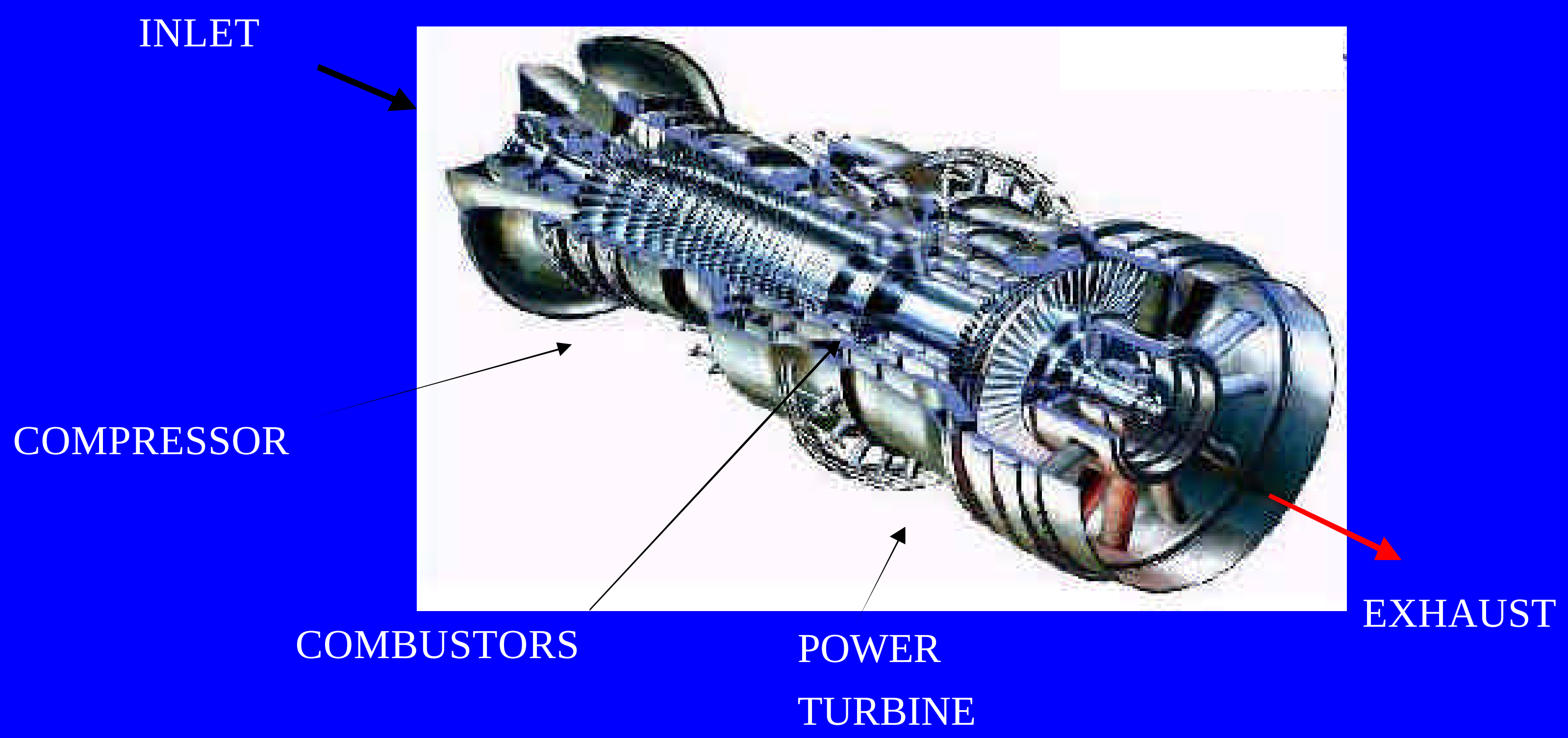
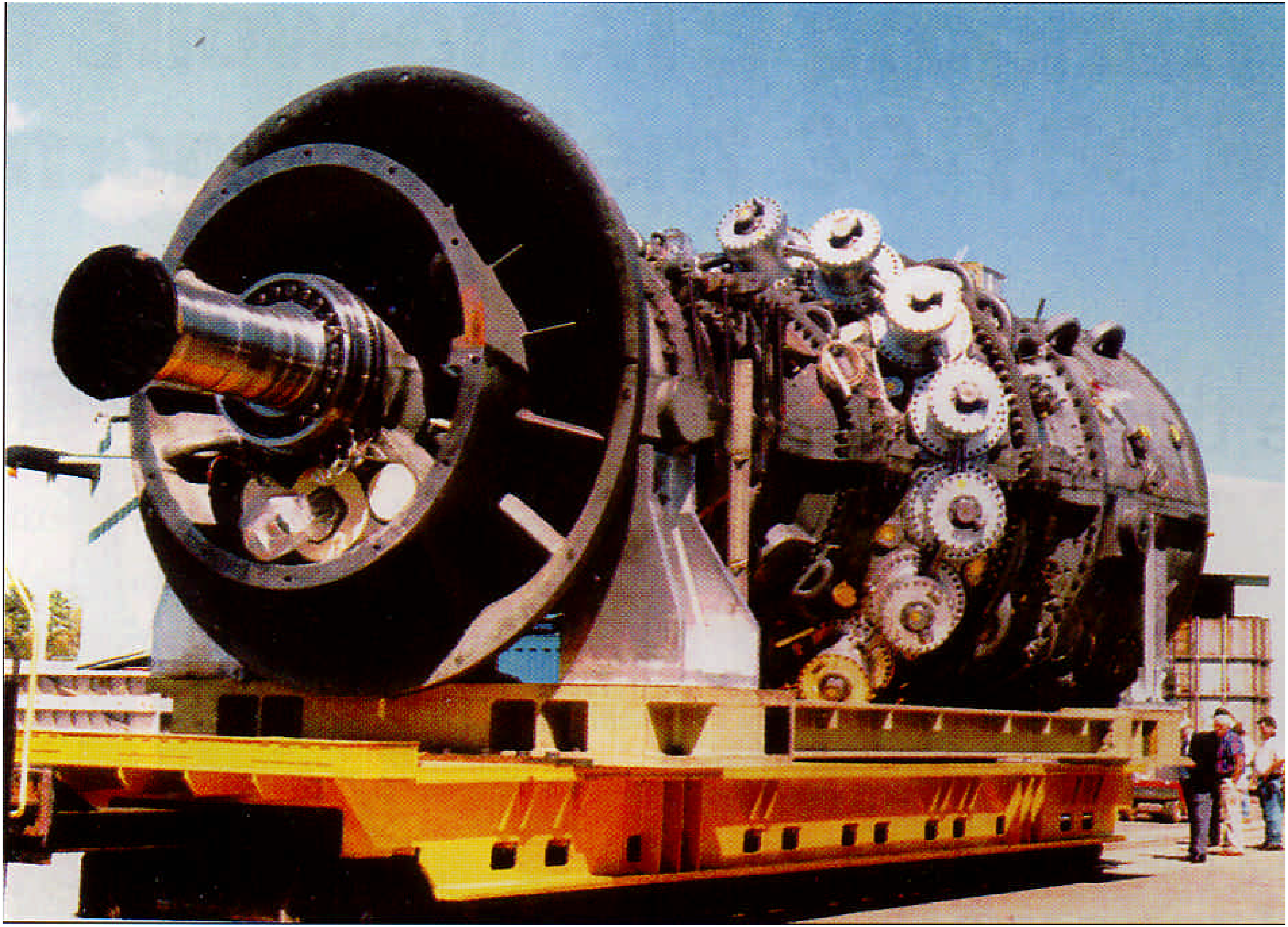
Advanced gas turbine power cycles

