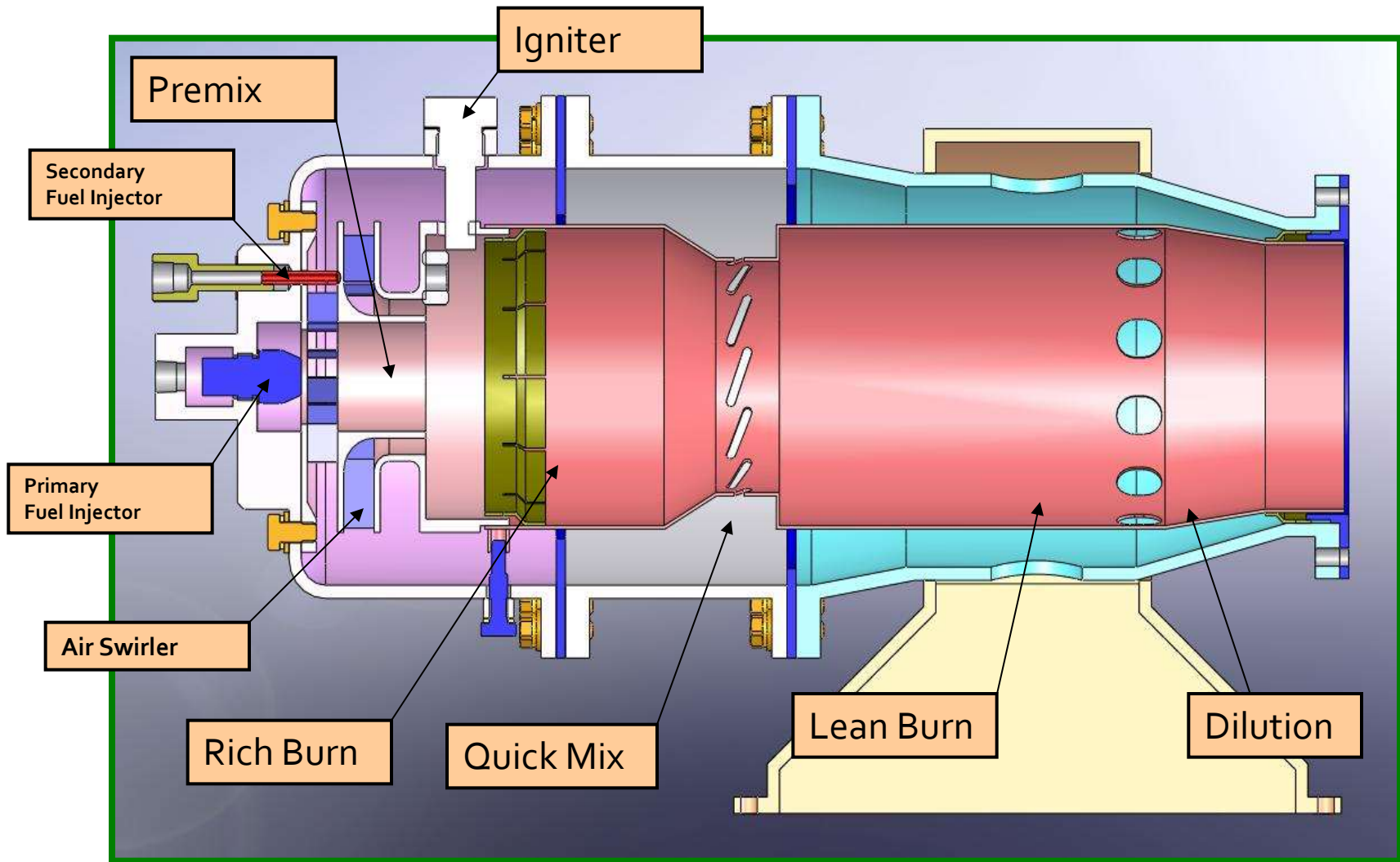
1000 K ← TEMPERATURE RANGE OF CONVENTIONAL COMBUSTORS → 2500 K



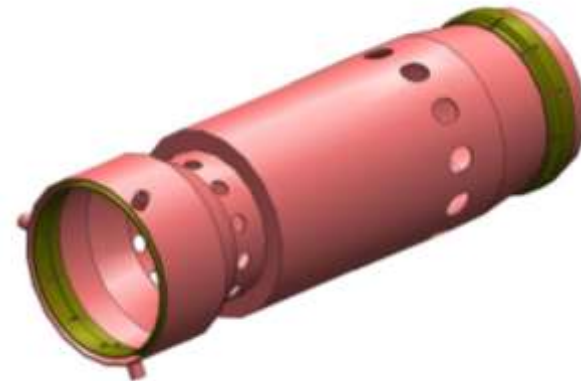
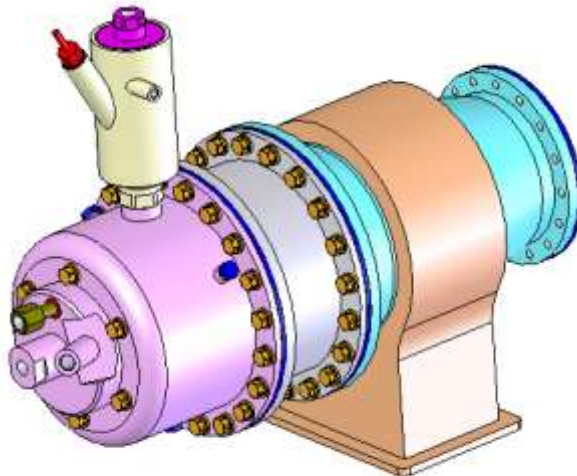
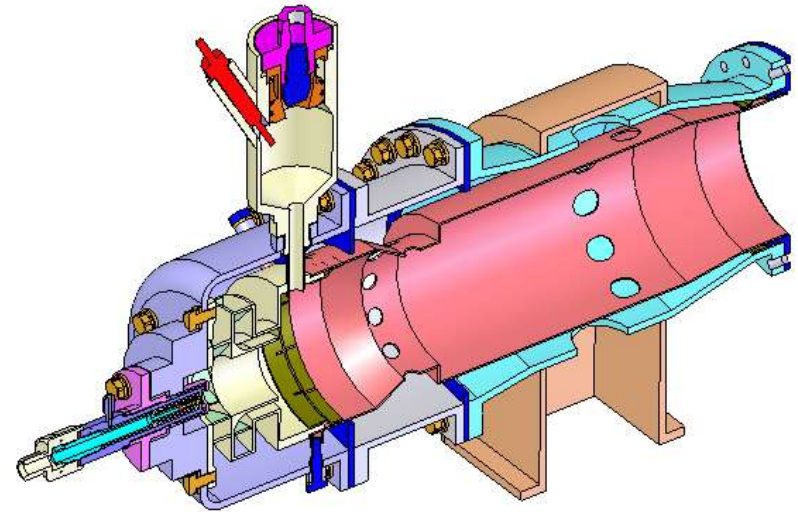
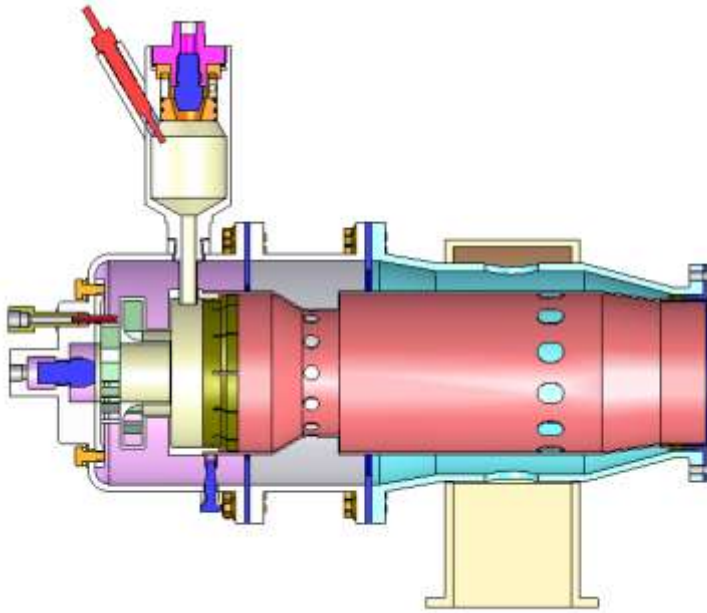
Combustion Chamber – RQL Technology



Combustion Chamber Structure



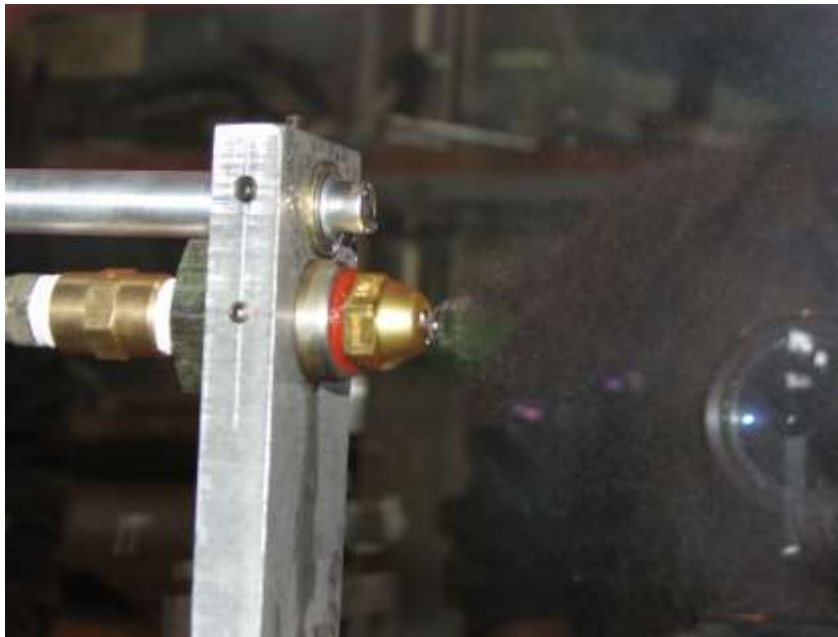
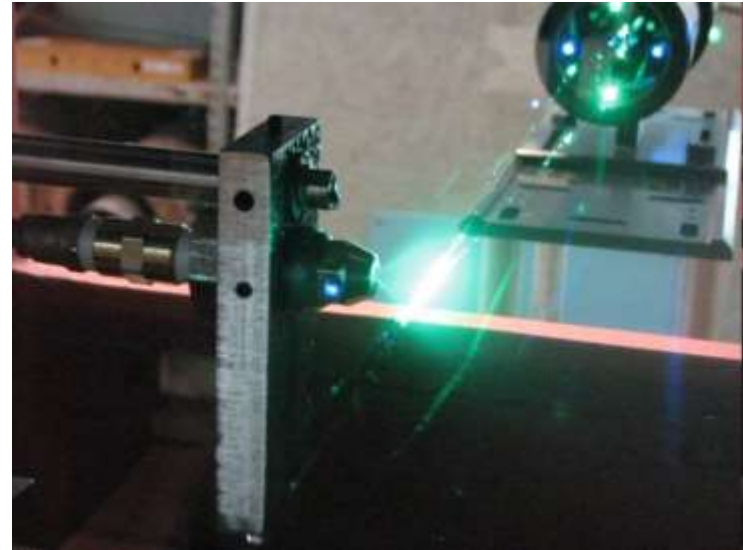
RQL Combustor



