Institute for
Thermal Turbomaschinery
and Machine Dynamics

Graz University of Technology
Erzherzog-Johann-University

Thermische Kraftwerke höchsten Wirkungsgrades ohne CO2-Ausstoss

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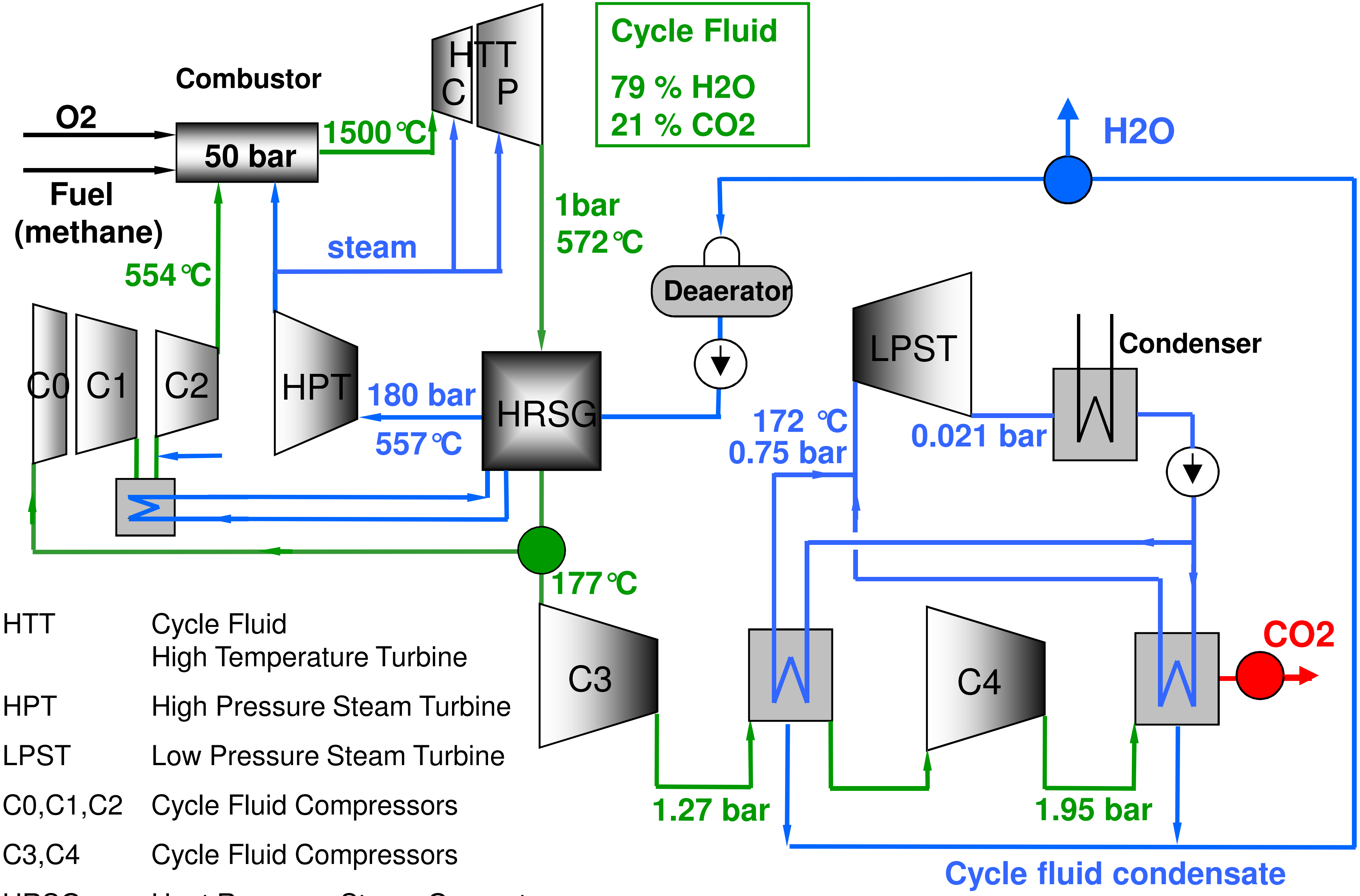
Technische Universität Graz