Chris Hodrien

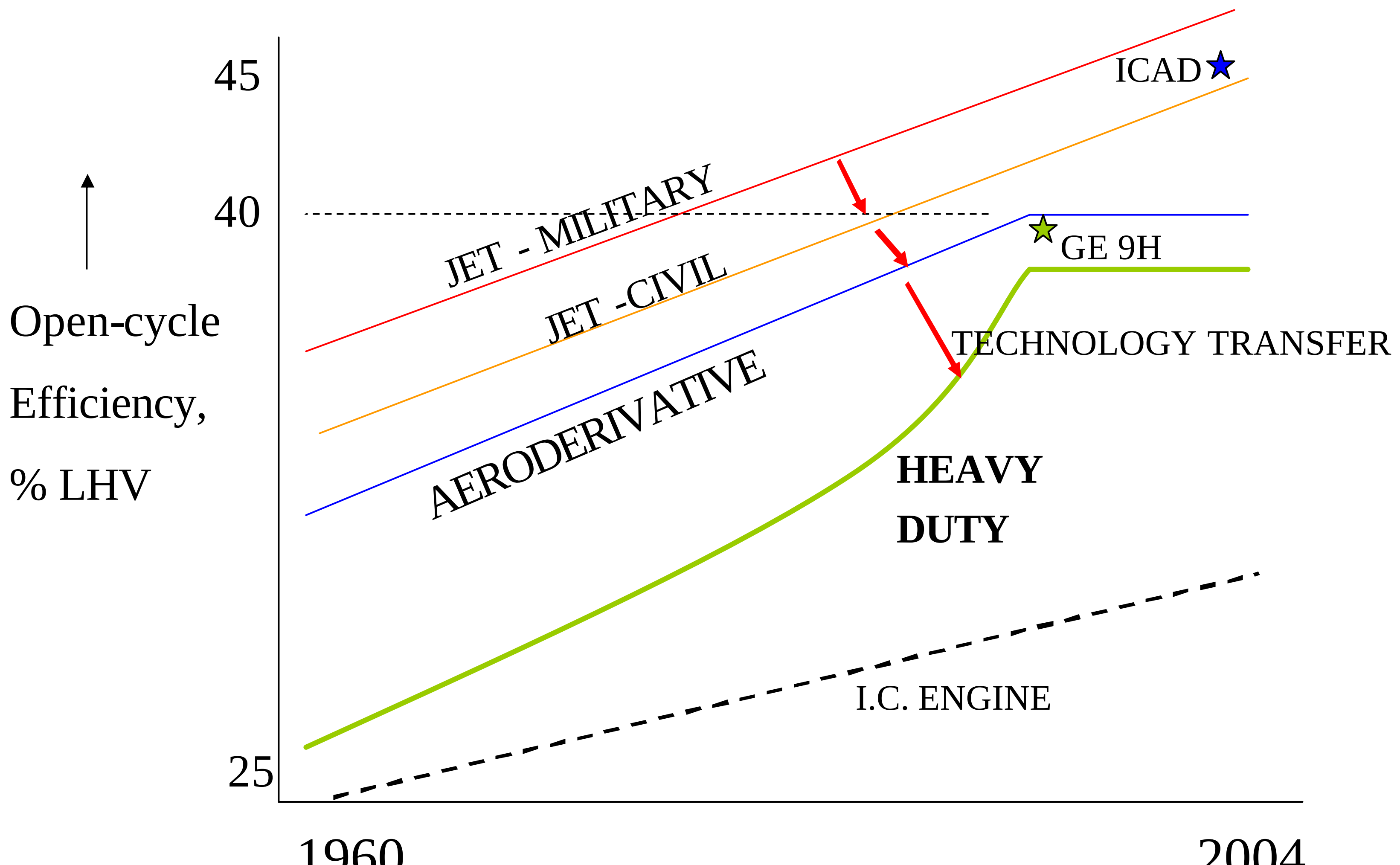


Typical aero-derivative GE LM6000, 40 MW

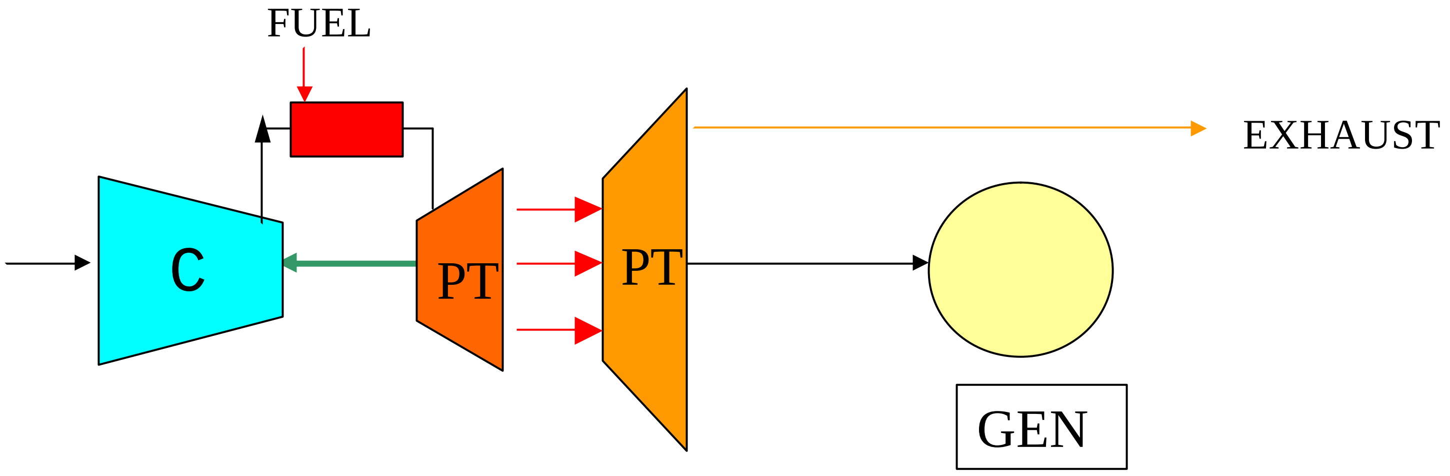
Heavy-duty GT (GE9H) 370 tonnes



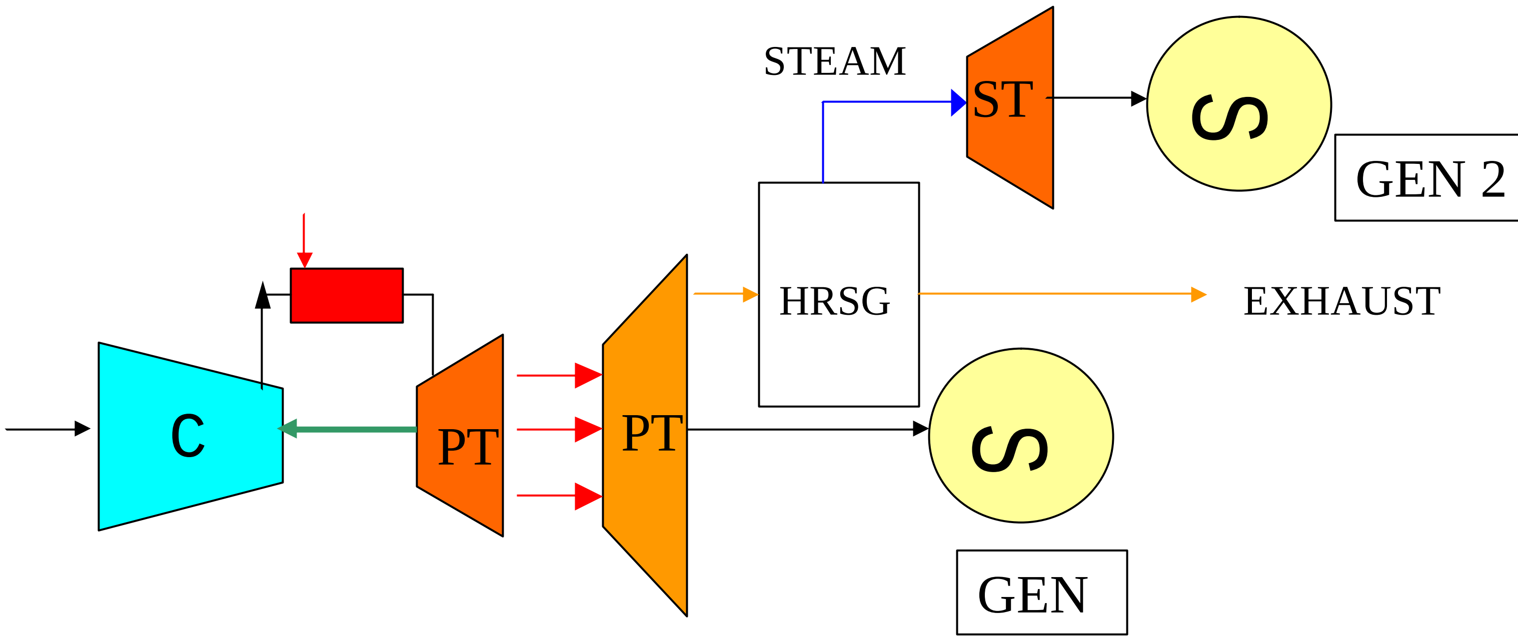
GT design convergence



GT schematic



Combined Cycle (CCGT) principle



Cost: +90% (per kW)

Efficiency: +22%

Power: +50%

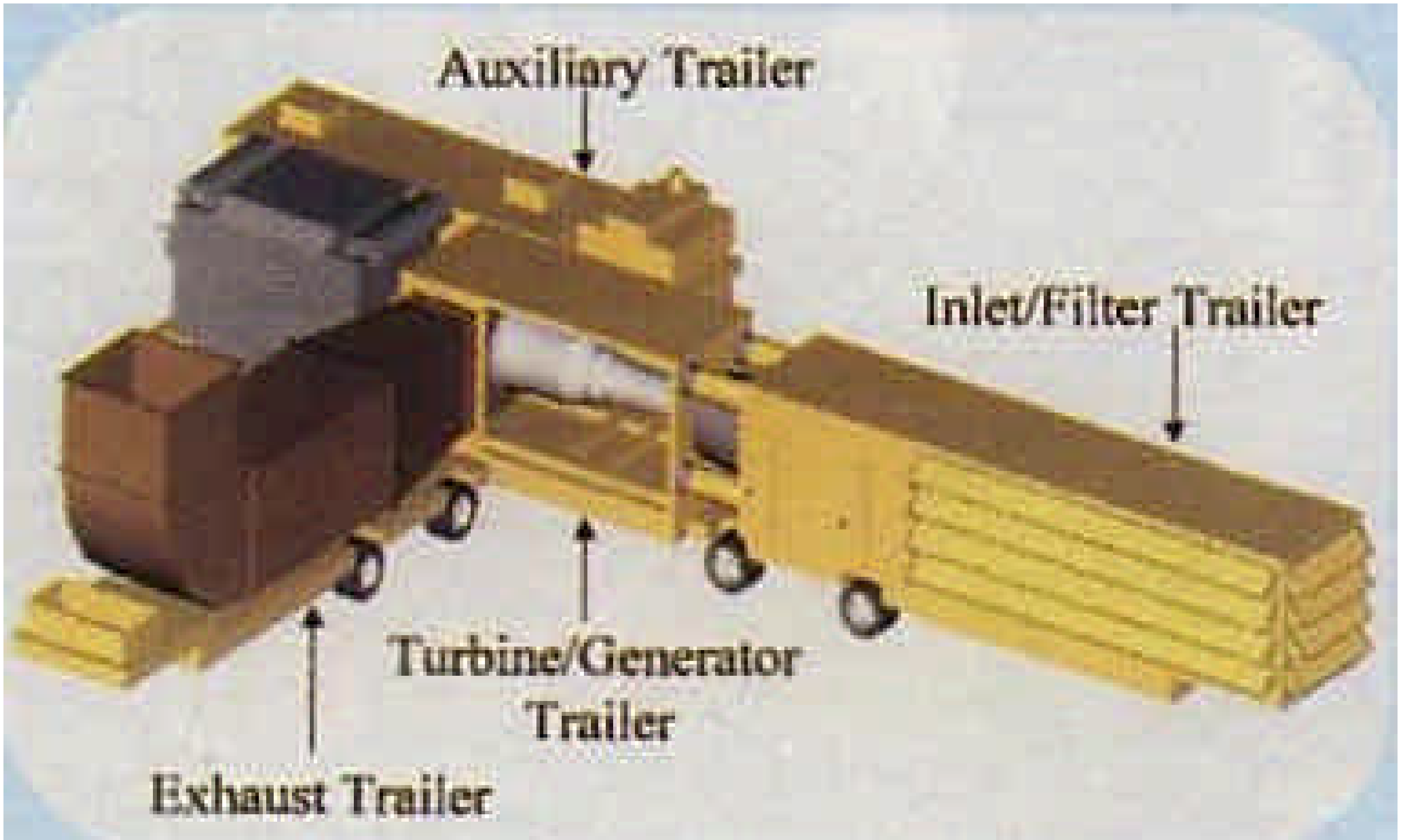
CCGT: state of the art

- Standard air-cooled GT: 58% LHV, 430 MW (1+1)
- GE 9H steam-cooled GT: 60% LHV, 480 MW (1+1)
- Nox g'tee (full load, NG) 25 ppm, 10 ppm available, lower in advanced dev't
- Dry cooling option
- Fuel-flexible NG/ distillate oil
- Combustors available for syngas (for IGCC) and H2 (for C capture/renewable H2) (some models)
  - result of extensive combustion R&D investment

CCGT Plant with “dry” air-cooled condenser

Takasago Machinery Works, Japan 1999 MHI/Westinghouse W701G 1+1

23MW mobile power plant (GE LM-2500)