eTeg 2060- Parts

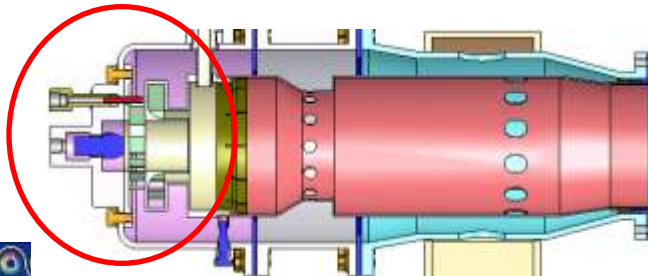


eTeg 2060- Component tests



Fuel Injector Spray SMD measurements

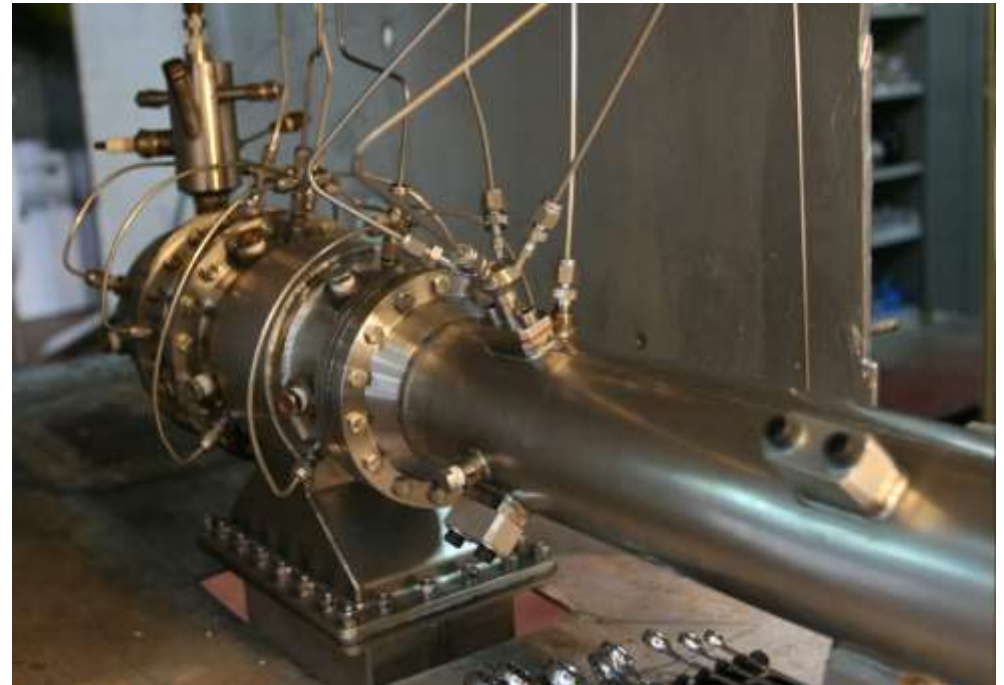
eTeg 2060- Component tests



eTeg 2060- Component tests



eTeg 2060- Component tests



eTeg 2060– Parts

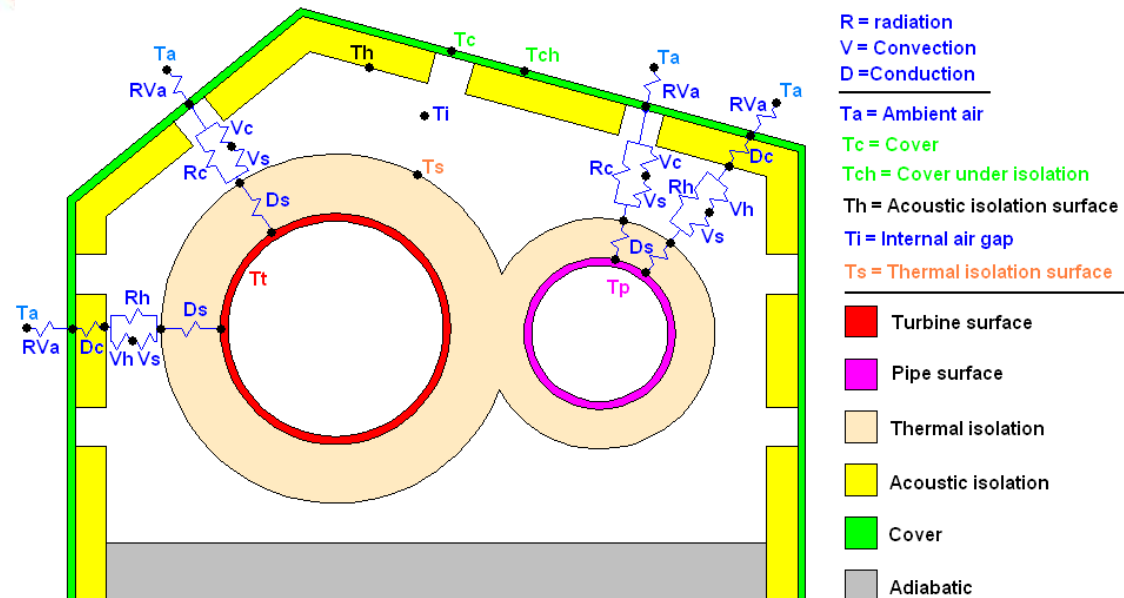
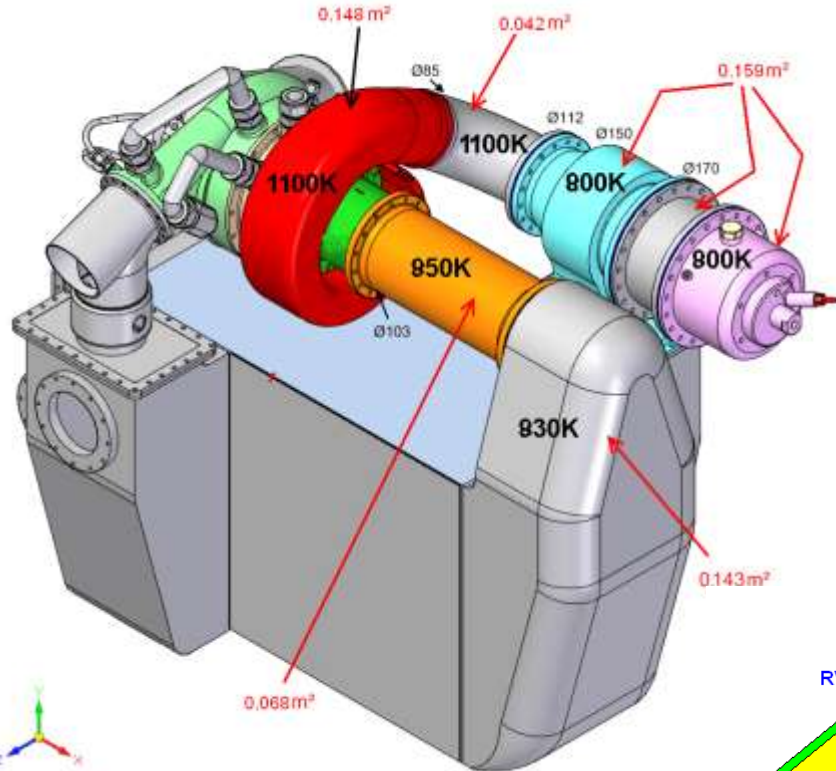
Main parts materials :

- ▶ Turbine/ Turbine nozzle : Nickel based alloy, MAR M 247
- ▶ Compressor/Diffuser : Al 2024 – T3
- ▶ Combustor, hot section scrolls and ducts : Hastalloy X
- ▶ Cold section Scrolls and ducts : Al cast A 356 – T6
- ▶ Shaft and medium Temperature parts : SS 15-5 PH
- ▶ Combustor liner : Plasma ceramic coating on the inner surfaces.
- ▶ Recuperator : Inconel 625 (SS347)

eTeg 2060

Thermal & Acoustic Cover

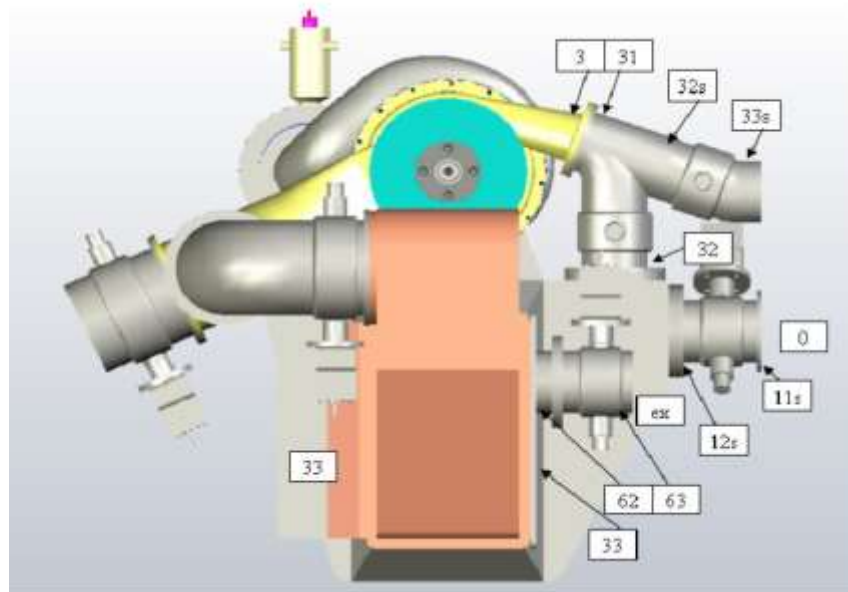
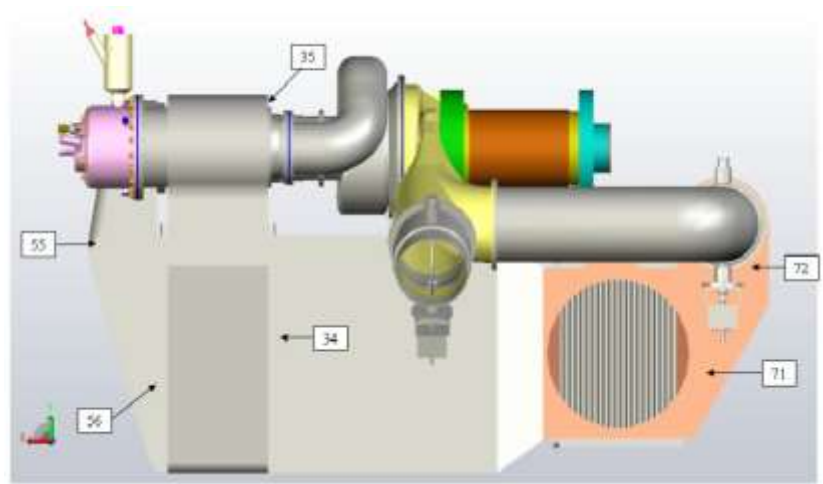
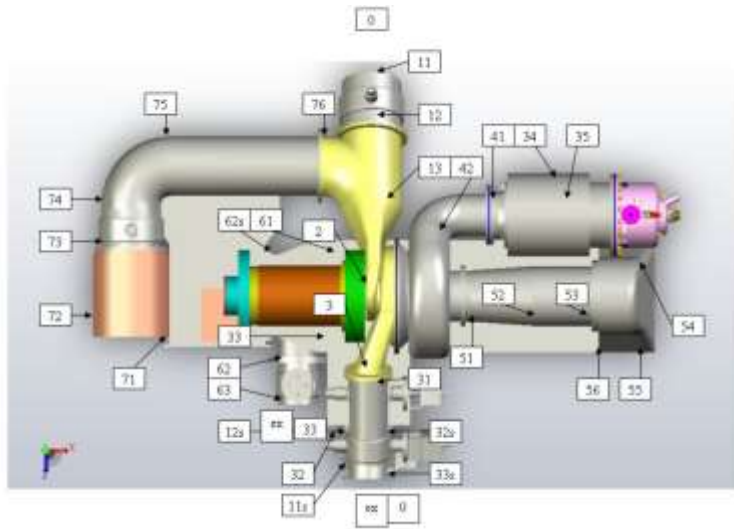
Thermal & Acoustic Cover Design



