U.S. DOE 2018 UTSR Meeting

Bechtel National, Inc. – FE0031618

Turbo-Compound Reheat Gas Turbine Combined Cycle

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Best Thermodynamic Cycle (Only Four Processes)

The Objective: Approximating Carnot Cycle

- Isentropic Compression
- Constant Volume Heat Addition
- Isentropic Expansion
- Constant Pressure Heat Rejection

Existing Version: ICE – that's why gas-fired diesels are nearly 50% efficient!
This is why "detonation combustion" is investigated…

Holtzwarth Gas Turbine (1905)

Curtis Wheel (Turbine)

Combustion Chamber
(“Explosive” Constant Volume Combustion)

Second Best Cycle (> Four Processes)

The Objective: Approximating Carnot Cycle

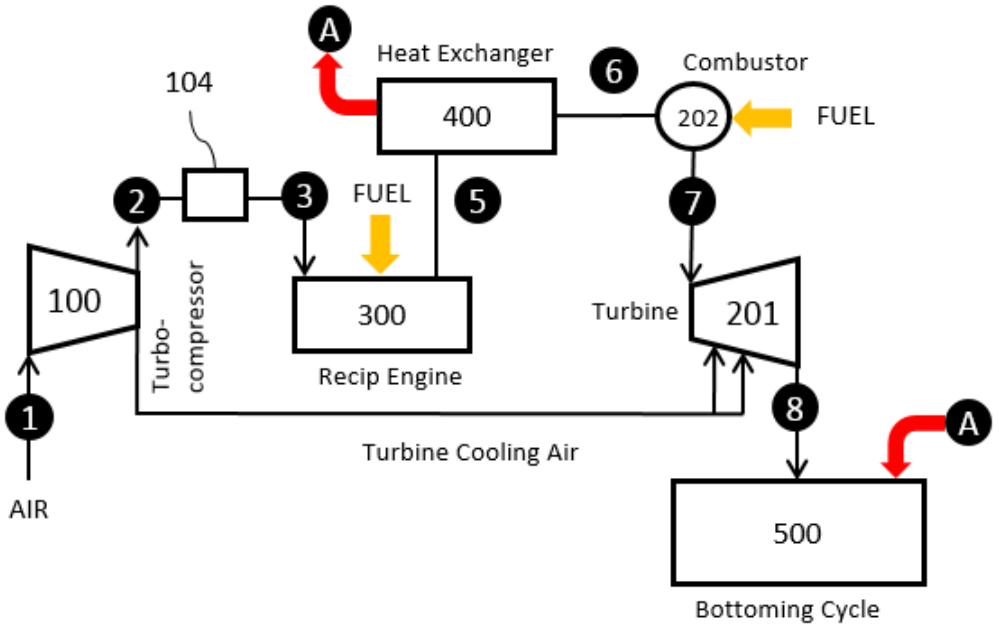
- Isentropic Compression
- Heat Addition
- Isentropic Expansion
- Heat Addition
- Isentropic Expansion
- Constant Pressure Heat Rejection