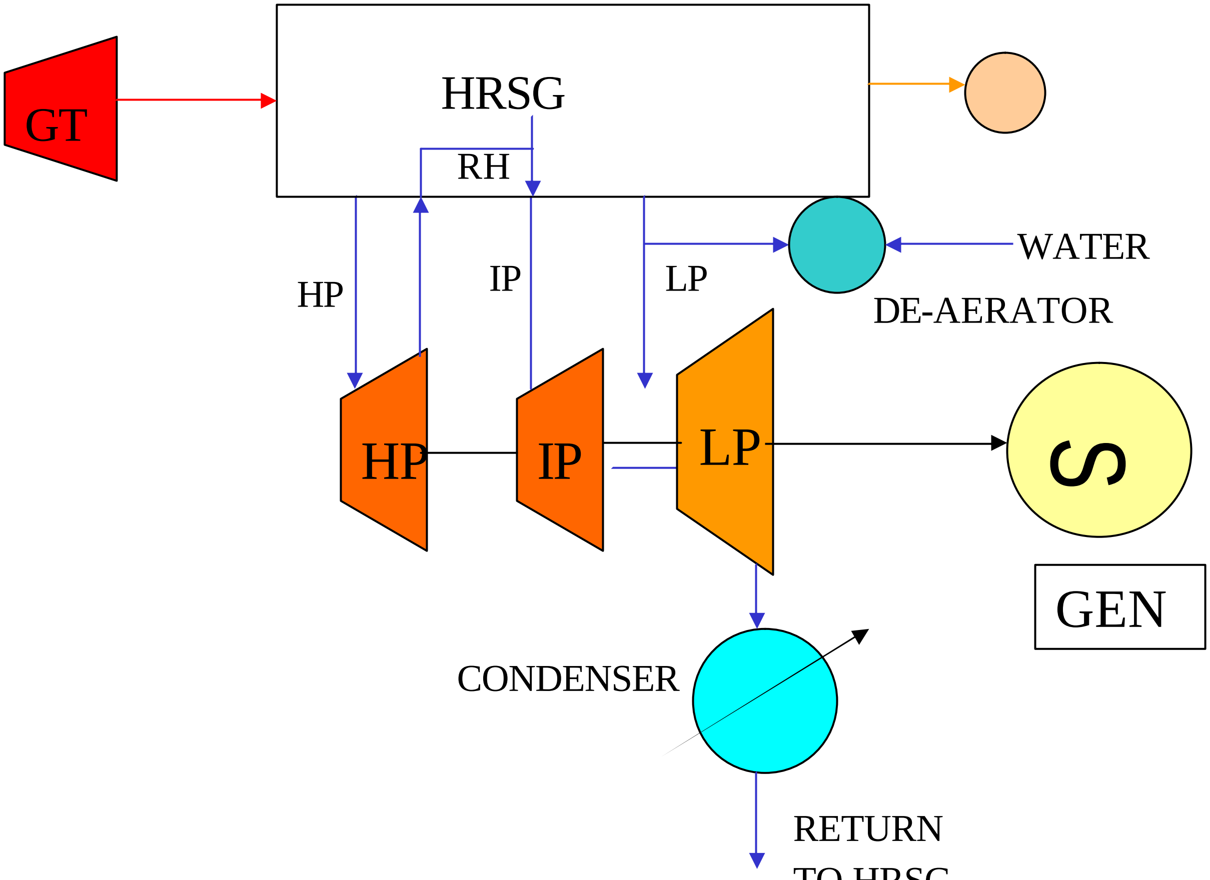
Barge-mounted CCGT -1

Mangalore, India 4+1 CCGT 2490MW on delivery ship

A) Advanced Combined Cycles (CCGT)

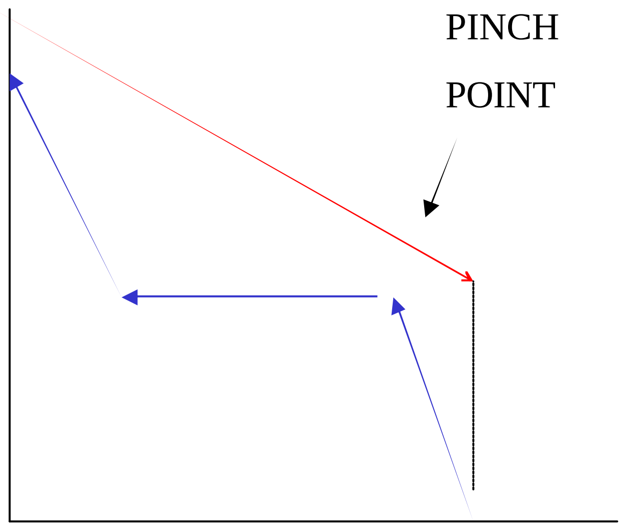
- Better steam bottom cycle:
  - Multi-pressure
  - Reheat
  - CCGT eff’y improved 48 -> (58-60)% LHV in 20 years
- Kalina (ammonia) cycle
- Organic Rankine Cycle (ORC) bottoming

3-pressure/reheat steam cycle
(3-admission turbine)

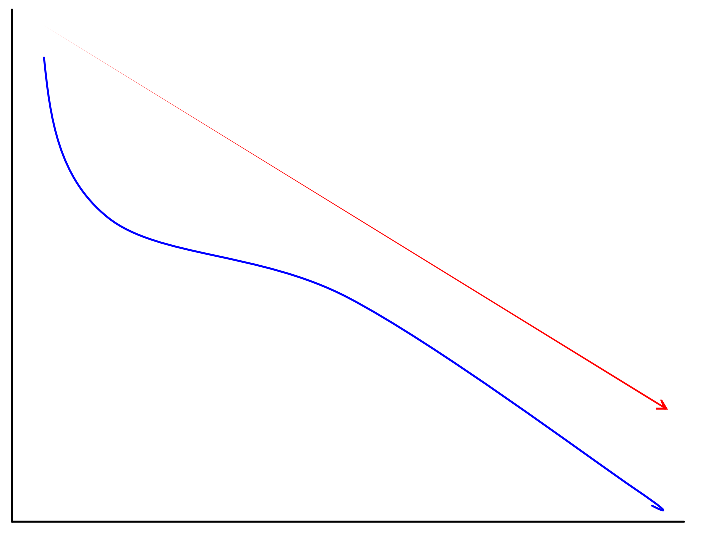


Typical pressures for a 3-pressure steam cycle: 40 atm, 16atm, 7atm.

Kalina Cycle vs. CCGT – cooling curves



CCGT



Kalina cycle –

More heat recovered

Area between curves = wasted exergy (potential work)

B) Advanced simple GT cycles

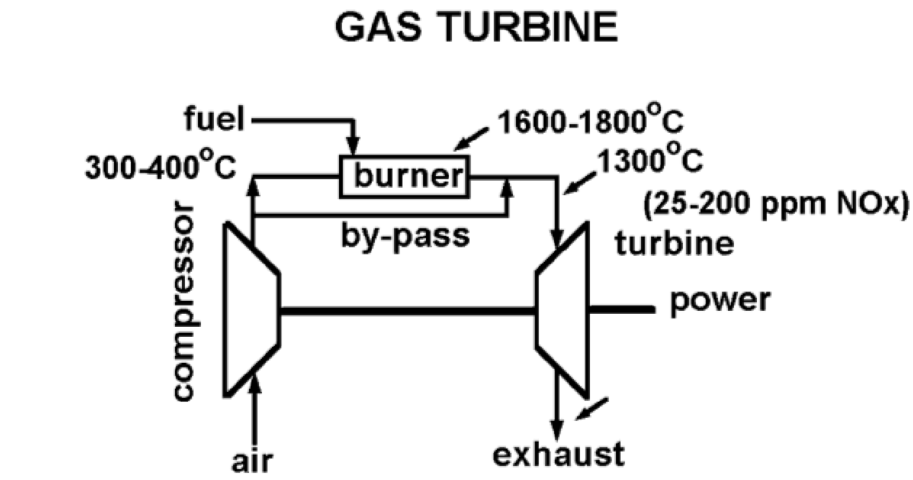
Targets:

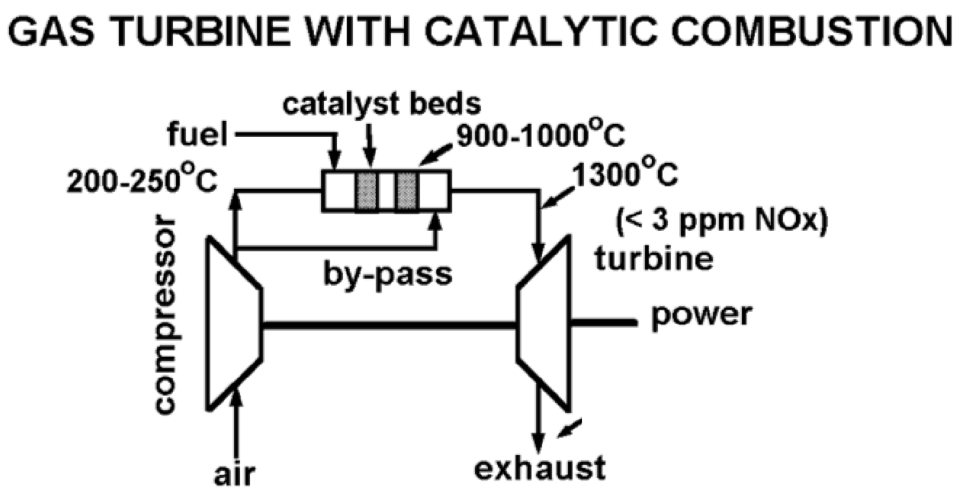
- Efficiency improvement:
  - “mid-range” generation
  - better than simple GT (40-50% LHV) at lower cost and better **flexibility** than CCGT
- Better part-load efficiency
- Better “hot-day” efficiency
- Lower NOx
- Carbon capture (CCS)??

Advanced simple GT cycles

- Catalytic combustion
- Reheat
- Steam-cooled GT
- Inlet-chilled
- Recuperated
- Spray-Intercooled (SPRINT)
- Intercooled (ICAD)
- Steam injection (STIG)
- Humid Air turbine (HAT cycle)
- Chemically Recuperated GT (CRGT cycle)

Catalytic Combustion for NOX reduction

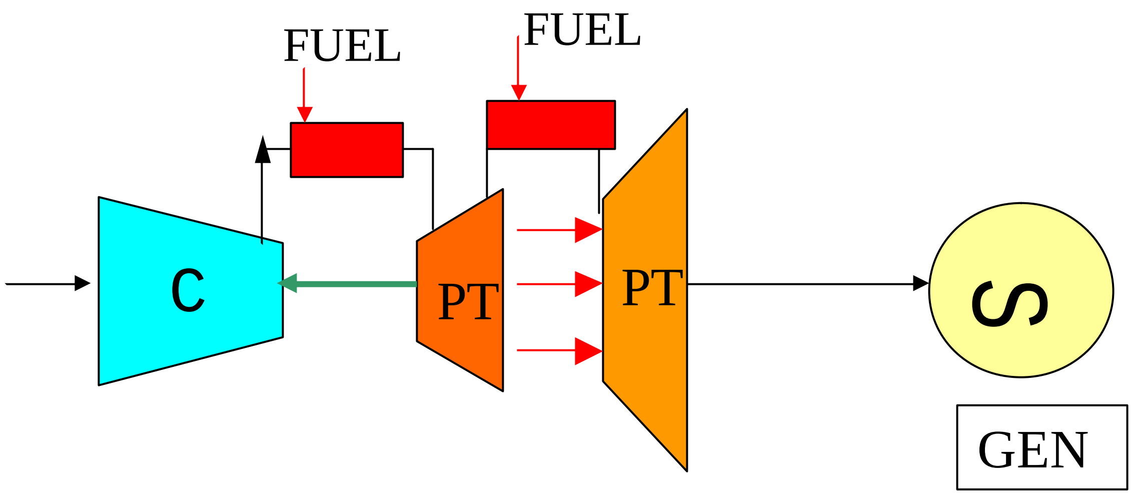




Source: Dr J M Rhine

Reheat GT cycle
(ex: Alstom GT24/GT26)