eTeg 2060

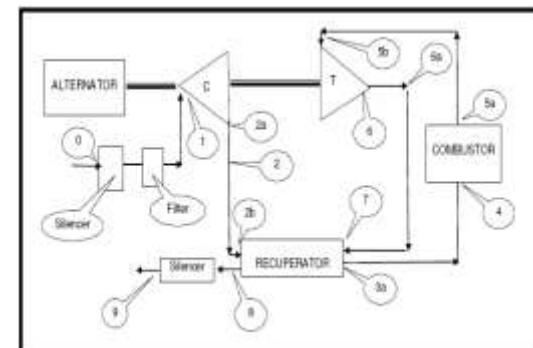
Performance

Cycle parameter definition

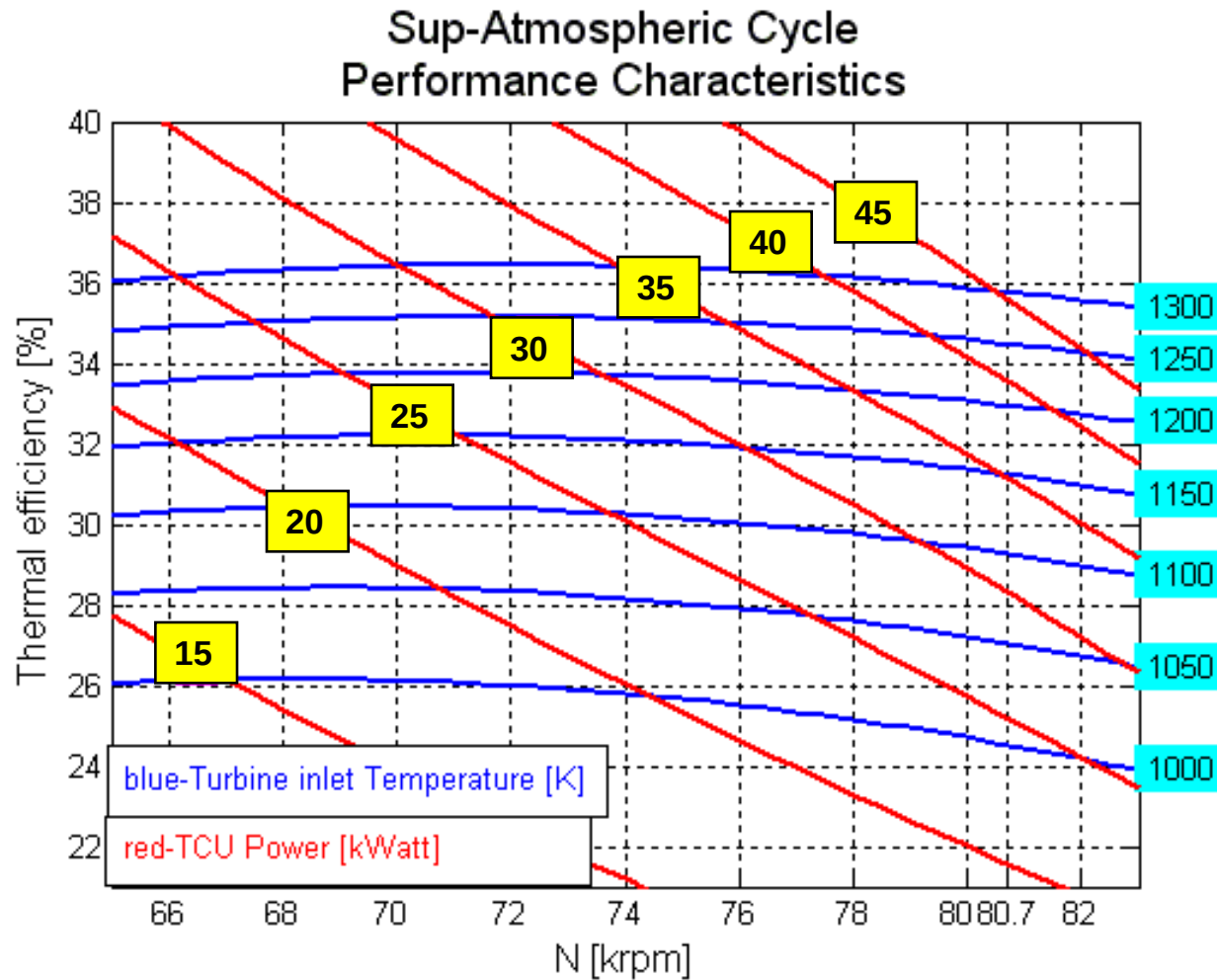


Cycle parameter definition

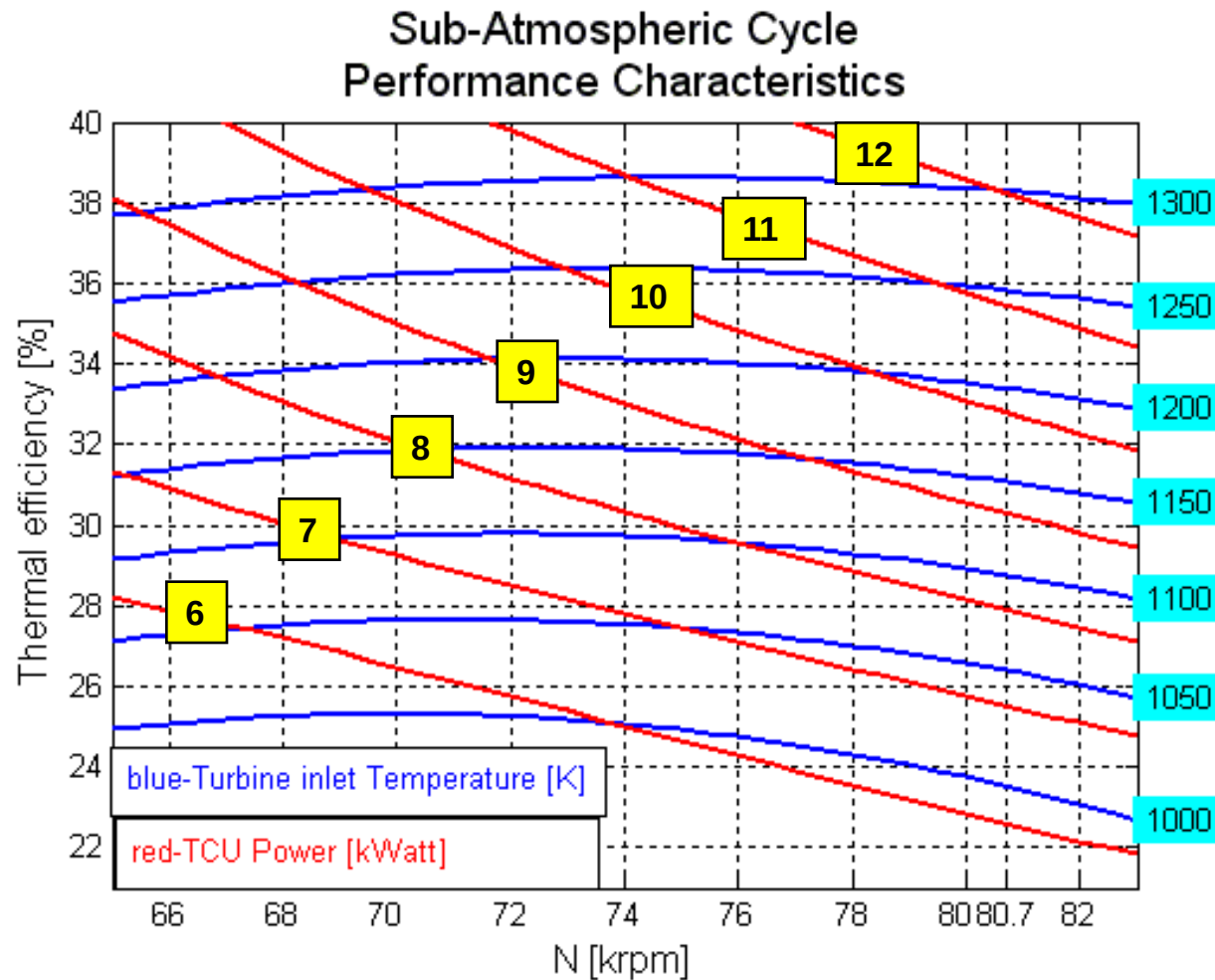
Cycle Parameters								Cycle Par./Pressure Losses			
St.	Name	T °K	P Kpa	Flow Kg/Sec	H Kj/Kg	Eff. %	ΔH Kj/KG	St.	Name	PL Kpa	
0	Ambient										
1a		288	101.35		289.44			1a-1	Filter dp.	0.2	
1	Comp. Inlet	288	101.15	0.3174	289.44			2a-2b	Duct Comp.	1.55	
2a	Comp. Outlet	420.0	296.208		423.39	0.785	133.95		CPR		2.93
2b	Rec. In	420.0	294.658					2b-3a	Rec. Cold dp	7.49	
3a	Rec. Out	1005.14	287.165		1050.87	0.892	1050.87	3a-4	Inlet Duct to comb.		
4	Comb. In	1005.14	287.165	0.2974				4-5a	Comb. dp	12.3	
5a	Comb. Out	1314	274.874	0.2993	1423.46	0.995	372.58		F/A		0.006 257
5b		1314	274.874								
5b	Turbine In	1300.43	273.084	0.3088	1408.37	0.852		6-7	Turbine Diffuser	1.79	
6	Turbine Out	1075.83	107.373	0.3088	1140.38		267.99		TPR		2.56
6a	Diffuser	1075.83									
7	Rec. Hot In		105.583					5a-5b			
8	Rec. Hot Out	490.728	102.563					7-8	Rec. Hot dp	3.02	
9	HX Out		102.163					8-9		0.4	
									Bleed out %		0.031
									Bleed Turbine %		0.032



Turbo-Generator Performance



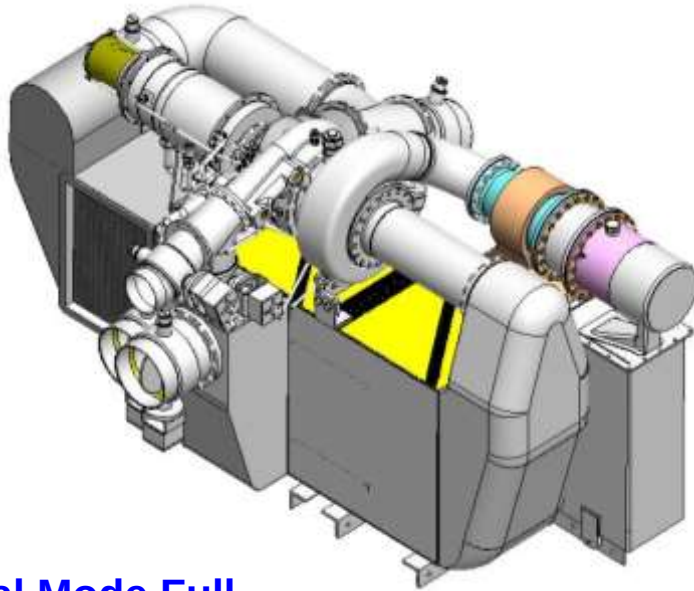
Turbo-Generator Performance



Model Derivatives

eTeg 2060 - Dual Mode Full Recuperation

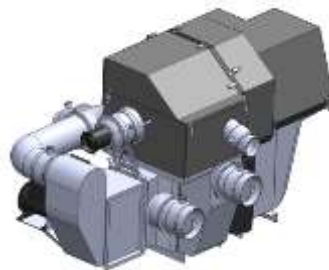
Base Model



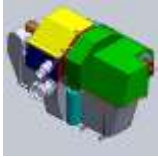
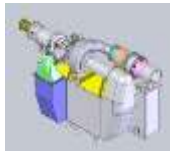
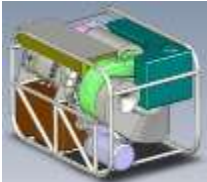
**Dual Mode Full
Recuperation**

**42 KW / 35% / 140 Kg
1349 x 790x 890 mm**

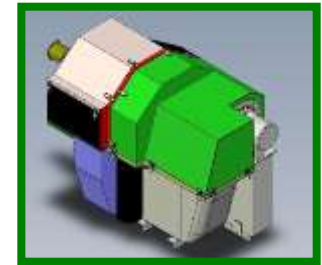
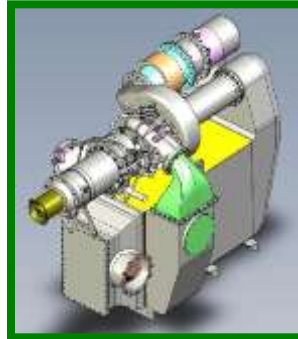
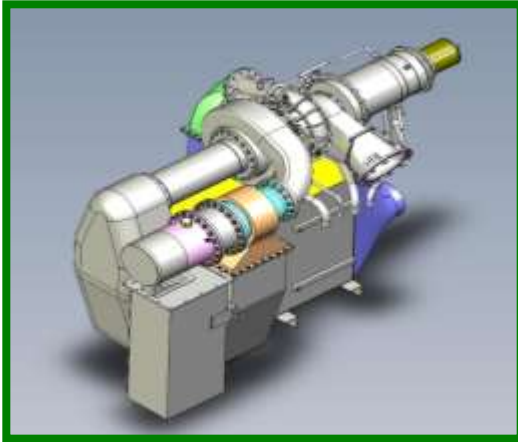
**Efficiency : 36 %
Weight : 120kg**



eTeg 2060- Configuration Derivatives

N o	Assembly File name	Dimensions LxWxH [mm]	Powe r KW	Eff . %	Weig ht Kg	Pic 1	Pic 2 (No Casing)	Description/ Comments
1	ETV- 12-2	1349 x 790x 890	42	35	150			Dual Mode Full Recuperation
2	ETV-13Sup	1120 x 575x 720	42	35	110			Single Mode Full recuperation
3	ETV- 13SupNoRecup	720 x 555 x 585	46	16	65			Single Mode No recuperation
4	ETV- 13SupNoRecupS R2	720x470x500	42	27	90			Single Mode Small recuperator V1 (70%)
5	ETVSmallRecAs sy_Generator	720x470x500	42	27	90			Single Mode Small recuperator V2 (70%)