12. SYMPOSIUM ENERGIEINNOVATION

Alternativen für die Energiezukunft Europas

15. – 17. Februar 2012
TU Graz, Österreich

Cycle Scheme for 600 MW net output



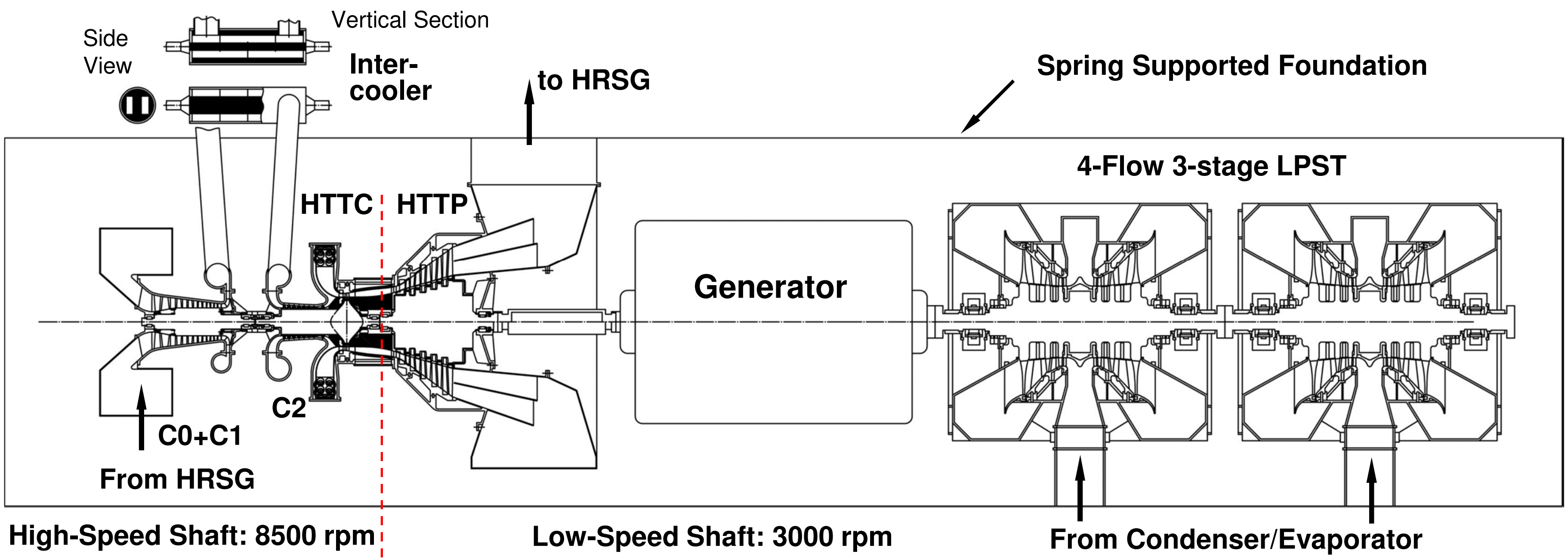
HTT	Cycle Fluid High Temperature Turbine
HPT	High Pressure Steam Turbine
LPST	Low Pressure Steam Turbine
C0,C1,C2	Cycle Fluid Compressors
C3,C4	Cycle Fluid Compressors
HRSG	Heat Recovery Steam Generator

Graz Cycle Power Balance

	400 MW	600 MW		400 MW	600 MW
HTT power [MW]	617.9	908	Net shaft power [MW] w/o mechanical losses	504.7	746
HPT power [MW]	49.9	62	Total heat input Q_{zu} [MW]	758.6	1100
LPST power [MW]	71.6	101	**Thermal cycle efficiency [%]**	**66.52**	**67.6**
Total turbine power P_T [MW]	**739.4**	**1071**	Electrical power output [MW] incl. mechanical, electrical & auxiliary loss	490.7	724.6
C0 power [MW]	-	8.8	**Net electrical cycle efficiency [%]**	**64.68**	**65.71**
C1 power [MW]	131.1	178	O_2 generation & compression P_{O2} [MW]	74.7	109
C2 power [MW]	82.6	108	**Efficiency considering O_2 supply [%]**	**54.83**	**55.83**
C3+C4 power [MW]	15.5	23	CO_2 compression to 100 bar P_{CO2} [MW]	13.0	18.6
Pump power [MW]	5.5	7.2	**Net power output [MW]**	**403.0**	**597**
Total compression power P_C [MW]	**234.7**	**325**	**Net efficiency [%]**	**53.12**	**54.14**

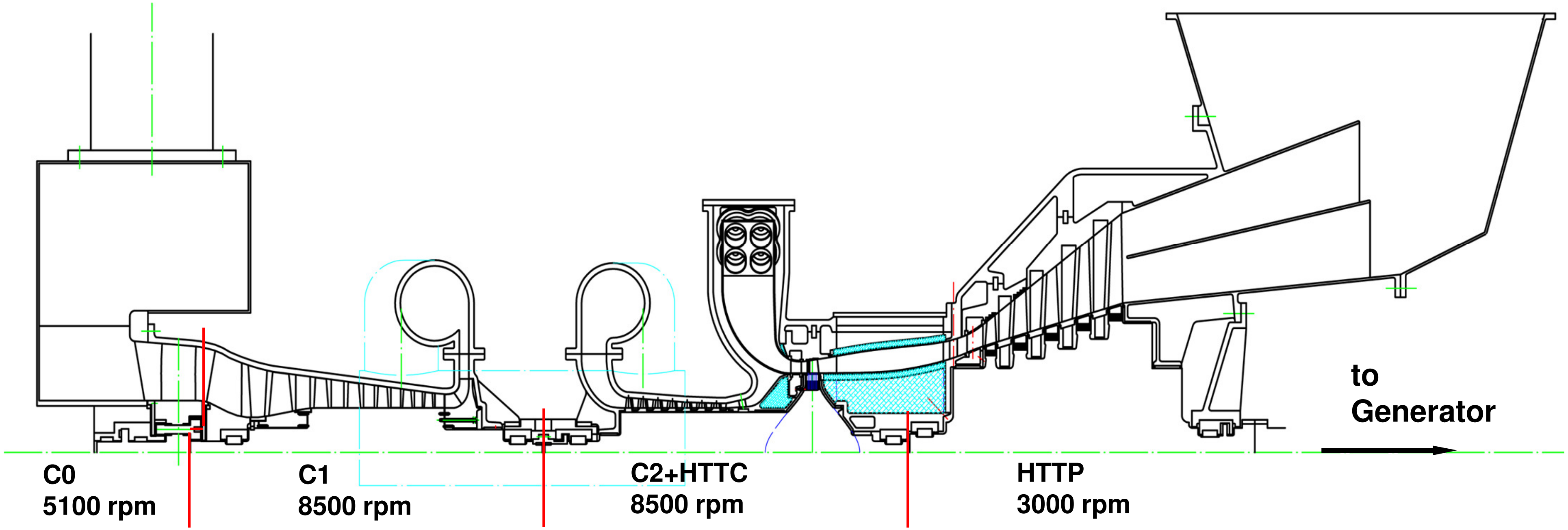
Arrangement of Main Turbo Shaft - 725 MW