Allows more fuel to be burned + power gen'd within metal temp. limit



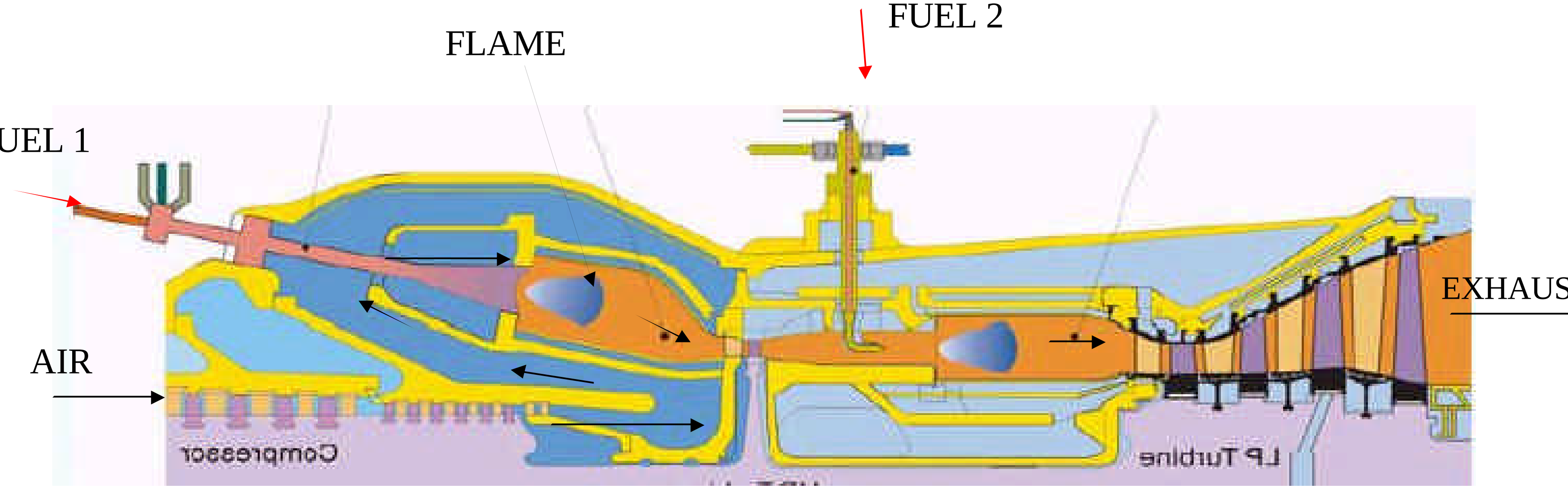
Cost: +5%

Efficiency: +3%

Power output: +40%

Better part-load efficiency +NOx

Alstom GT26 Reheat turbine



MAIN AIR

COOLING AIR

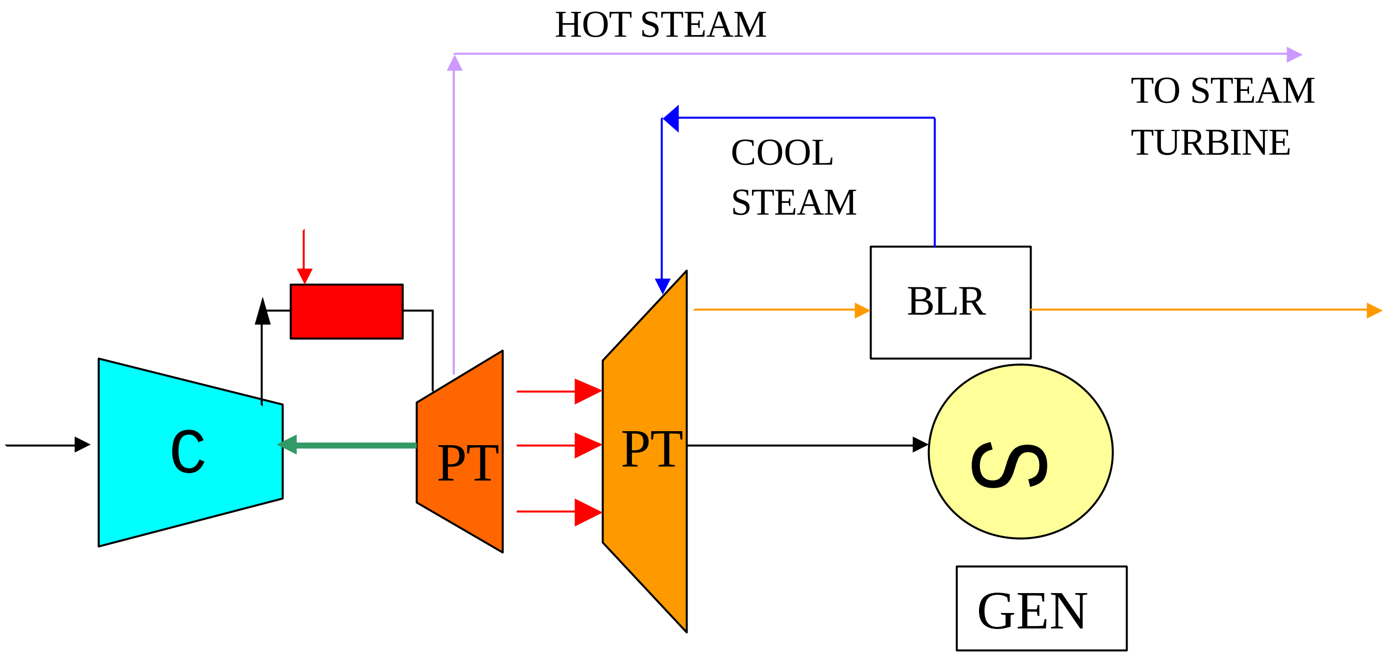
HOT GAS PATH

ROTOR (SOLID)

ROTOR BLADES (“BUCKETS”)

FIXED BLADES (“NOZZLES”)

Steam-cooled GT (GE 9H)



Cost: +10% (per KW)

Efficiency: +2% (in CCGT)

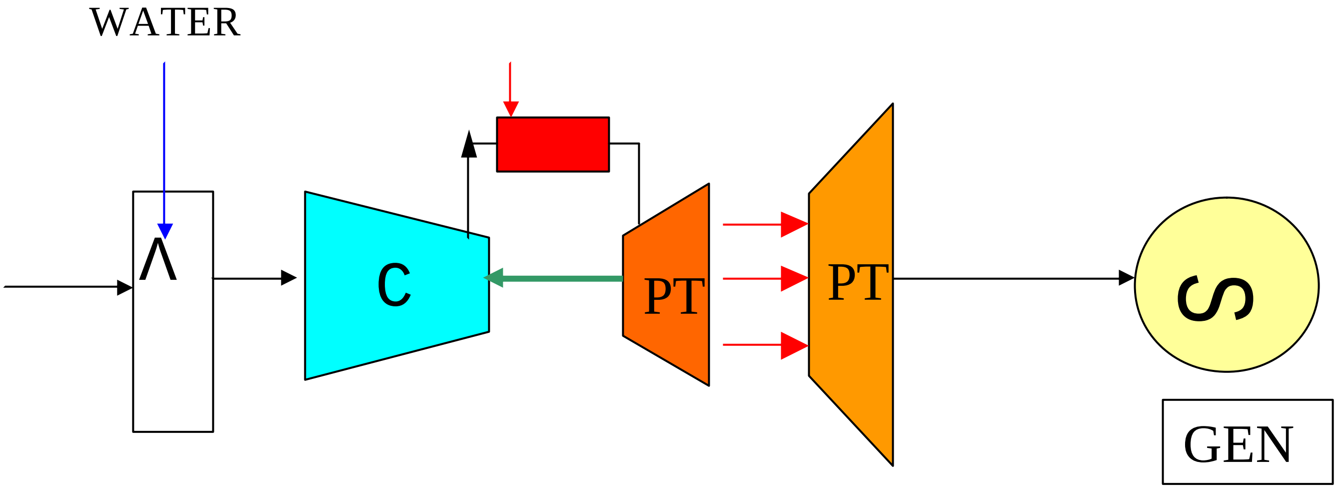
Power: +20%

Inlet chilling 1– evaporation or “micro-fogging”

Hot countries: GT power output is lowest at time/season of max. demand

Increases air density + mass flow at low cost

-BUT Only works if inlet air is dry



Cost: +5%

Efficiency: +2%

POWER +20% (AT 35 ºC/ **dry** air)

Inlet air evaporative cooling (fogging)

Inlet chilling 2 –refrigeration

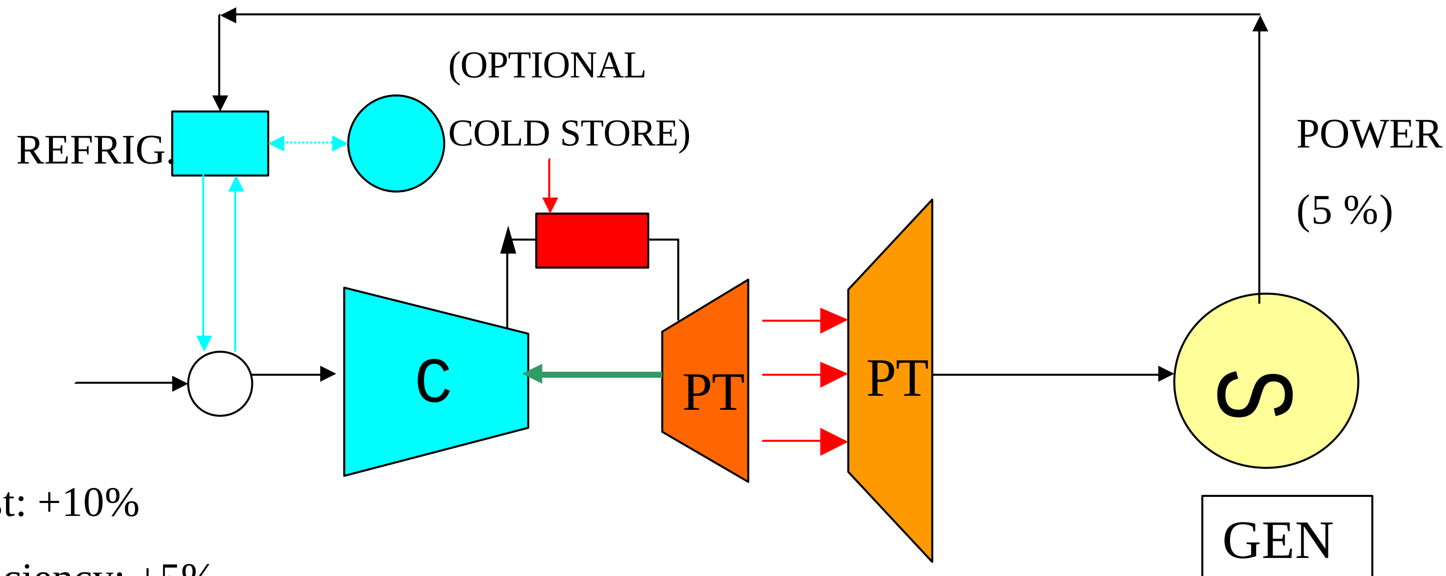
Increases air density +mass flow

Higher cost but still works if inlet air is wet

Uses some of the extra power made

Absorption chilling option [NOT shown] (use exhaust heat, less power)