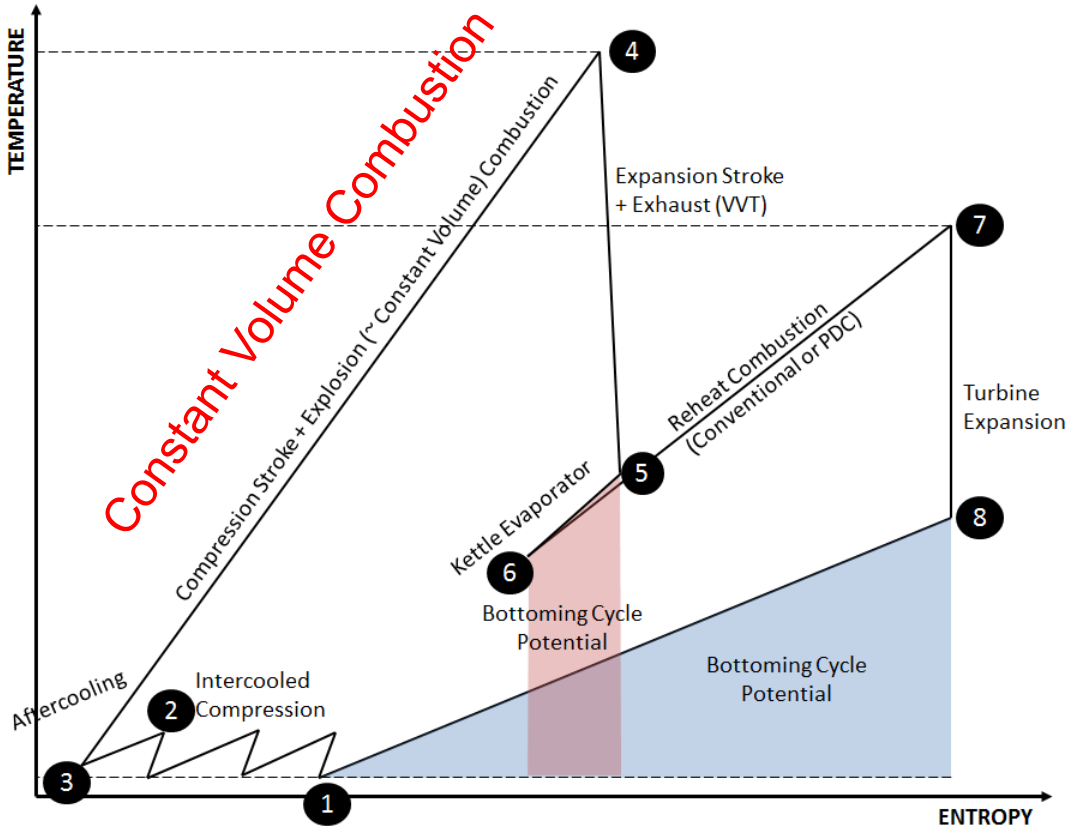
Very High Cycle Pressure Ratio

"Imitation" of Isothermal Heat Addition

Existing Version: ABB/Alstom/GE/Ansaldo GT24/26 Gas Turbine…

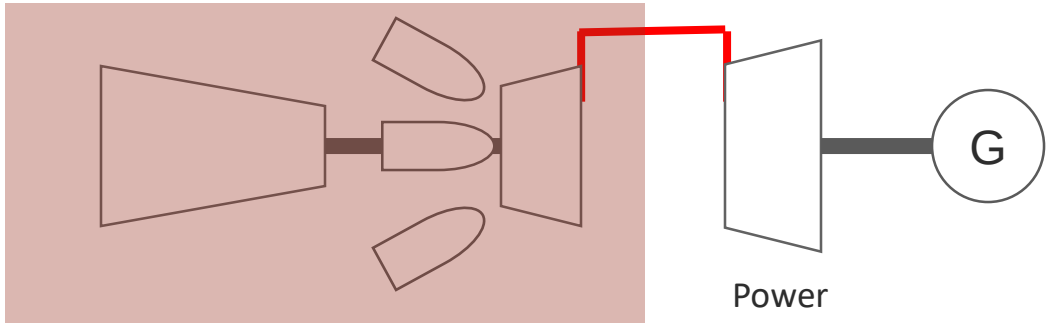
Turbocompound Reheat
Two Cycle Enablers in One