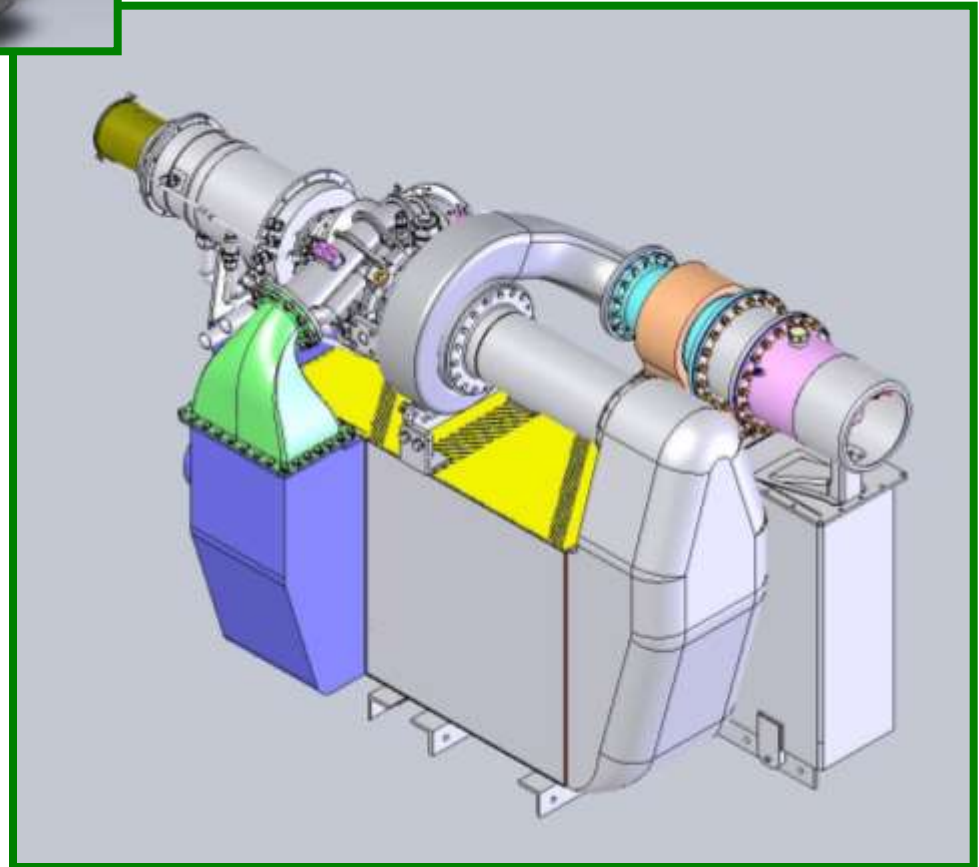
Model Derivatives



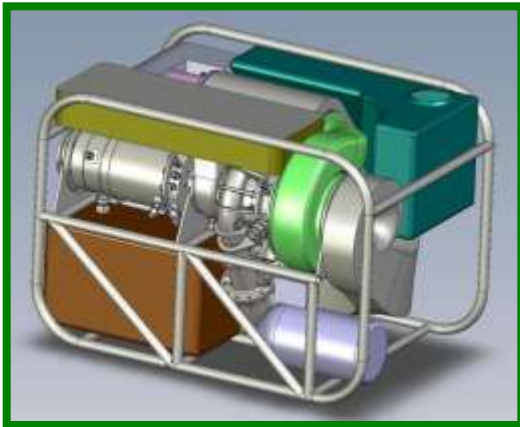
Single Mode Full Recuperation

42 KW / 35% / 110 Kg

1120 x 575x 720 mm



Model Derivatives



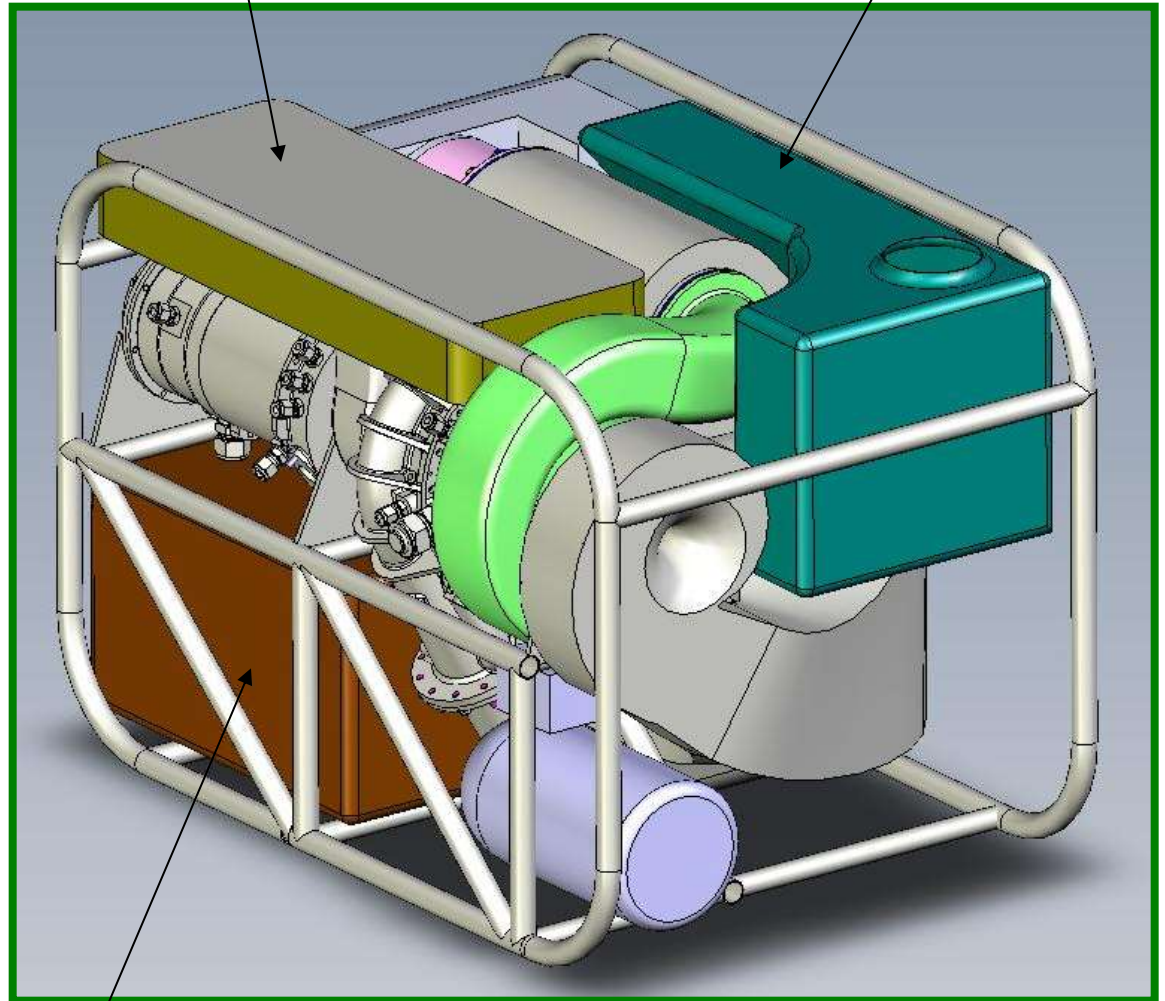
Air Filter

Fuel Tank

Single Mode 70%
Recuperation

42 KW / 27% / 90 Kg

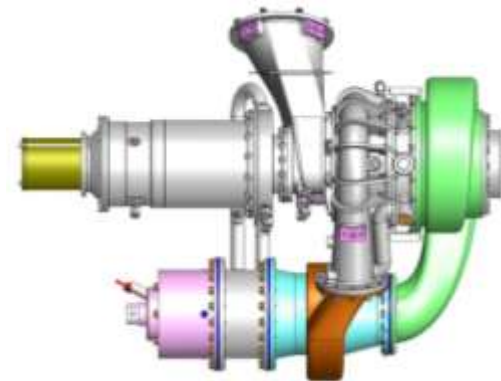
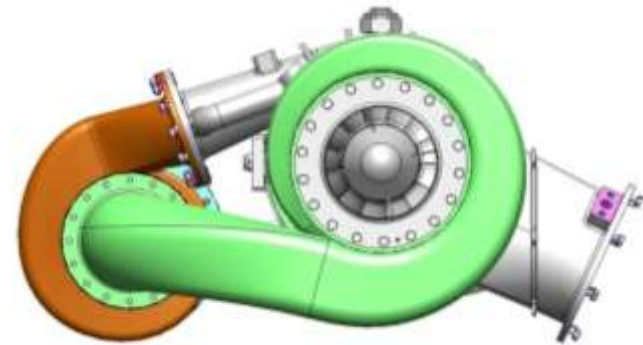
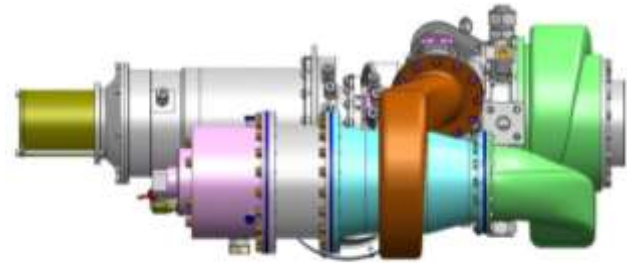
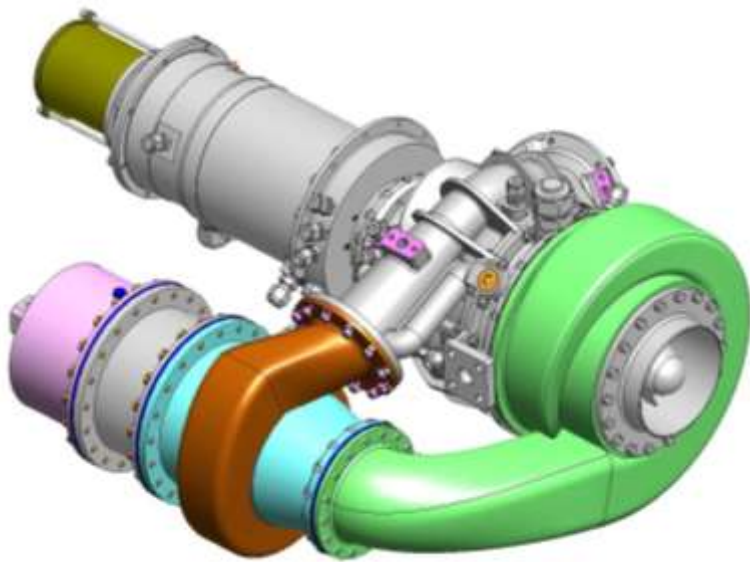
720x470x500 mm



Oil System



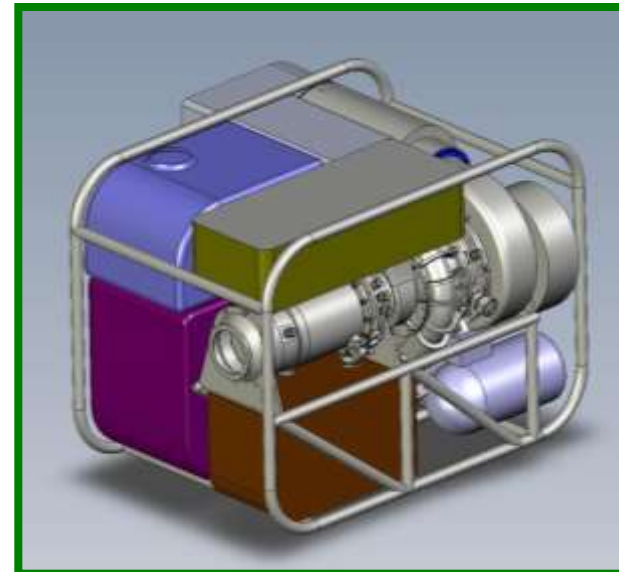
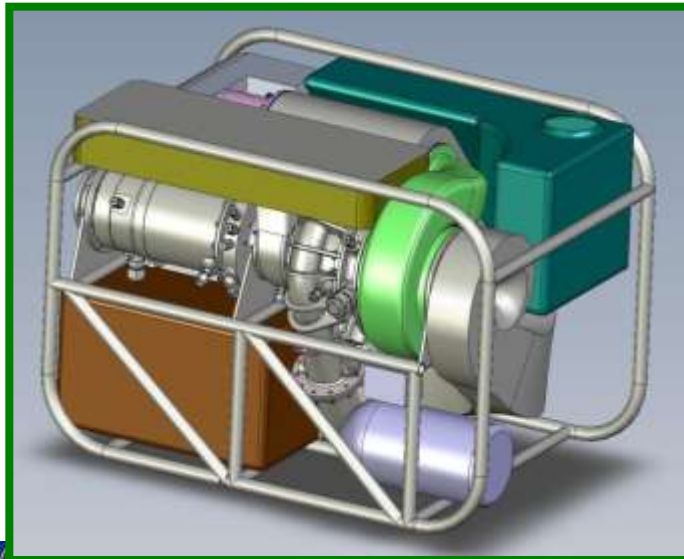
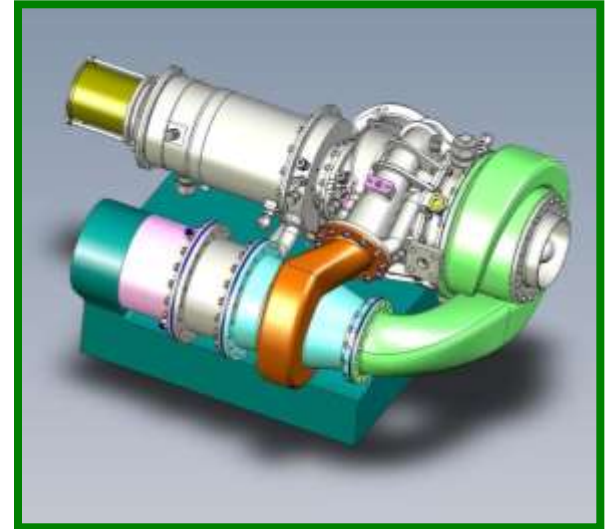
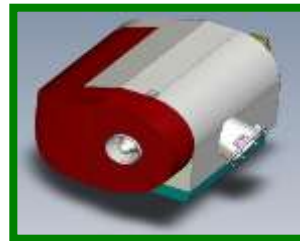
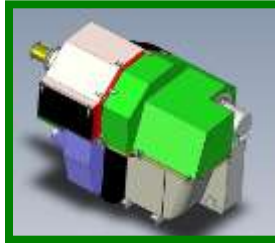
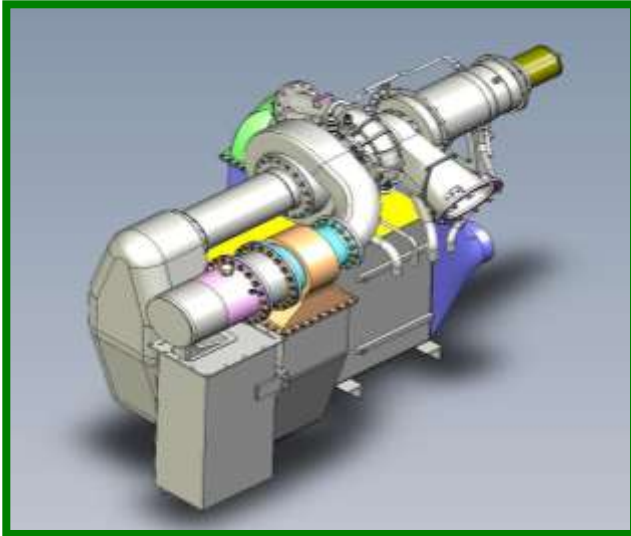
Model Derivatives – Single Mod No Recuperation