- Main gas turbine components on two shafts for 600 MW net output
- Compression shaft of 8500 rpm: cycle compressors C0, C1 and C2, driven by first part of HTT, the compressor turbine HTTC
- Power shaft of 3000/3600 rpm: power turbine HTTP as second part of HTT drives the generator
  Four-flow LPST at the opposite side of the generator
- Shafts on same spring foundation
  Intercooler between C1 and C2 on fixed foundation connected to HRSG



Main Turbo Shaft

- Main gas turbine components on two shafts for 600 MW net output
- Higher power obtained by design improvements (higher compression ratio, higher peak temperature)

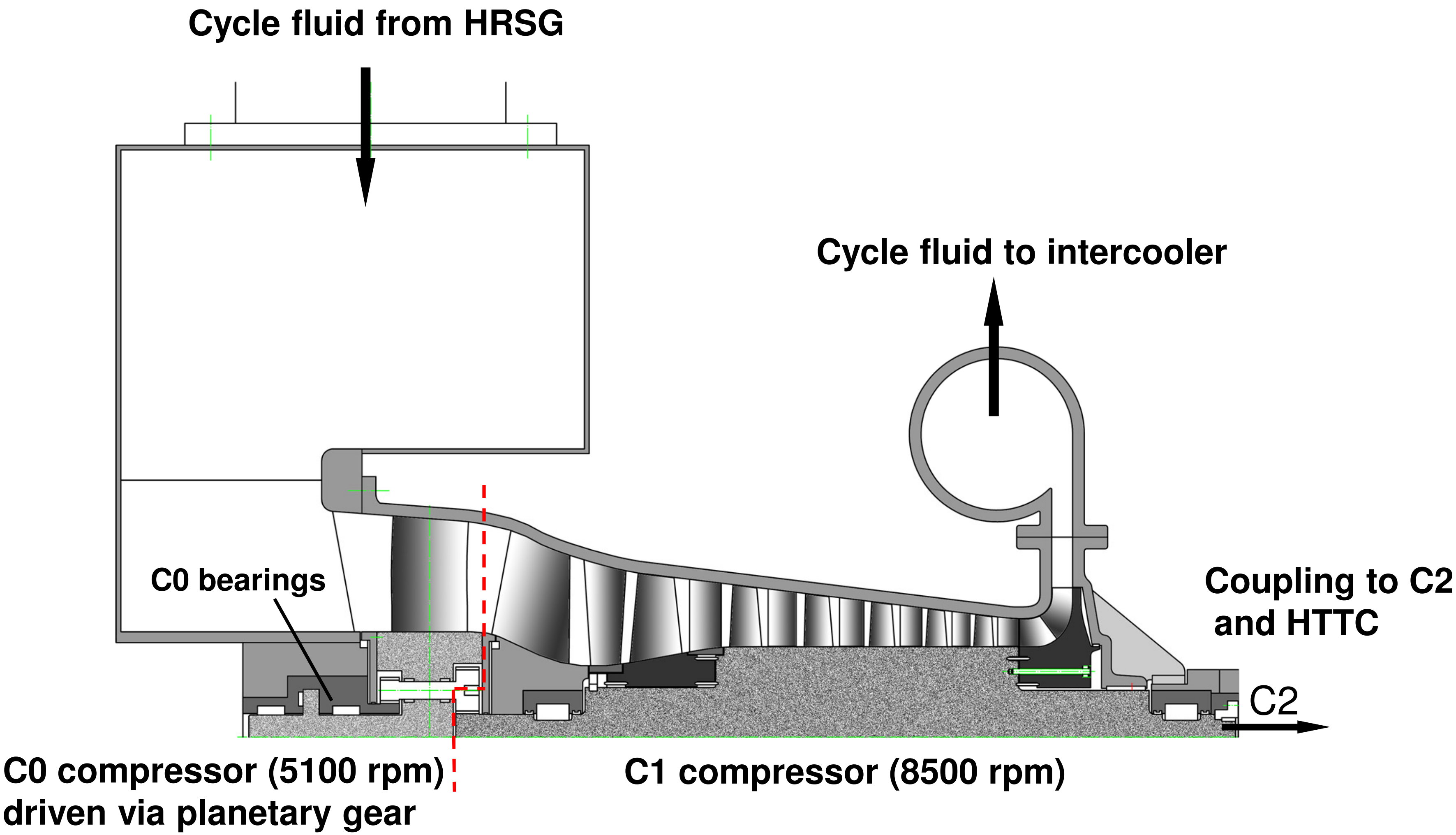


Single stage transonic turbine drives compressor shaft (C0, C1 and C2)