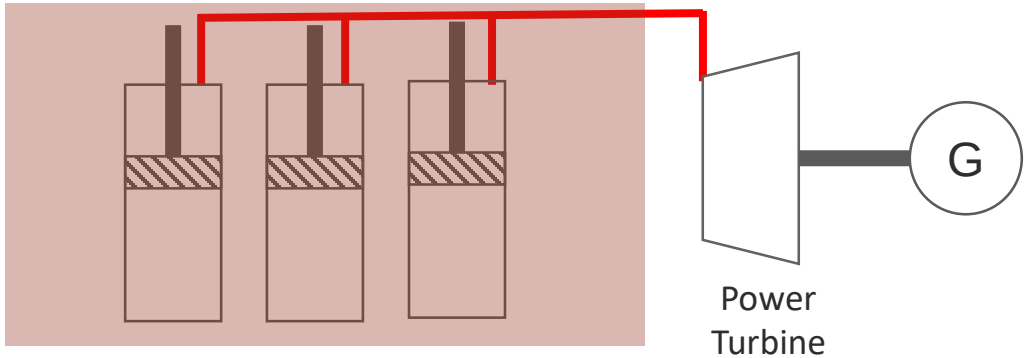
BACKGROUND

GAS GENERATOR: JET ENGINE



AERODERIVATIVE GT

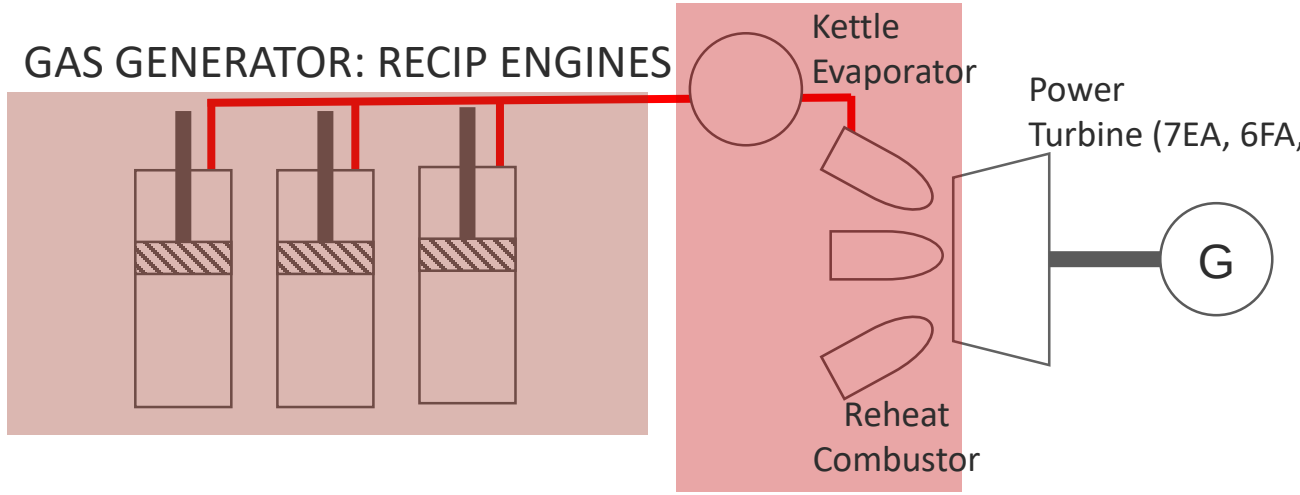
GAS GENERATOR: RECIP ENGINES



TURBOCOMPOUND ENGINE

- Gotaverken (Sweden) diesel gas generator plus turbine drive for railroad locomotive (1933)
- Pratt & Whitney PT1 aircraft engine (1941)
- Napier Nomad (UK) aircraft engine (1950-55)
- Scania/Volvo truck engines (current)
- Fort George Power Plant in Mauritius (2000)

GAS GENERATOR: RECIP ENGINES



TURBOCOMPOUND REHEAT GTCC

US Patent 9,249,723 (2/2/2016)

Project Objectives

The objective of this project is to develop of the proposed Turbo-Compound Reheat Gas Turbine Combined Cycle (TC-RHT GTCC) technology to a stage of readiness for a small-scale demo/test system to be built and run to prove:

(i) successful integration of the key components;

(ii) operability; and

(iii) multifuel compatibility.

This effort will advance the maturity of this technology to a TRL 6 or 7.