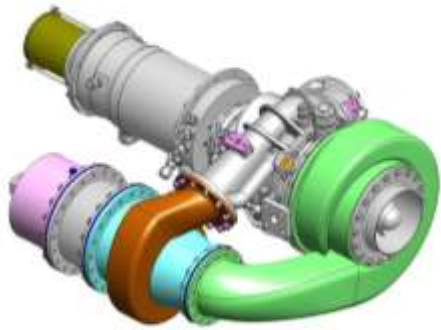
Single Mode No
Recuperation

45 KW / 17% / 65 Kg
720 x 450 x 270 mm

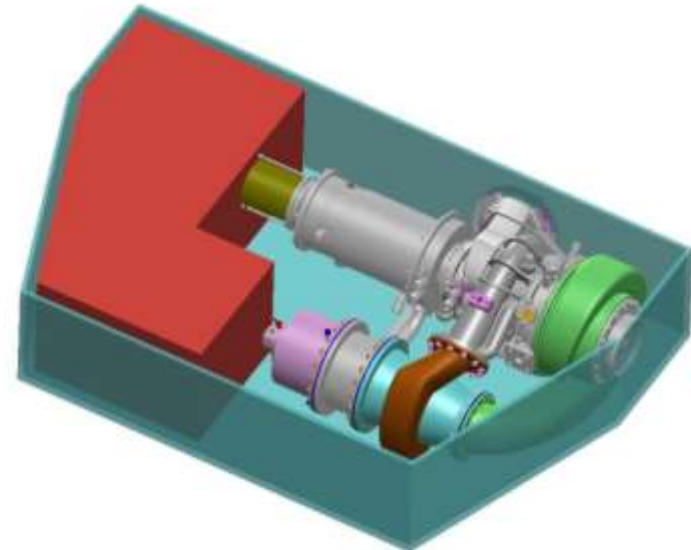
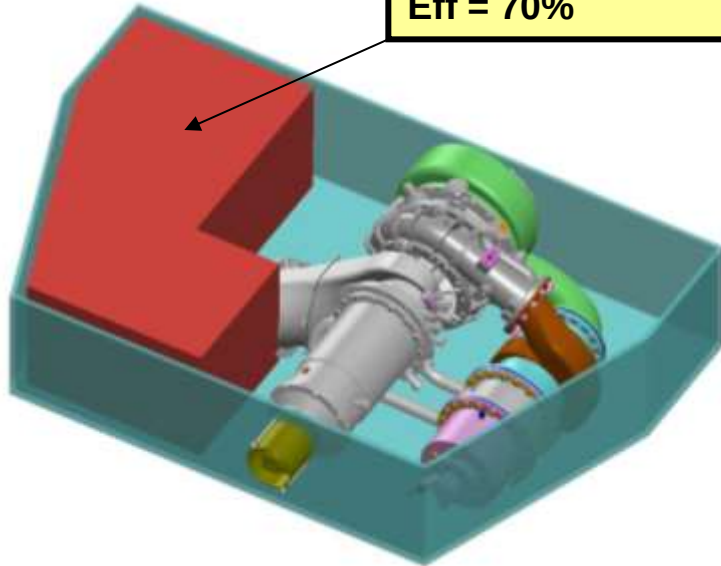
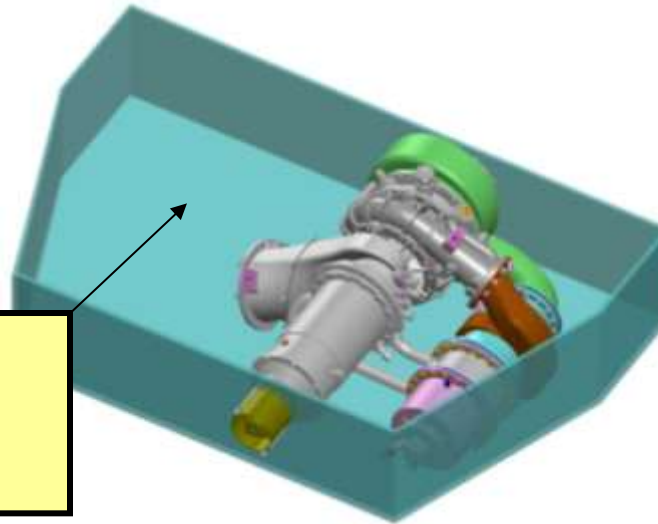
Model Derivatives



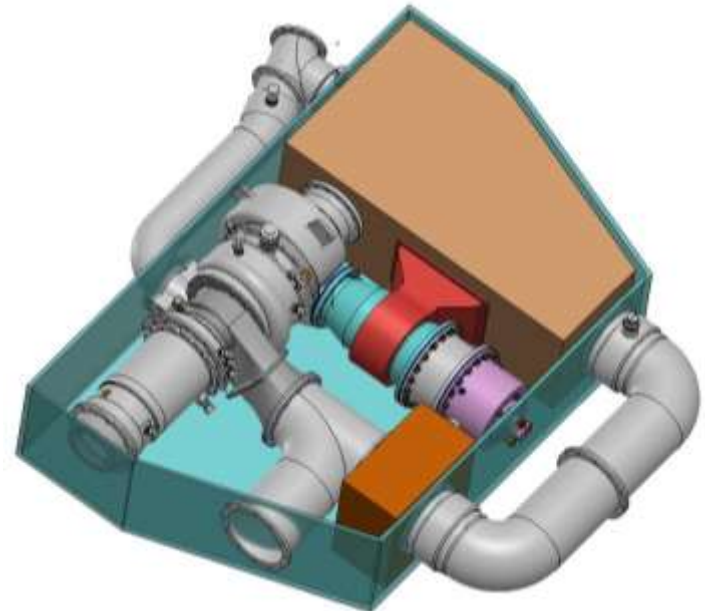
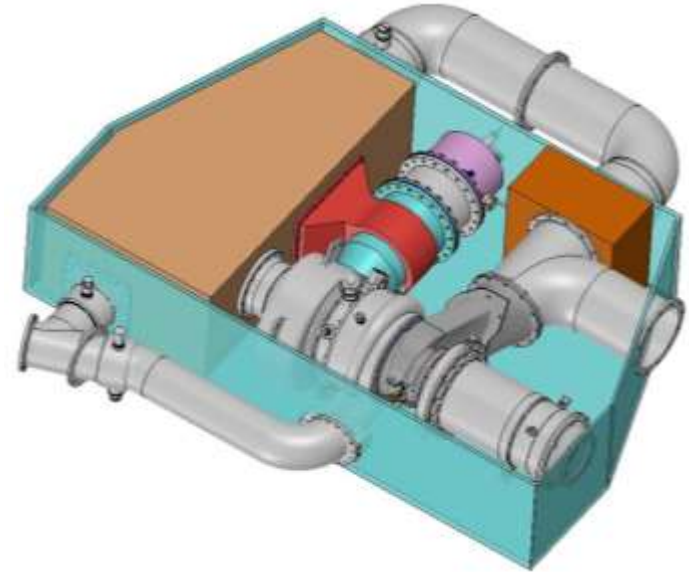
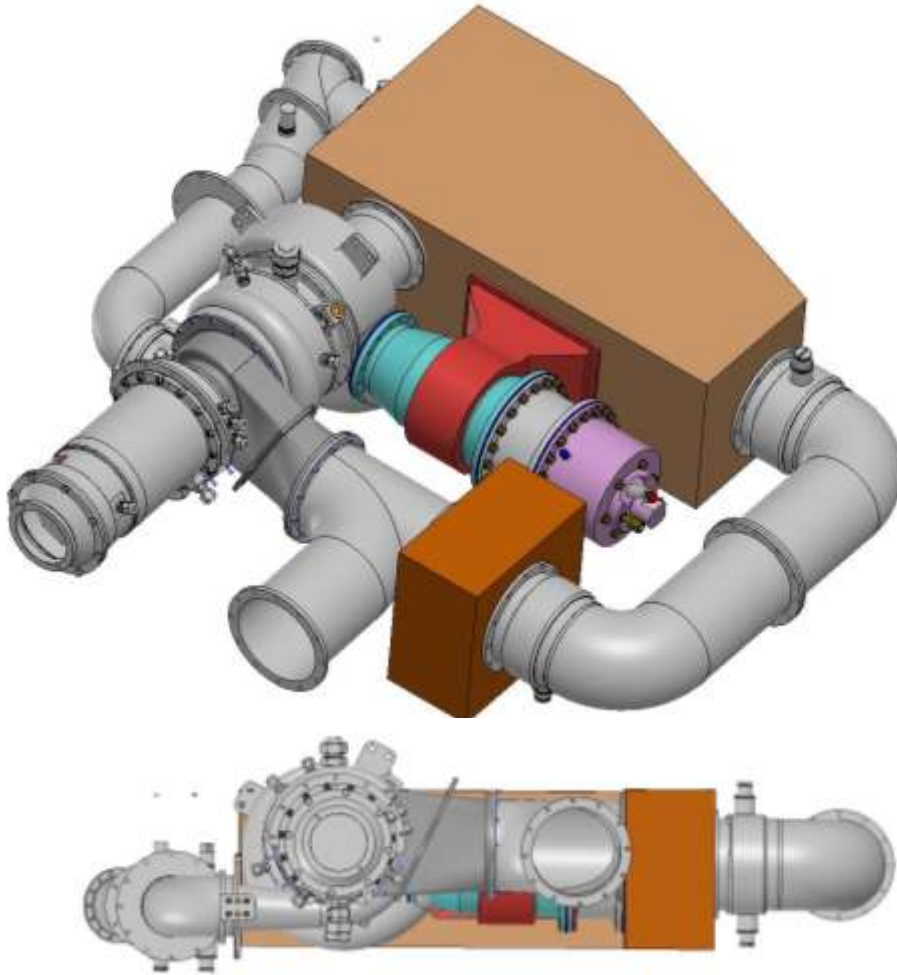
Model Derivatives – Single mode