Power turbine HTTP –
5 subsonic stages at 50 Hz
4 subsonic stages at 60 Hz

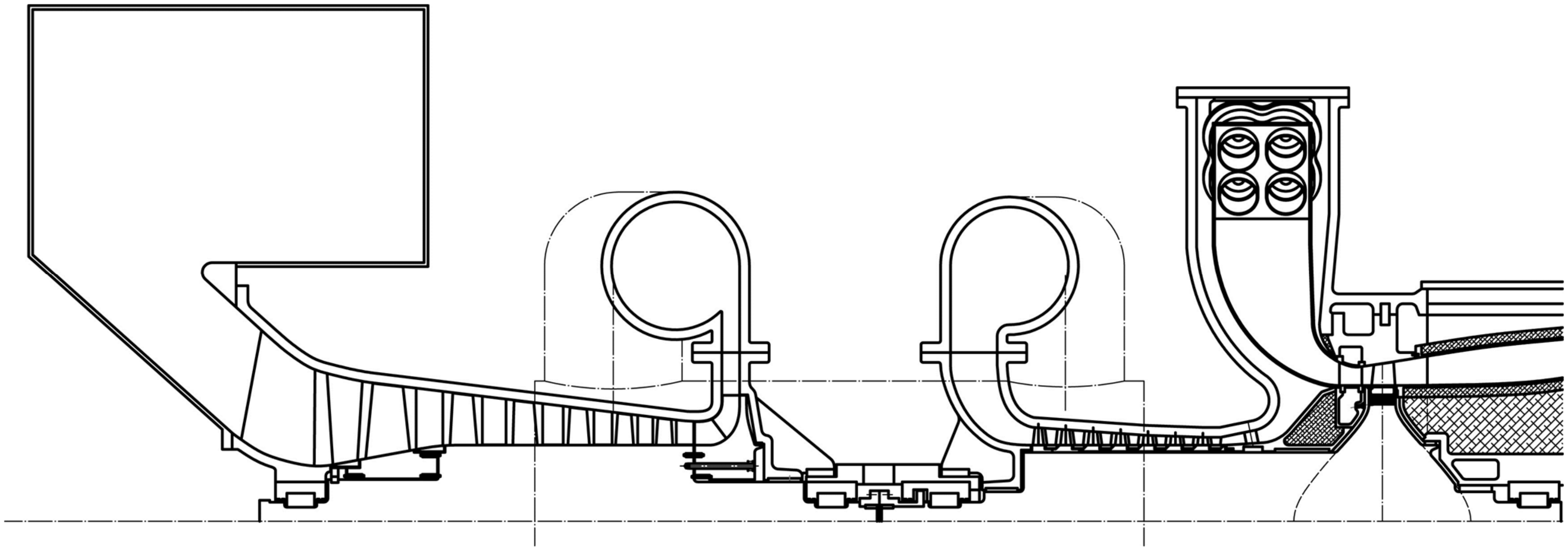
C0 and C1 compressor details

- **Pre-arranged loading compressor C0 serves for higher mass flow to combustion chamber keeping volume flow to C1 equal to previous layout**
- **Speed change allows to keep tip Mach number at 1.3**



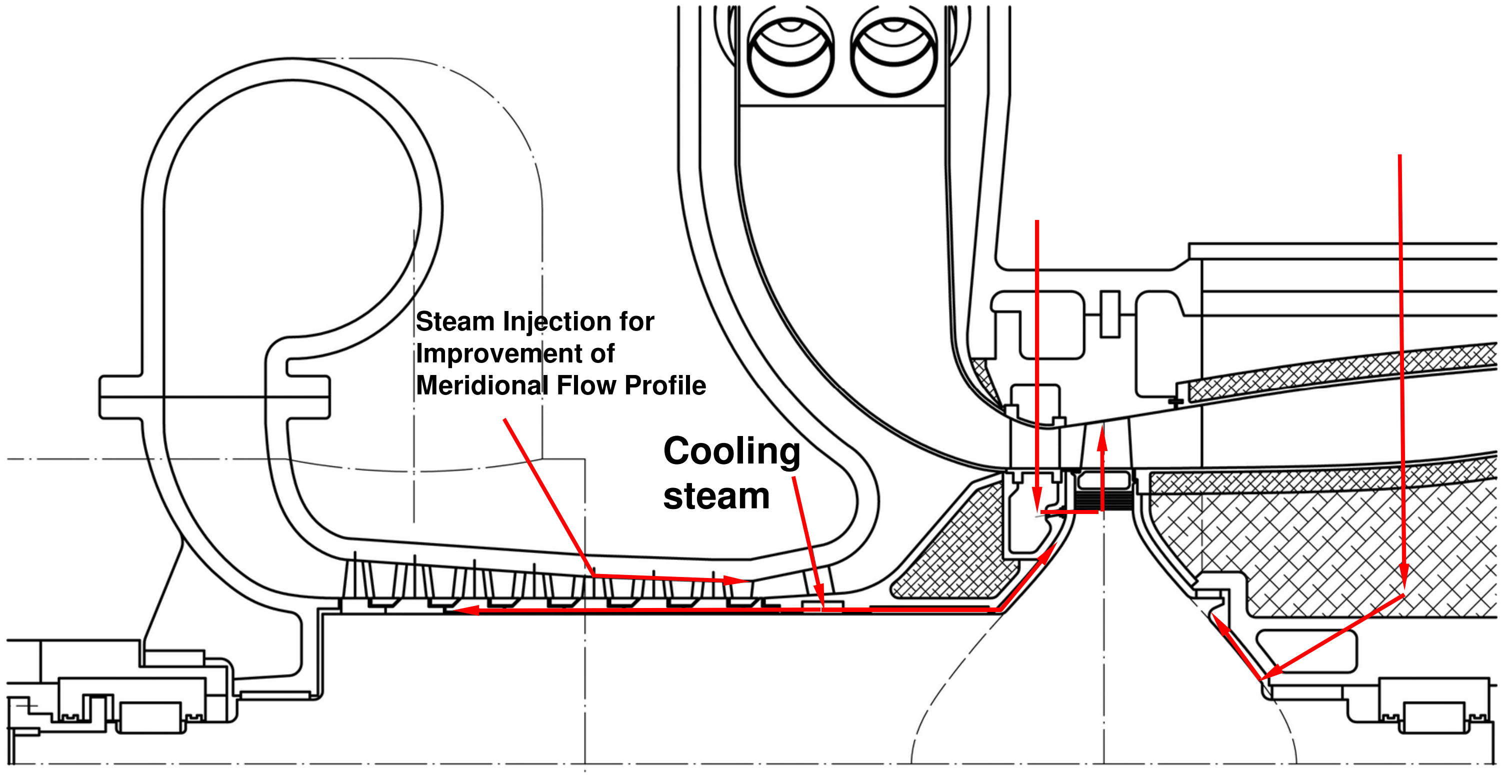
High Speed Shaft (8500 rpm)