Tasks

1. PMP
2. Market Study (Done)
3. Investigation of Fuel Flexibility (In Progress)
4. Conceptual Plant Design
5. Heat and Mass Balances
6. Technology Maturity Plan

Determining Potential Market in the US - Key Screening Criteria

New Peakers

Projects under development[2]

Includes GT, CCGT, IC and Fuel Cell

Planned Capacity < 250 MW

Coal Conversion[1]

Operating Coal Plants

Age > 50 years

Operating Capacity < 300 MW

[1] Criteria based on conversion analysis by BWXT

[2] Excludes all terminated developments

Source: SNL, Power Engineering, BWXT

There Are Significant Opportunities in the US

	Capacity	Market Size*	Geography
1 New Peakers	3.9 GW	$3-4.5B	California, Texas, and Michigan
2 Coal Conversion	5.5 GW	$5-6.5B	Iowa, Michigan, and Illinois

*Assuming $900-1200 / kW

US Peaker Projects Under Developments Is An Attractive Initial Market

State	Power Plant	Owner	Combined Cycle	Fuel Cell	Gas Turbine	Internal Combustion	Total MW
CA	Grayson Repowering - Combined Cycle	Glendale City of	149				149
	Grayson Repowering Combustion Turbine	Glendale City of			128		128
	Huntington Beach Repowering CT	AES Southland Development, LLC			200		200
	Stanton Energy Reliability Center	W Power, LLC			92		92
		Wellhead Energy, LLC			92		92
TX	BP Chocolate Bayou	INEOS USA LLC			100		100
	City of Victoria (CityVict) Project	Agilon Energy, LLC			100		100
	Formosa Utility Venture	Formosa Plastics Corporation, USA	244				244
	Victoria Port (VictPort) Project	Castleman Power Systems International, LLC			100		100
MI	A.J. Mihm Generating Station	Upper Michigan Energy Resources Corporation				55	55
	Erickson Combined Cycle Project	Lansing Board of Water & Light	250				250
	F.D. Kuester Generating Station	Upper Michigan Energy Resources Corporation				128	128
NY	Gowanus Gas Turbines Station	Astoria Generating Company LP			100		100
	Nisa Electric Generation Project	Allegheny Energy Supply Development Service, LLC	85				85
		NYC Energy LLC	85				85
	Ogdensburg Cogen Repower	Alliance Energy, New York LLC	92				92
LA	New Orleans Power Station	Entergy New Orleans, LLC			226		226
	New Orleans Power Station (IC)	Entergy New Orleans, LLC				126	126
SD	Astoria Station Project	Otter Tail Power Company			250		250
FL	Arvah B. Hopkins RICE (Tallahassee IC Plant)	Tallahassee City of				75	75
	Auburndale Repower	Lakeland City of			130		130
AZ	Sundt Generation Modernization Project	Tucson Electric Power Company				200	200
MA	West Medway II	Exelon Generation Company, LLC			200		200
MN	Mankato Power Plant	Southern Power Company	200				200
PA	Towanda Township Gas Plant	Gateway Green Energy Holdings LLC	165				165
OH	Ohio State University Cogeneration CHP	Axium Infrastructure US Inc.			60		60
		ENGIE North America, Inc			60		60
NM	Rio Grande CT	El Paso Electric Company			87		87
CT	Beacon Falls Energy Park	CT Energy & Technology, LLC		63			63
VA	James River Cogeneration Plant (City Point)	City Point Energy Center LLC			54		54
Total (MW)			1,270	63	1,979	584	3,896