Space for
Recuperator &
headers
Eff = 70%

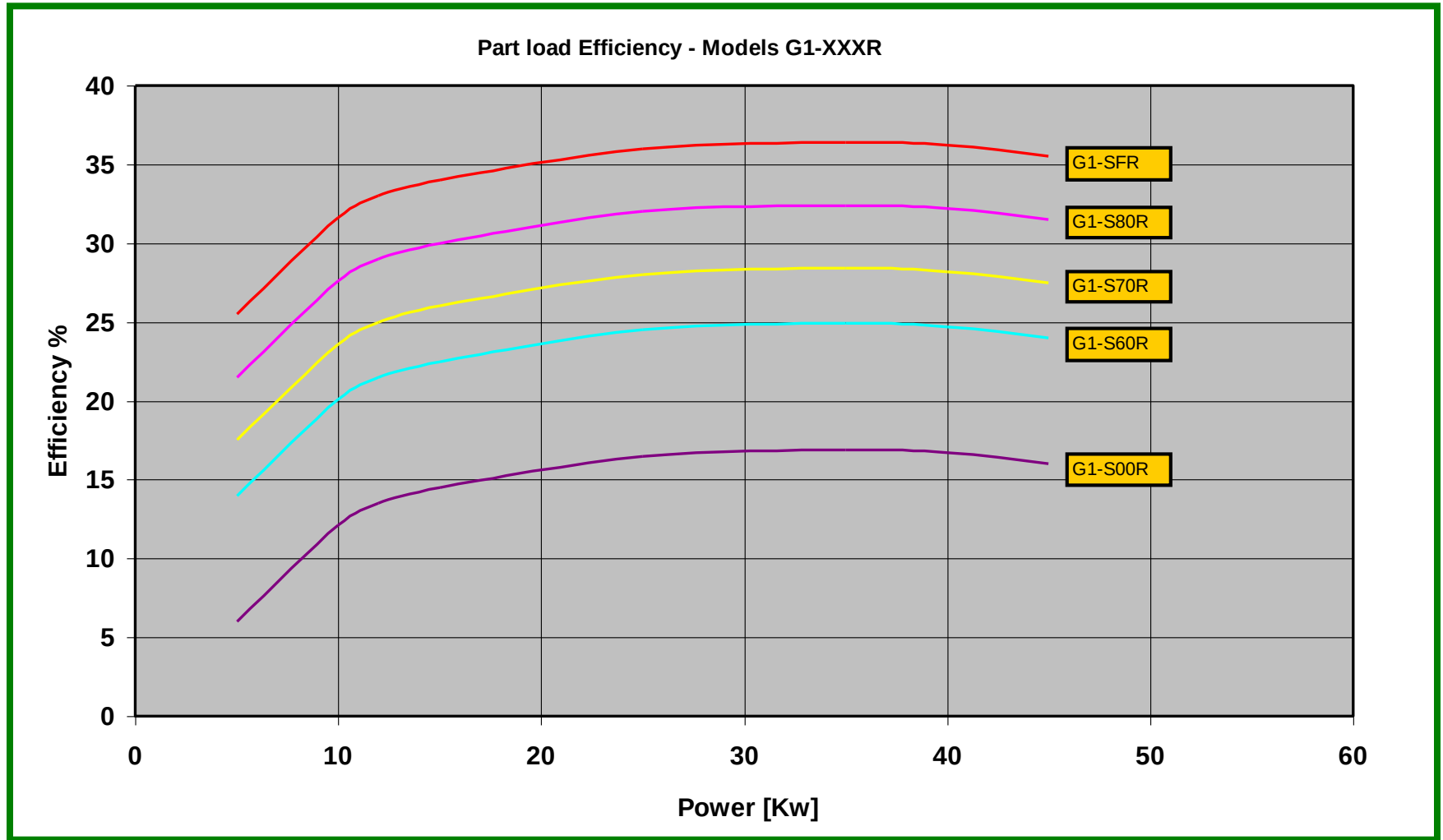


Dual Mode Full Recuperation in VW space



Single/Dual Mode Full
Recuperation - Flat
42 KW / 35% / 140 Kg

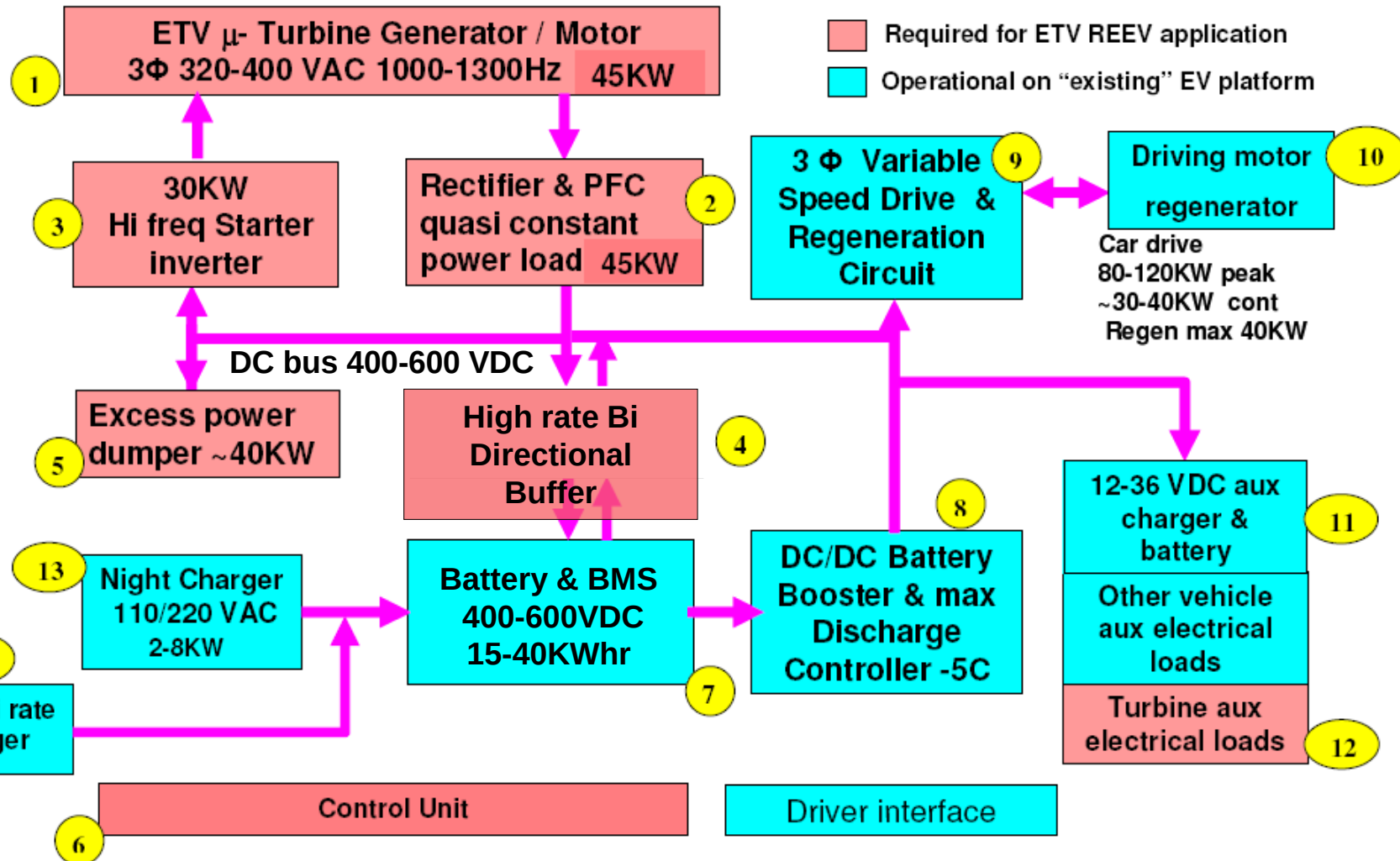
eTeg 2060- Model Performance



eTeg 2060

Power Electronics

EP-3 Power system: A generic approach for integration with existing EV & hybrid platforms