- Compressors C1 und C2 for working fluid (79% H_2O/ 21 % CO_2) and HTTC



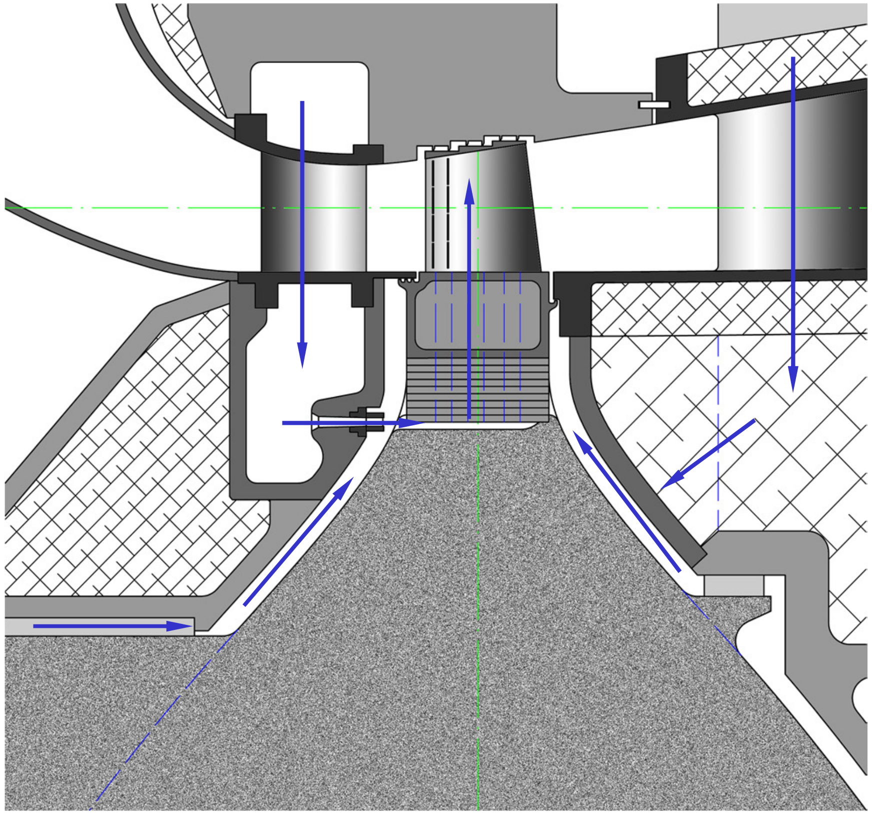
Steam Cooling Details of HTTC and C2

- HTTC and C2 on common shaft with a disk of constant stress
- Disk is cooled on both sides with cooling steam of 300℃
- Cooling steam on right-hand-side: balancing of axial thrust
- C2 rotor: cooling to avoid creep

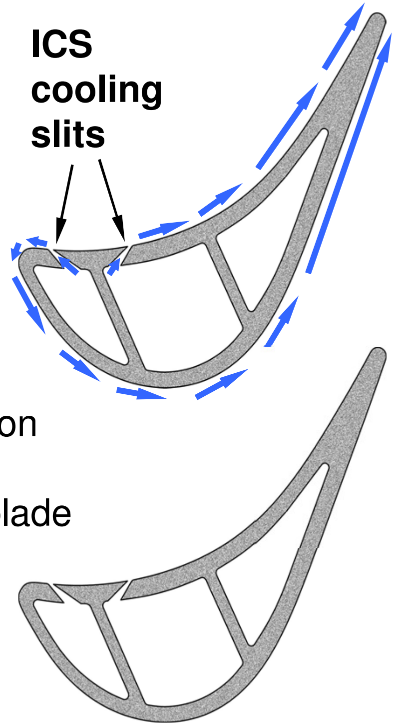


Transonic Stage Steam Cooling

- Cooling steam entry through hollow nozzles
- Collection in inner annular chamber
- Jet in partly tangential direction to provide optimal inflow into blade root
- Radial outflow of cooling steam through fir-tree root into hollow blade in innovative cooling system (ICS)