Option to **store** chilling from cheap overnight power



Cost: +10%

Efficiency: +5%

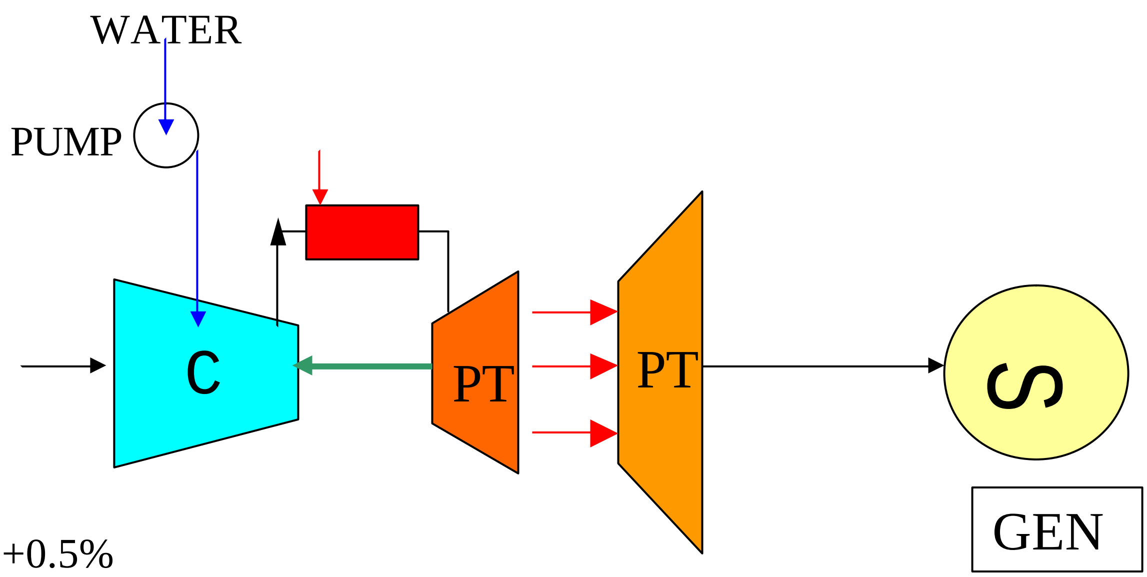
POWER +20% **net** (AT 35 ^{o}C/ DAMP air)

Water Spray Intercooling (SPRINT)

Reduces compressor power use

Increases total mass flow like STIG

Must ensure micro-droplets + high purity to avoid blade erosion



Cost: +5%

Efficiency: +0.5%

POWER: +9%

Better part-load and hot-day efficiency

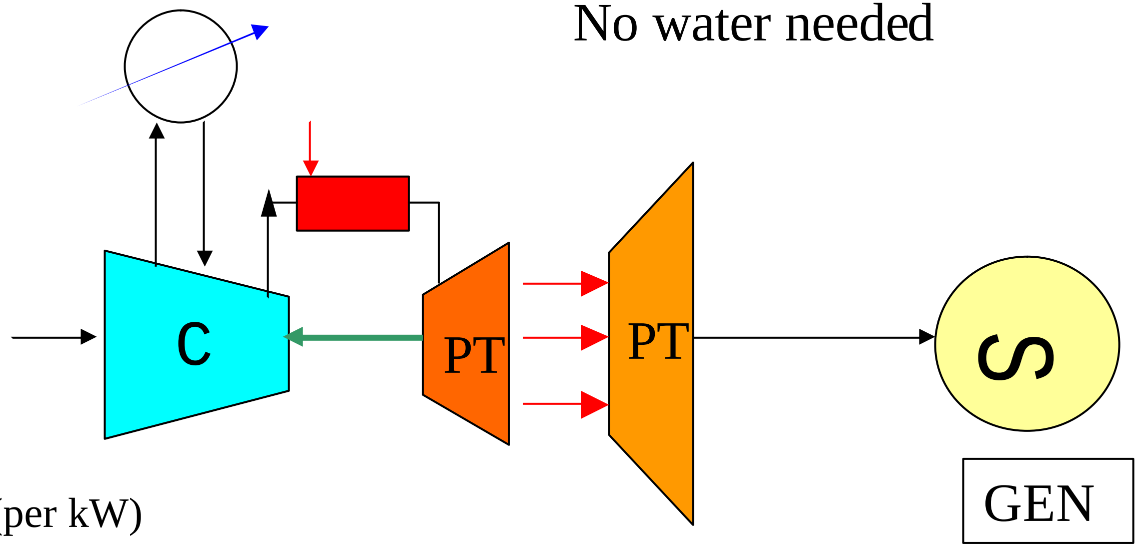
Dry Intercooling (ICAD)
(R&D Prototype - GE)

Major new development ($200M R&D costs)

Initiated by CAGT international collaborative project

Very difficult aerodynamic design + stresses

No water needed



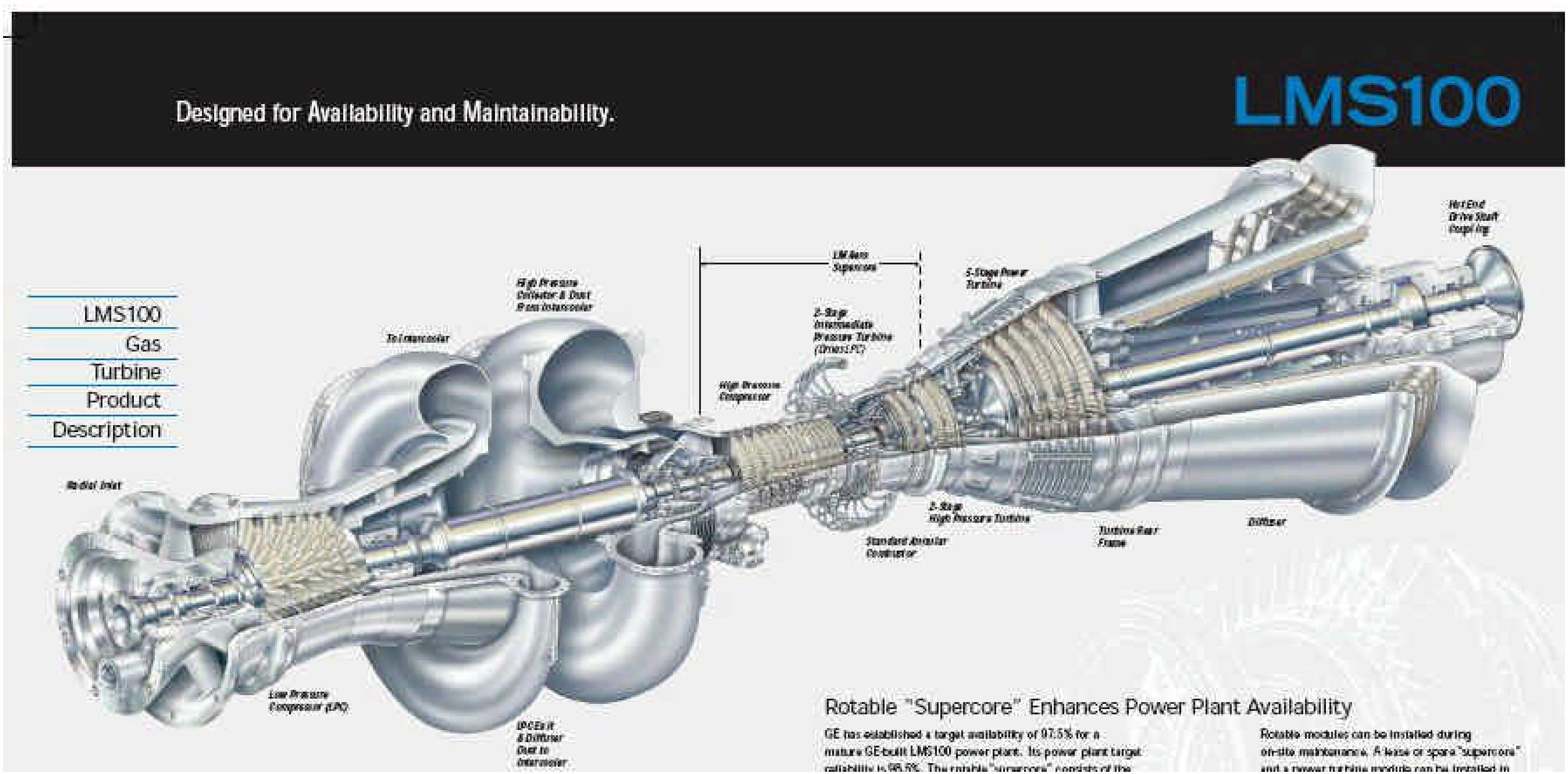
Cost: **MINUS** 25% (per kW)