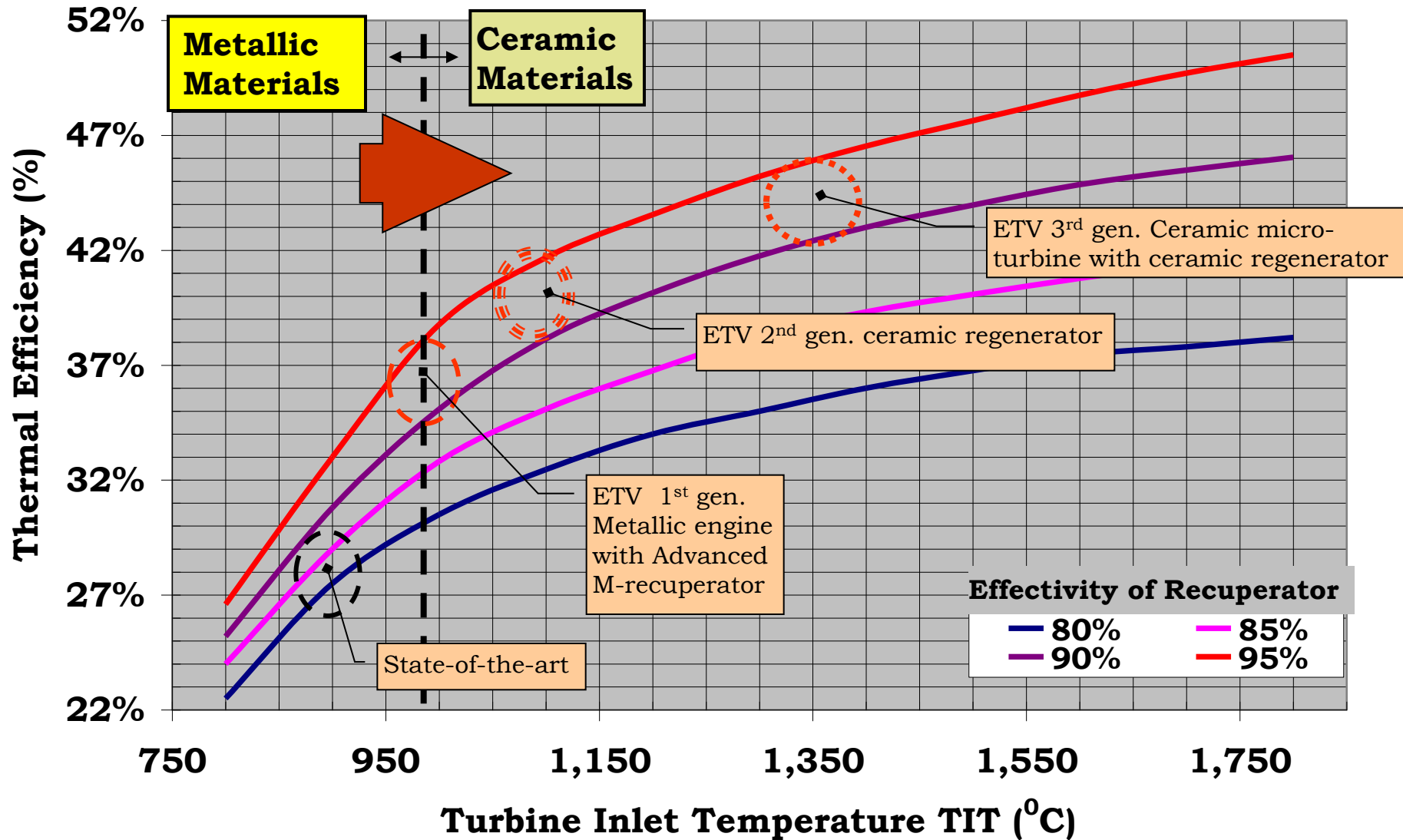
eTeg 2060 On test bench



eTeg 2060

Microturbine Development Road Map

Development roadmap of turbine technology

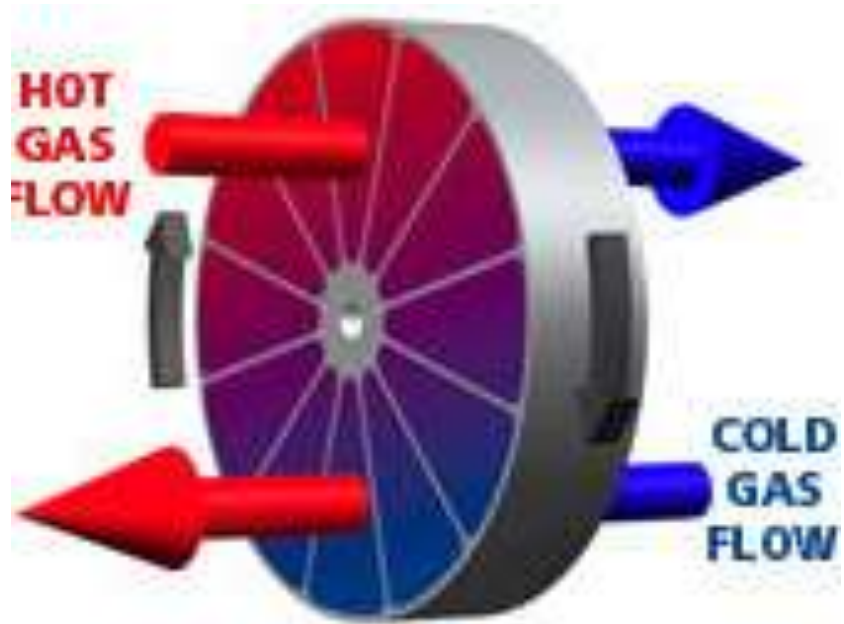


Ceramic Regeberator

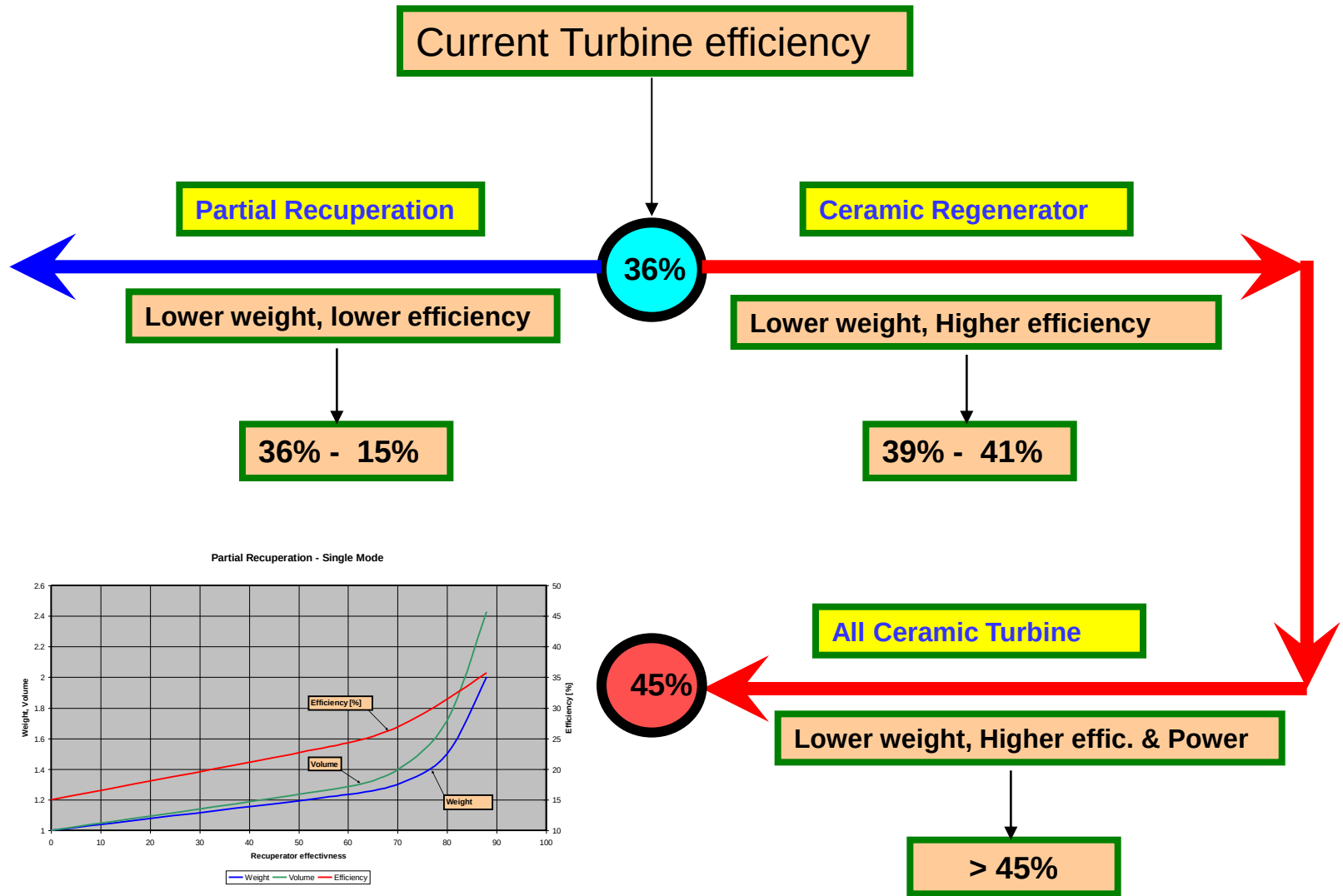
Recuperator



Ceramic Regenerator



eTeg 2060 – Novel Heat exchanger / Partial REC.

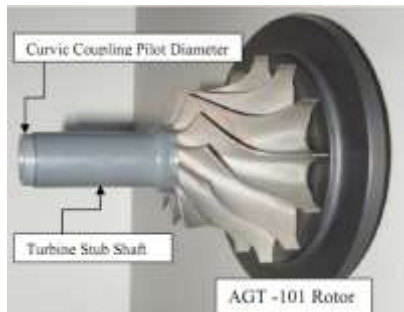
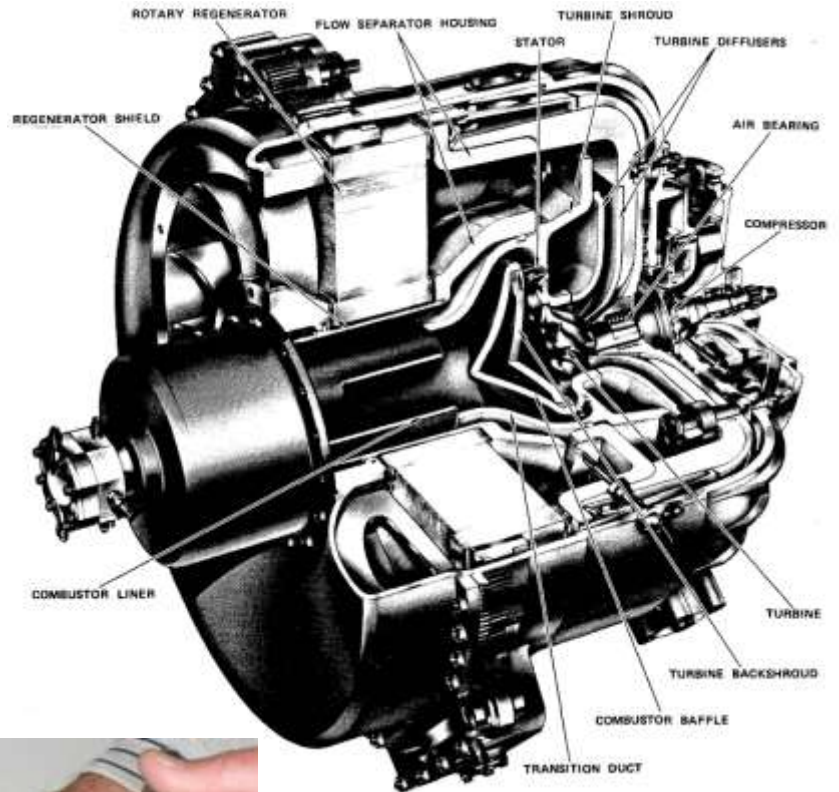


Ceramic Regenerator programs

All Ceramic programs including Ceramic Regenerators :

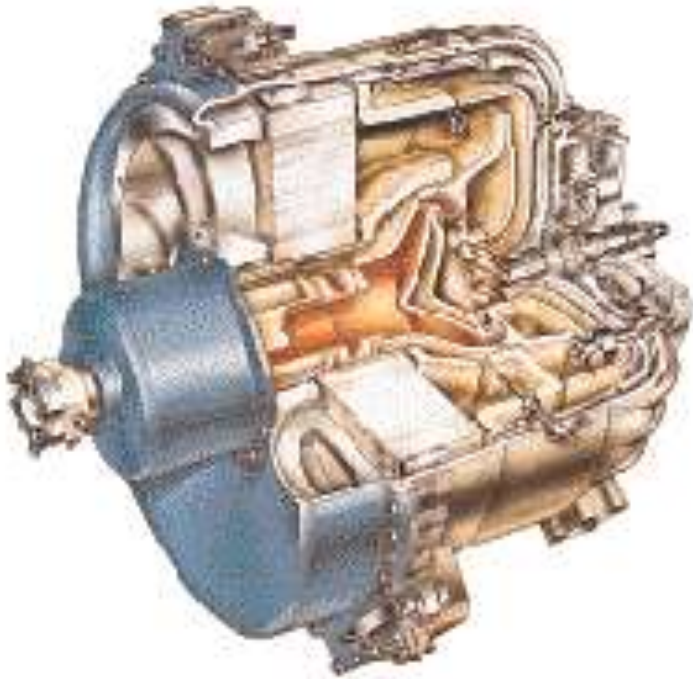
- ▶ Ford GT – 707 : 71-78 (LAS core material failed)
- ▶ Ford/Garrett AGT 101 (No direct core failure, did failed several times due to external FOD parts from the engine)
- ▶ ATTAP program : 87-94, Allison AGT – 5, operated 5000 hr at 1385 C
- ▶ NEDO program in Japan : 88-98, Kawasaki CGT 302 – 300 Kw, operated 2000 hr @ 1200 C
- ▶ AGATA 4 year European program : 94-98, 60 Kw Turbo generatot for electric vehicles

AGT 101 - All Ceramic Microturbine



Ford/Garret 79-87

All Ceramic Microturbines



**Ford/Garrett AGT101
(79-87)**

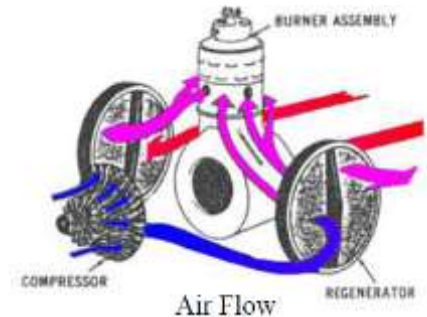
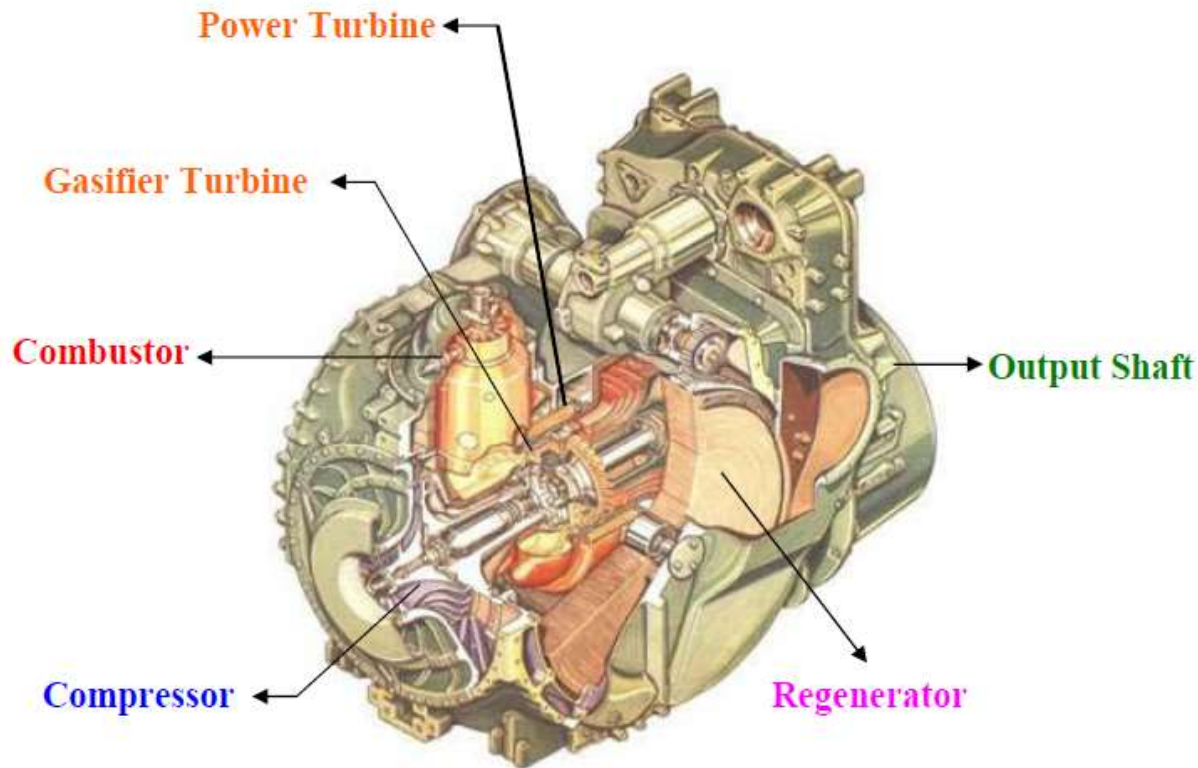
**Previous program :
Ford GT – 707 (71-87)**



Allison AGT-5

Allison - ATTAP – 87-94

All Ceramic Microturbines

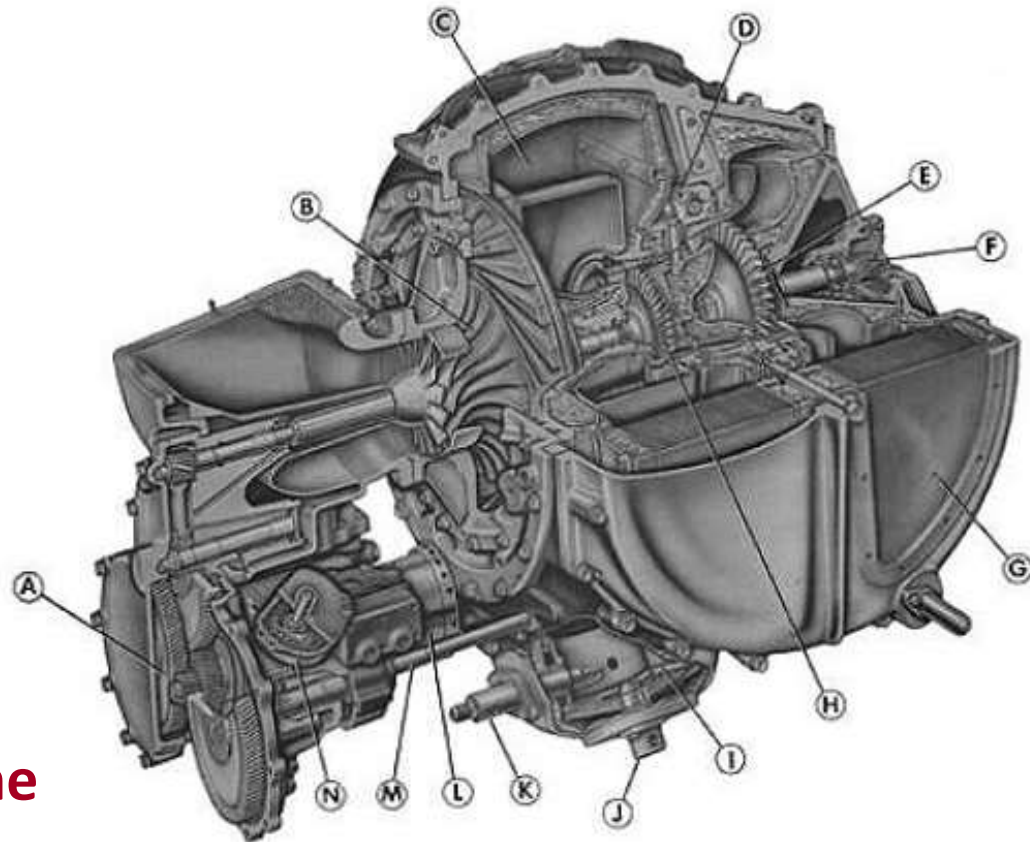


- Manufacturer: Teledyne Continental Motor
- Model No.: RGT-3600

Teledyne RGT-3600

280 KW (operational)

All Ceramic Microturbines



MAIN COMPONENTS OF THE TWIN-REGENERATOR GAS TURBINE:

- (A) accessory drive; (B) compressor; (C) right regenerator rotor; (D) variable nozzle unit; (E) power turbine; (F) reduction gear; (G) left regenerator rotor; (H) gas generator turbine; (I) burner; (J) fuel nozzle; (K) igniter; (L) starter-generator; (M) regenerator drive shaft; (N) ignition unit.