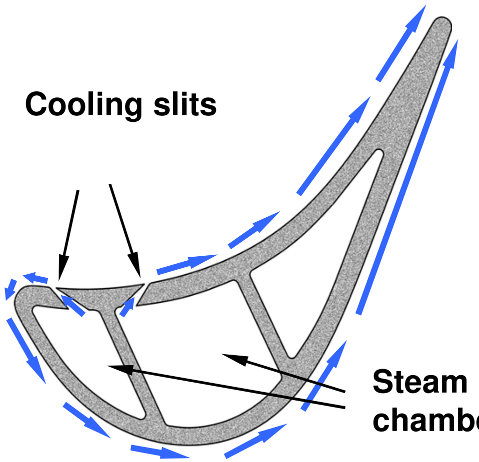


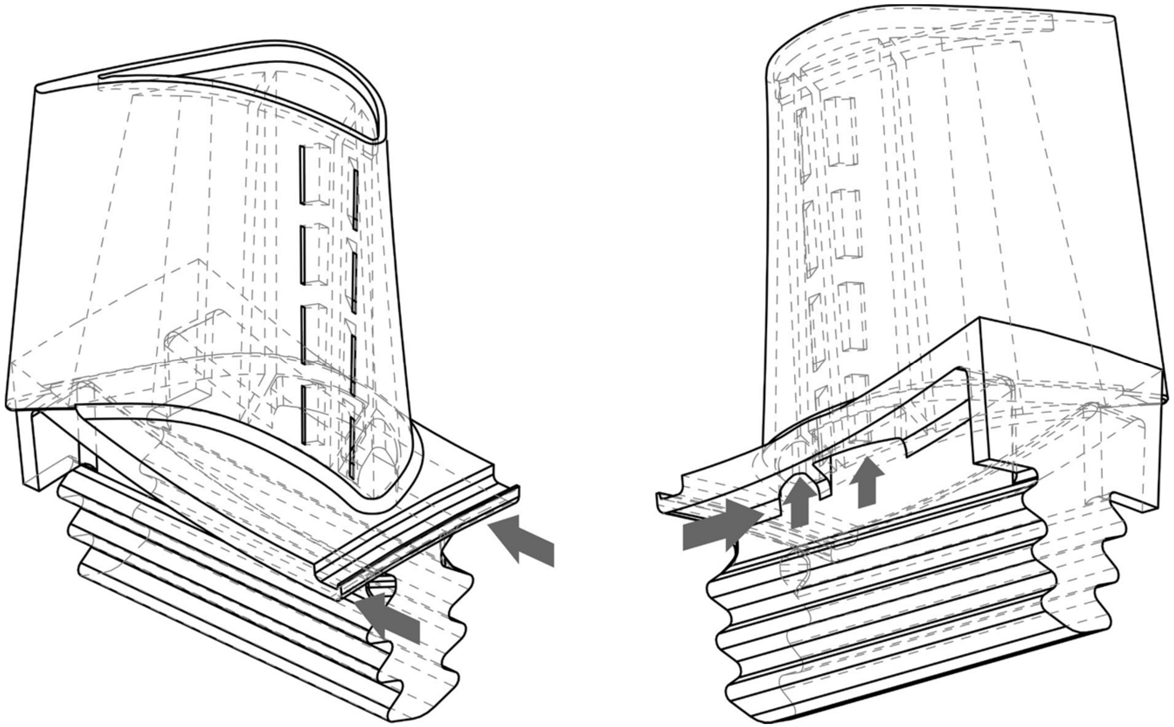
Exit of under-expanded transonic steam flow covering whole blade surface by a coherent layer of steam



High-reaction high-flow-efficiency blade channel

3D cooling arrangement of HTTC stage (previous work)