Partnership with a reputable OEM is key to gain nation-wide adoption

…While Coal to Gas Conversion Could Be The Next Target Market

State	Power Plant	Owner	Non-Cogen	Co-Gen	Total MW
IA	Lansing	Interstate Power and Light Company	230		230
	Muscatine	Board of Water Electric & Communications		223	223
	Burlington ST	Interstate Power and Light Company	216		216
	Clinton	Archer-Daniels-Midland Company		180	180
MI	River Rouge	DTE Electric Company		280	280
	Eckert Station	Lansing Board of Water & Light	197		197
	J.B. Sims	Grand Haven City of	70		70
	Shiras	Marquette City of	61		61
IL	Hennepin Power Station	Dynegy Midwest Generation, Inc.	294		294
	Marion	Southern Illinois Power Cooperative	290		290
WI	Pulliam	Wisconsin Public Service Corporation	215		215
	Biron Division	NewPage Wisconsin System Inc.		166	166
	Manitowoc	Manitowoc Public Utilities		102	102
IN	R. Gallagher	Duke Energy Indiana, LLC	280		280
	Whitewater Valley	Richmond City of	100		100
NE	Sheldon	Nebraska Public Power District	215		215
	Lon Wright	Fremont City of	119		119
CO	Martin Drake Plant	Colorado Springs Utilities	208		208
	Nucla	Tri-State Generation & Transmission Association, Inc.	100		100
NH	Schiller Coal	Atlas FRM LLC	140		140
		Castleton Commodities International LLC	140		140
MN	Hoot Lake	Otter Tail Power Company	138		138
	Silver Bay Power Company	Cleveland-Cliffs Inc.		105	105
NY	Kodak Park (Eastman Business Park Facility)	Ironclad Energy Ventures, LLC		120	120
		Stonepeak Partners LP		120	120
TN	Tennessee Eastman Division	Eastman Chemical Company		194	194
MO	Lake Road	KCP&L Greater Missouri Operations Company		139	139
	University of Missouri - Columbia	University of Missouri		51	51
MD	Luke Mill	NewPage Corporation		180	180
OH	Bay Shore	ArcLight Energy Partners Fund VI LP	136		136
UT	Kennecott Utah Copper	Kennecott Utah Copper Corporation		107	107
ND	R.M.Heskett Generating Station	Montana-Dakota Utilities Co	104		104
PA	P.H. Glatfelter Company - Pennsylvania	P H Glatfelter Co		89	89
KS	Tecumseh	Westar Energy (KPL)	65		65
CA	Argus Cogeneration	Searles Valley Minerals Operations Inc.		57	57
MT	Lewis & Clark	Montana-Dakota Utilities Co	53		53
NC	Canton	Evergreen Packaging Group		53	53
Total MW			3,370	2,166	5,536

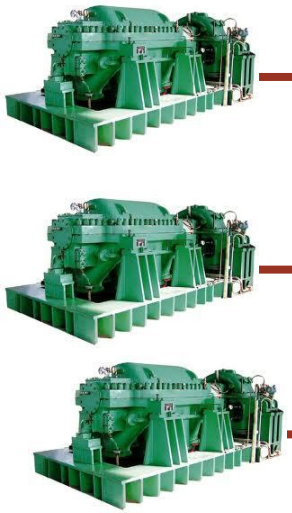
Source: SNL, Power Engineer

Detailed Engine Modeling (GT-Suite)

Exhaust valve open timing	Intake Valve Close Timing	P boost	P exh	T exh	Exhaust Gas Flow Rate	Peak Cylinder Pressure	BTE	Brake Power	BMEP
(CA deg)	(CA deg)	(bar)	(bar)	(deg C)	(kg/s)	(bar)	(%)	(kW)	(bar)
100	520	7	14	675.6	19.084	300	36.20	9686	22.00
100	508	7	12	653.8	17.942	272	38.59	9687	22.00
100	496	7	10	628.9	16.731	244	41.28	9685	22.00
100	483	7	8	601.8	15.606	214	44.26	9686	22.00
100	460	7	6	566.1	15.112	182	47.19	9686	22.00

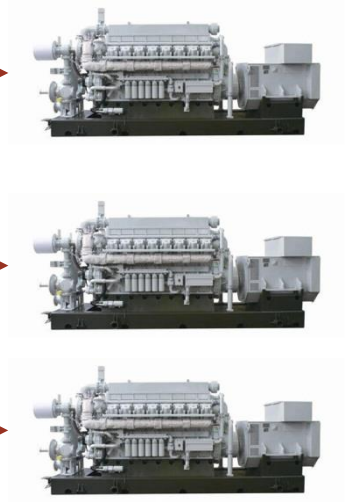
Trying to find the best modified operation point