**Chrysler gas turbine
and regenerator
(1956)**

Toyota Prius Conversion

Toyota Prius Conversion

Toyota Prius Conversion

Prius Hybrid



Prius PHEV



Grid Mains Charge
230 V/50 Hz



Toyota – Battery integration

- 72 Clusters connected in series, gives 230 V total
- Overall Battery Nominal energy is 7.7 Kwh



Microturbine and power electronics

eJet 21 Charging System



**6 Kw free turbine
Turboshaft**

Max RPM : 170000 RPM

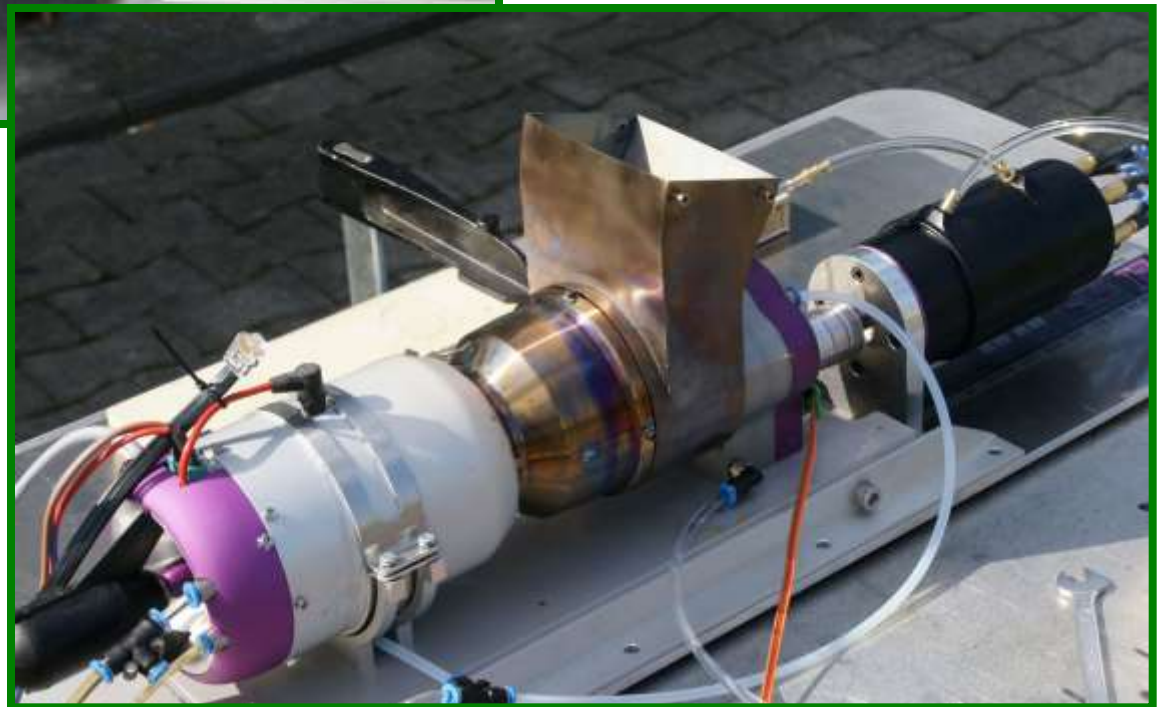
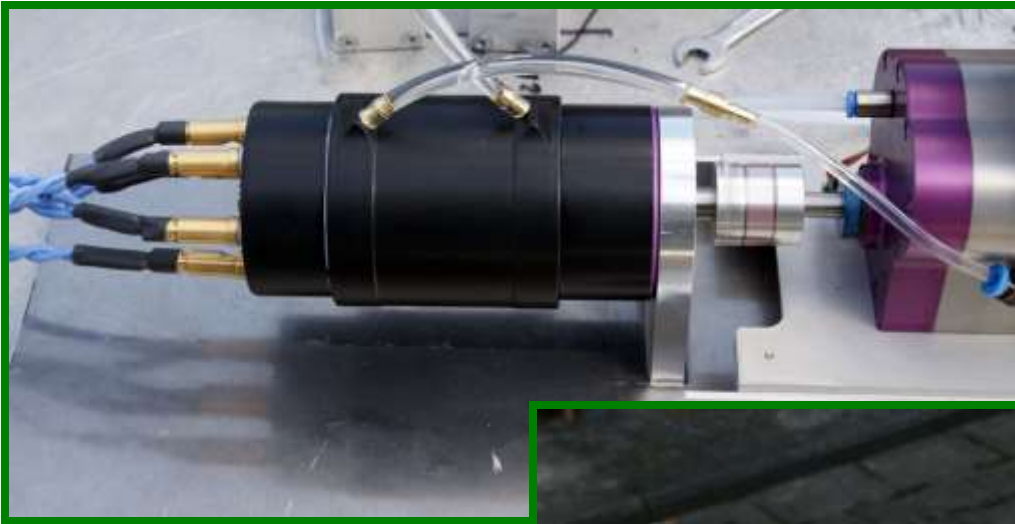
Weight : 5 Kg



AC Generator
11 Kw, 110 v AC
Max RPM : 50000 RPM
Weight : 1.6 Kg



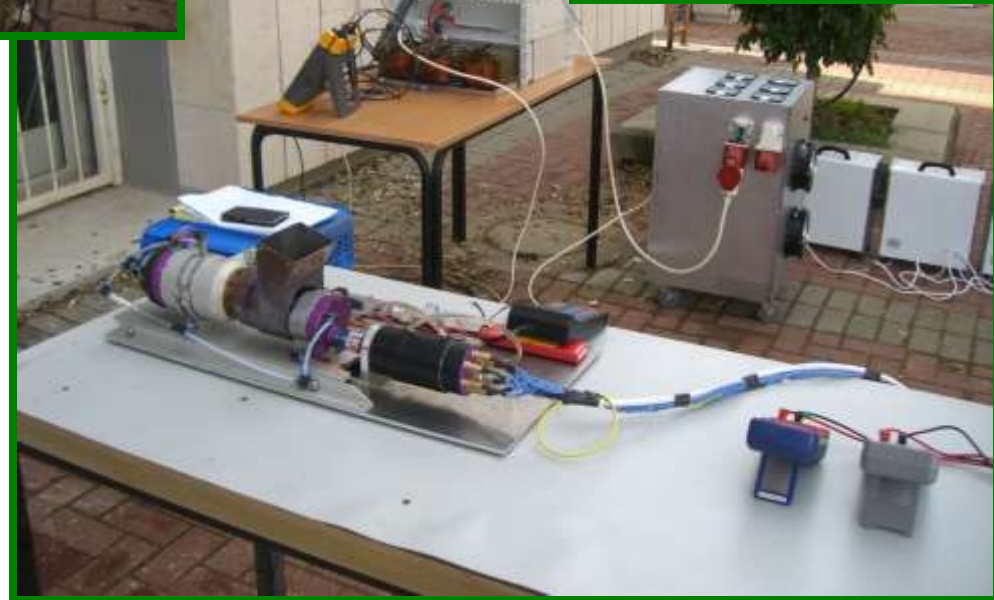
eJet 21 Charging System



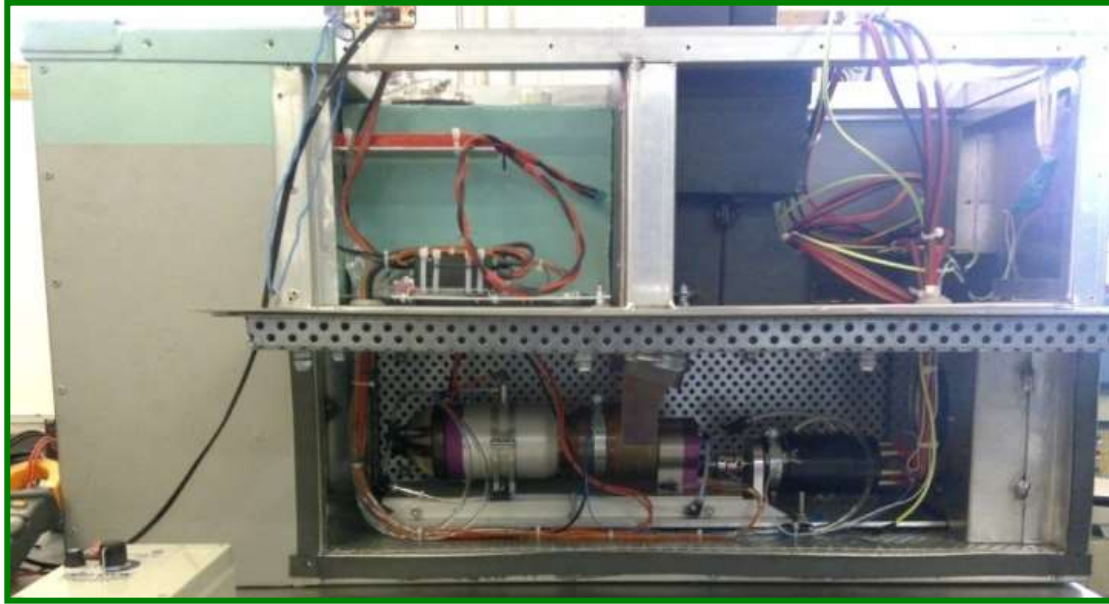
eJet 21 Charging System



eJet 21 Charging System



eJet 21 Charging System - Packaging



eJet 21 Charging System – Power Unit



eJet 21 Charging System-prius Integration



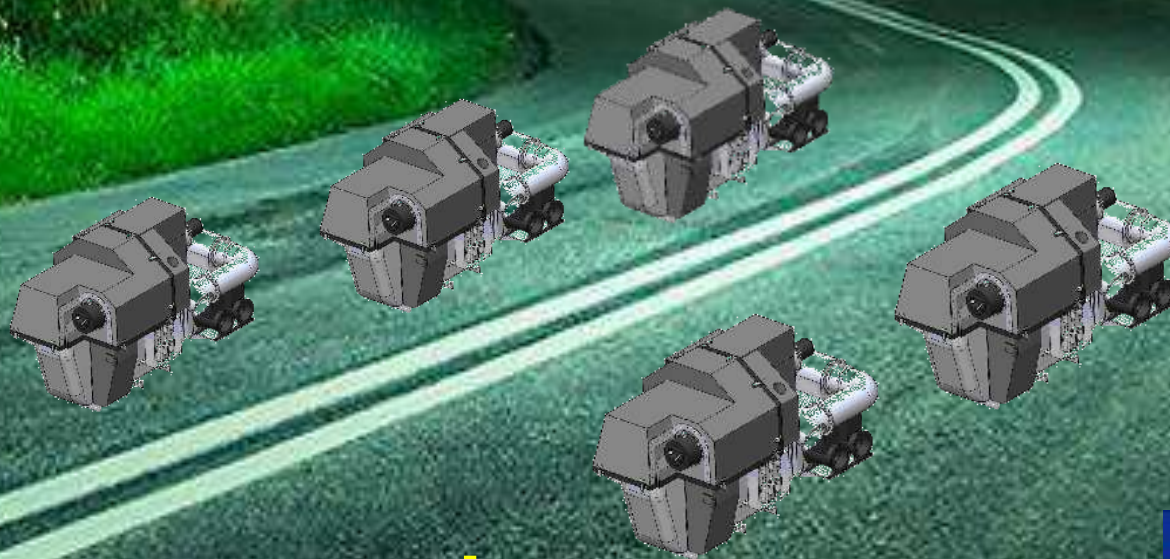
eJet 21 Charging System – Drive Test



Driving distance : 50 Km
On board Charging system



Thank you



Gery Ordan

13.9.22