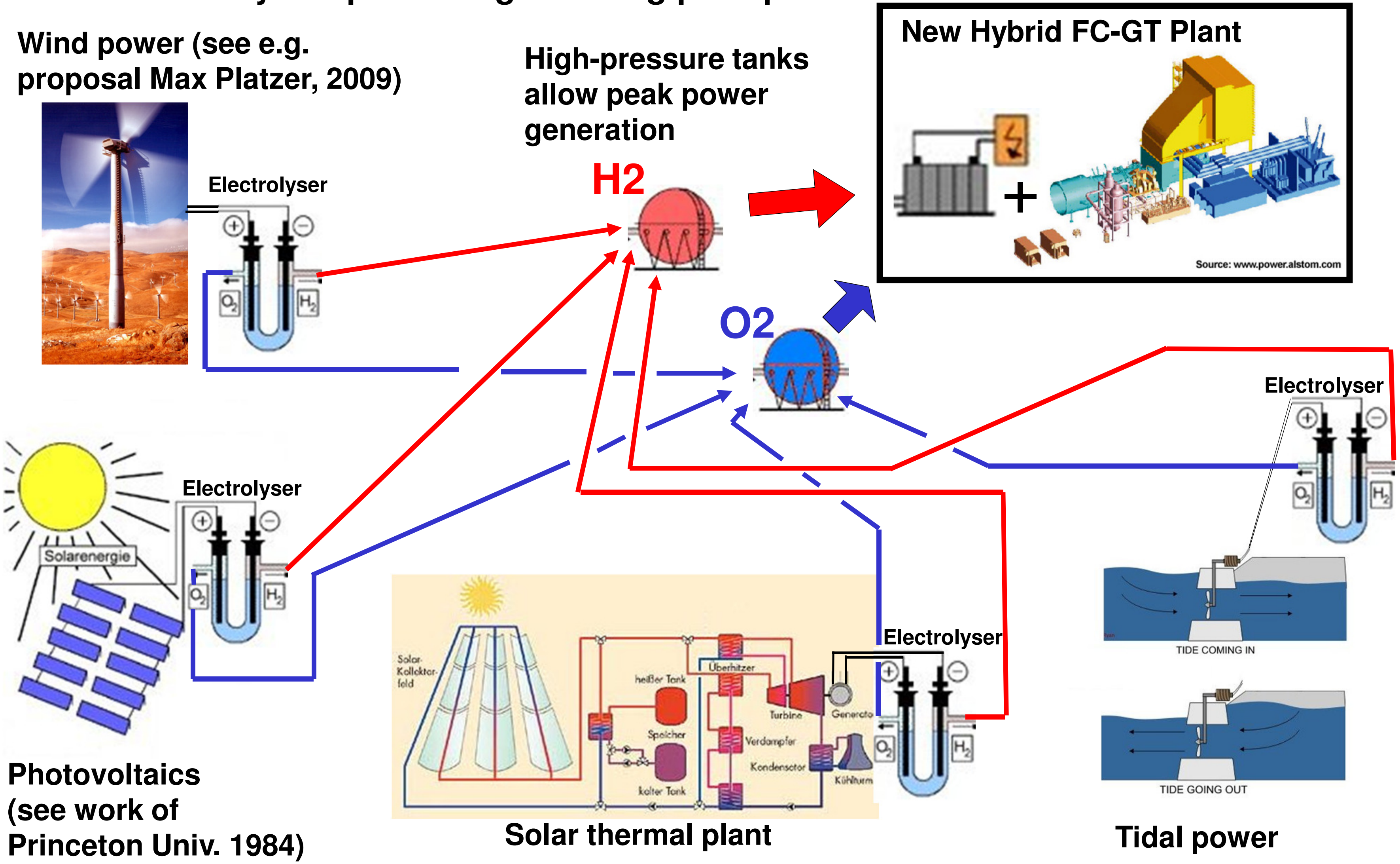




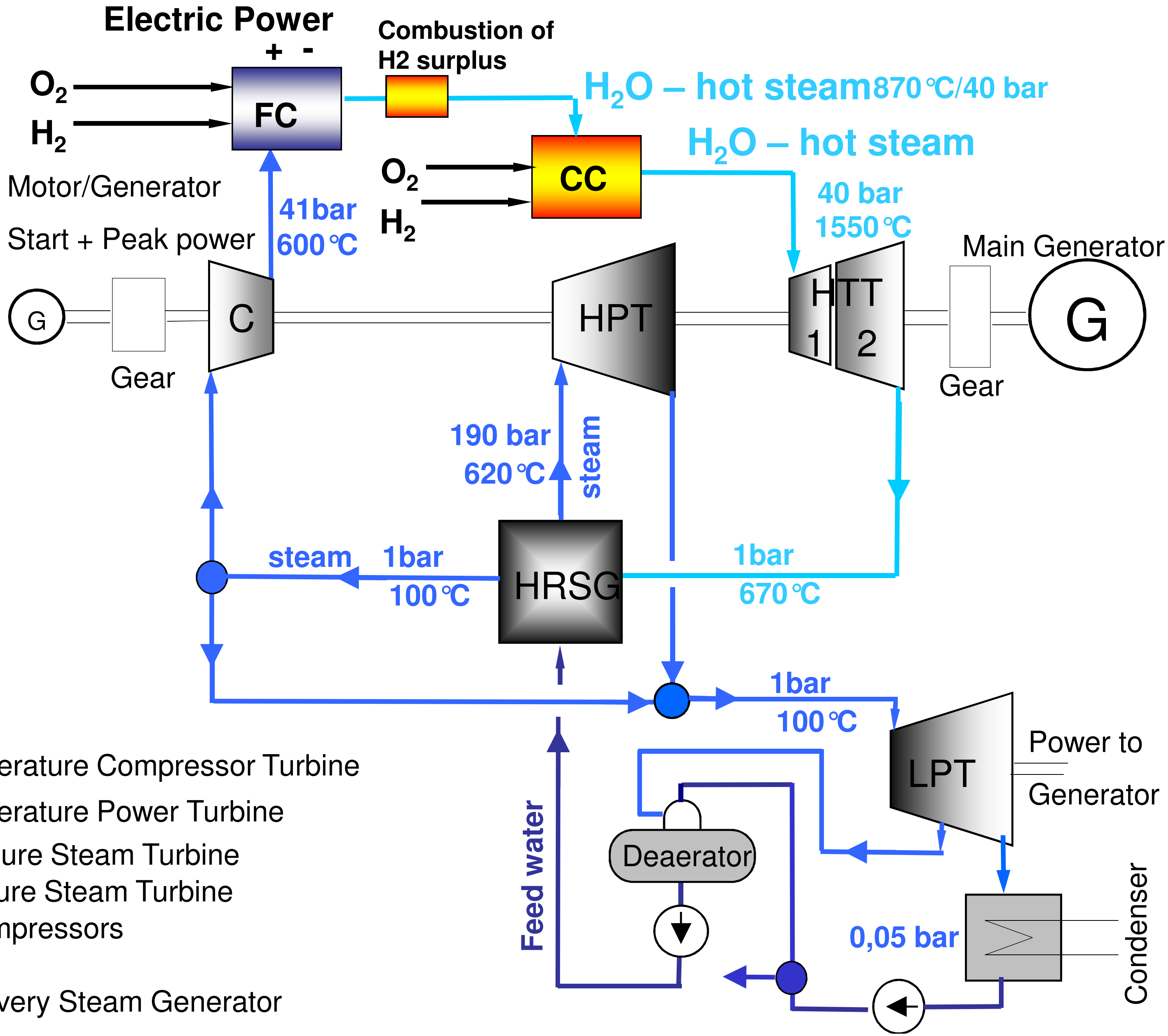
Blade with ICS steam cooling as proposed for 75 MW Graz Cycle presented at ASME Turbo Expo Atlanta 2003

Background - II

- **Power Plants using photovoltaics, tidal flow, wind, … produce electricity at different time periods and different locations**
- **Electrolysers split water and H2 and O2 are delivered to storage tanks which feed several new hybrid plants in generating peak power**