Turbocompound Reheat GTCC Power Plant



Centrifugal Compressors
(Off-the-Shelf, Intercooled Process Units)
22.2 MWe

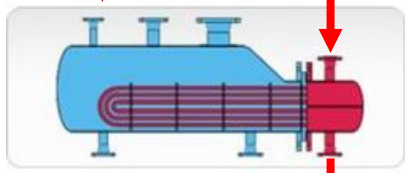
102 psia
122°F



5 x RICE, 48.4 MWe

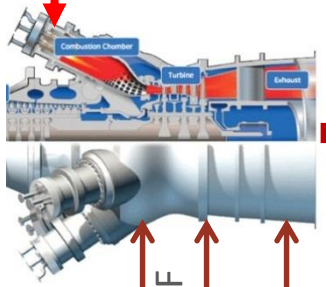
1,164°F, 145 psia

Kettle Boiler
(HP Steam Generation)



762°F

E-Class Turbine
2,100°F TIT
PR ~ 8.5
55.7 MWe



- 57% Efficient @ 100 MWe (Nominal)
- $800-$1,000 per kW CAPEX

< 250°F

Secondary Flows

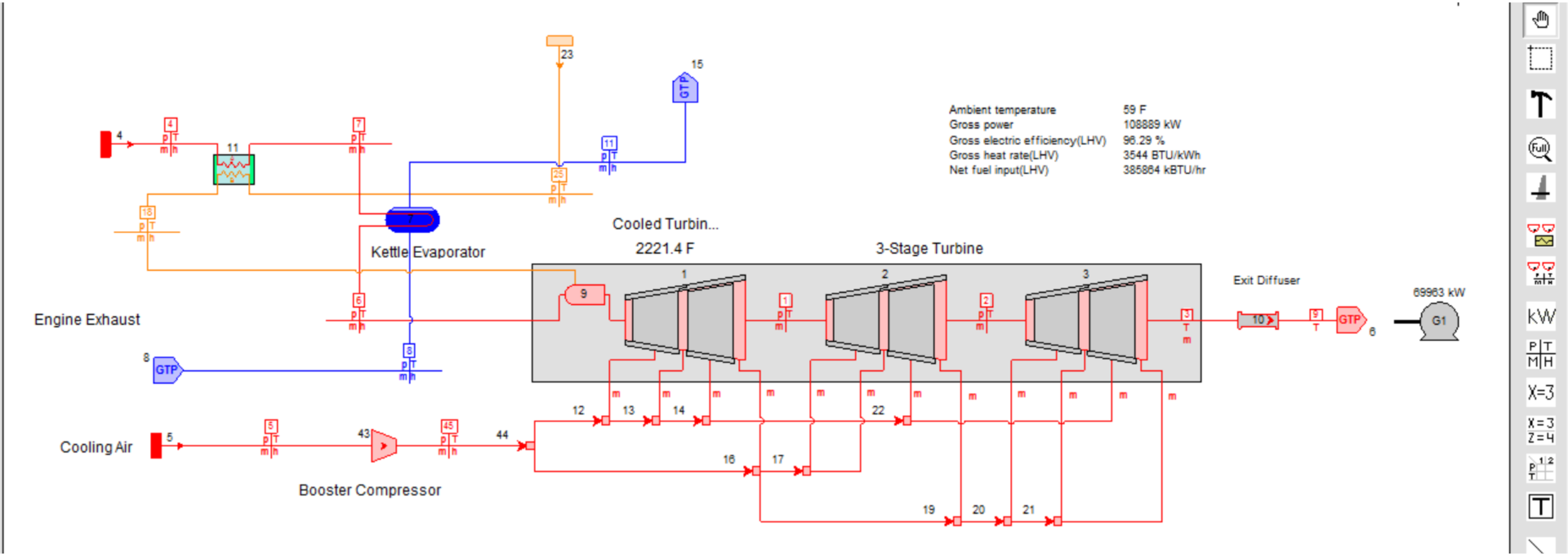
Steam Cycle
2P-Reheat
1,600 psig/1,000°F
1.2 in Hg. Condenser

STG 30.3 MWe

1,089°F
To the HRSG

US Patent 9,249,723 (Granted on February 2, 2016)

Stage-by-Stage Turbine (Thermoflex)



Bottoming Cycle (GT PRO)