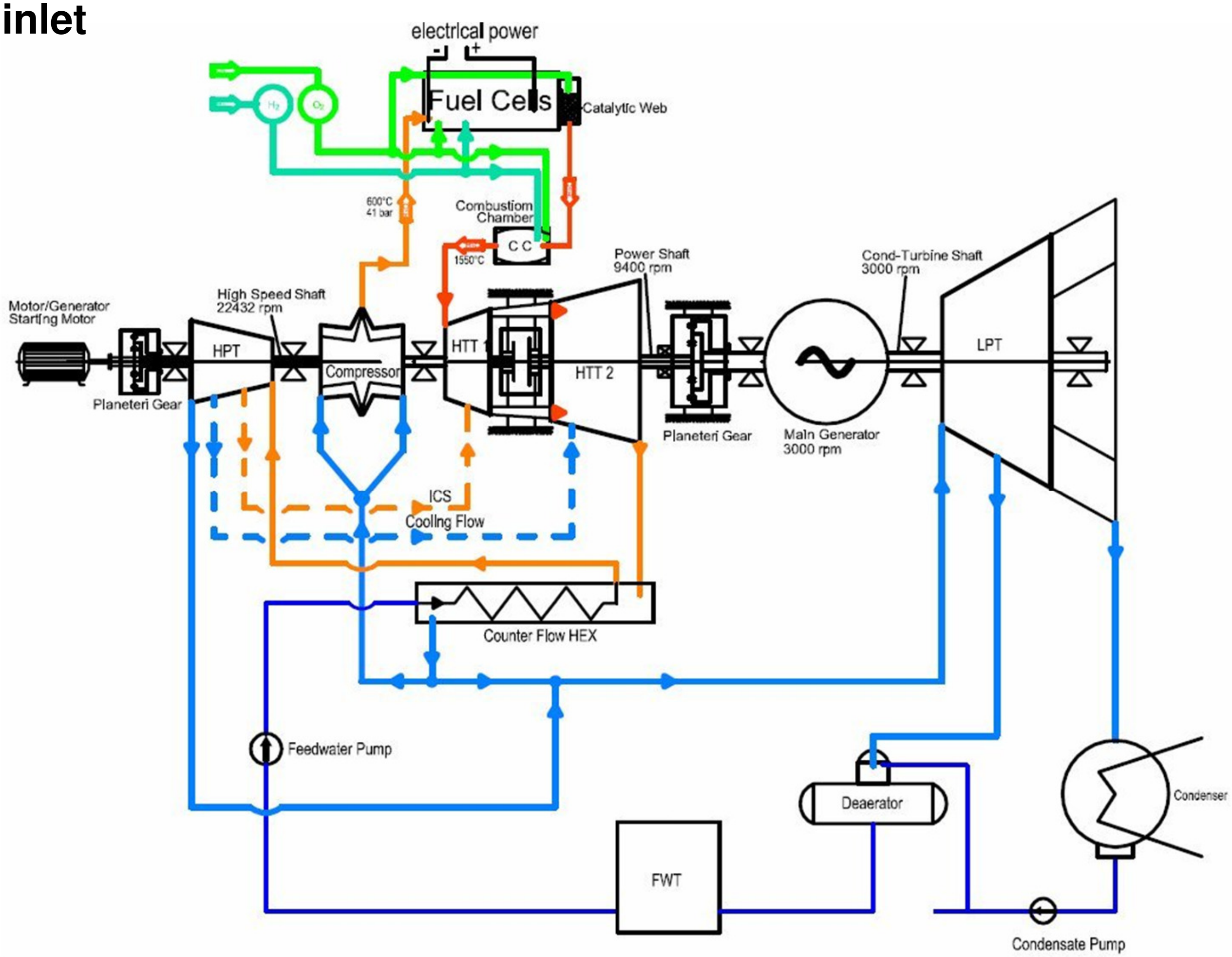
Principle Flow Scheme



HTT1	High Temperature Compressor Turbine
HTT2	High Temperature Power Turbine
HPT	High Pressure Steam Turbine
LPT	Low Pressure Steam Turbine
C	Steam Compressors
FC	Fuel Cells
HRSG	Heat Recovery Steam Generator

Hybrid Plant

- High-speed shaft of 22432 rpm with high-pressure turbine, steam compressor and HTTC
- HTTP runs at 9400 rpm and drives generator via a gear box
- Low-pressure turbine at 3000 rpm
- Arrangement of fuel cells between compressor outlet and turbine combustion chamber inlet



Power Balance

Fuel input	1.568 kg/s H_2, 12.44kg/s O_2
Total heat input	188 MW
HTT power	123.1 MW
HPT power	22.4 MW
LPT power	14.3 MW
Compressor power	47.8 MW
Total pump power	0.7 MW
Generator power	109.6 MW
Fuel cell DC power	30 MW
Fuel cell AC power	29.1 MW
Net electrical power	138.7 MW
Net efficiency	**73.8 %**

Turbomachinery Layout

Graz University of Technology

- **Compressor: double flow rotor with two axial stages on each side connected to a radial disk Symmetric arrangement creates an optimal flow situation in the radial diffuser**
  Axial stages: half of the compressor pressure head, first axial stages have a maximum tip Mach number of 1.4
- **High rotational speed of 22432 rpm to achieve a reasonable enthalpy drop for the HTT1 and especially for the HPT despite their small dimensions as a result of the low volume flow**
- **HTT2 at 9400 rpm: reasonable stage number of five at bearable disk stresses at the same time**
  Solid rotor design with blade lengths from 90 mm to 350 mm attached in fir-tree roots on small elongation disks on the rotor drum
  For the cooling: innovative cooling system ICS is applied
- **HPT: 50 % reaction blading and multiple stages at low rotor diameter**
  A balance piston is aranged in the usual way