Efficiency: +5%

POWER: **+100%**

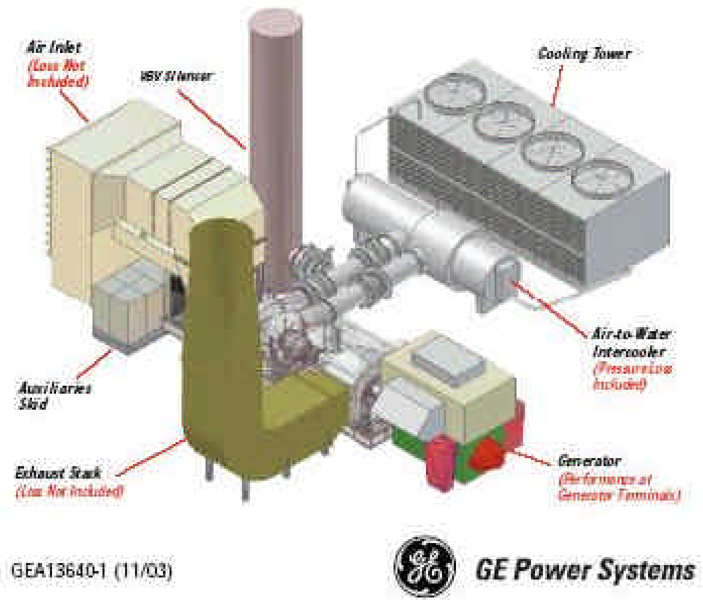
Better part-load and hot-day efficiency

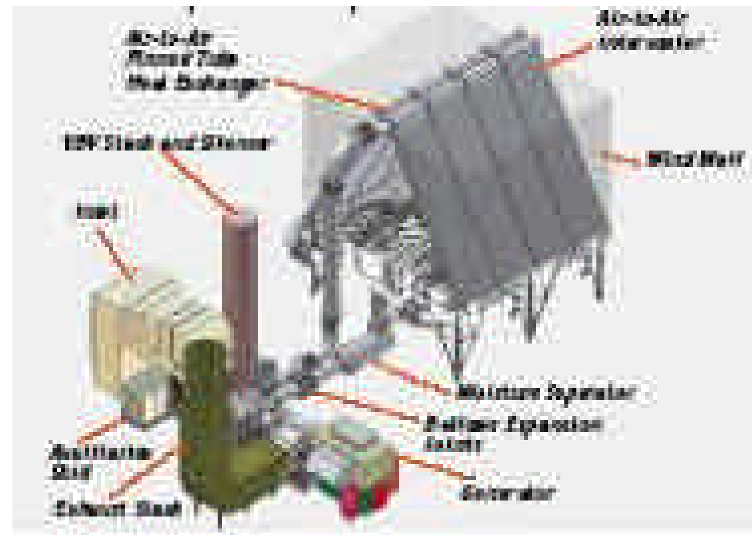
GE LMS-100 ICAD (intercooled)



Source: GE brochure

GE LMS-100 ICAD (intercooled)-2





Water cooling

Air cooling

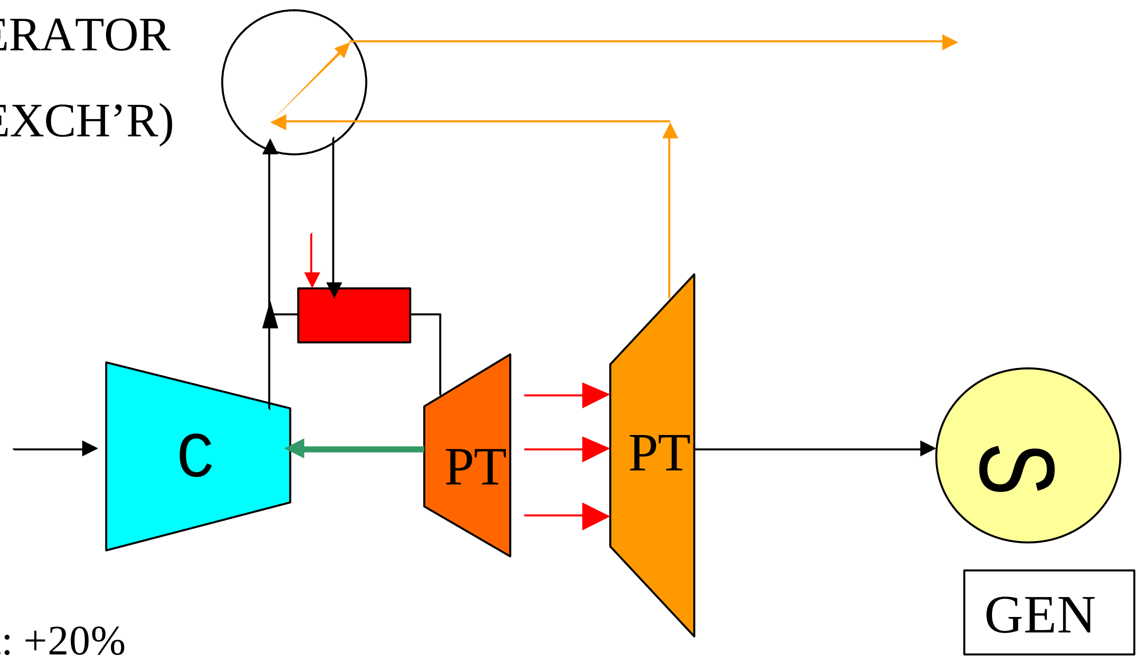
Source: GE brochure

Recuperated GT cycle
(e.g.: Solar)

Recuperator is bulky, costly + unreliable (leaks)

RECUPERATOR

(HEAT EXCH’R)



Cost: +20%

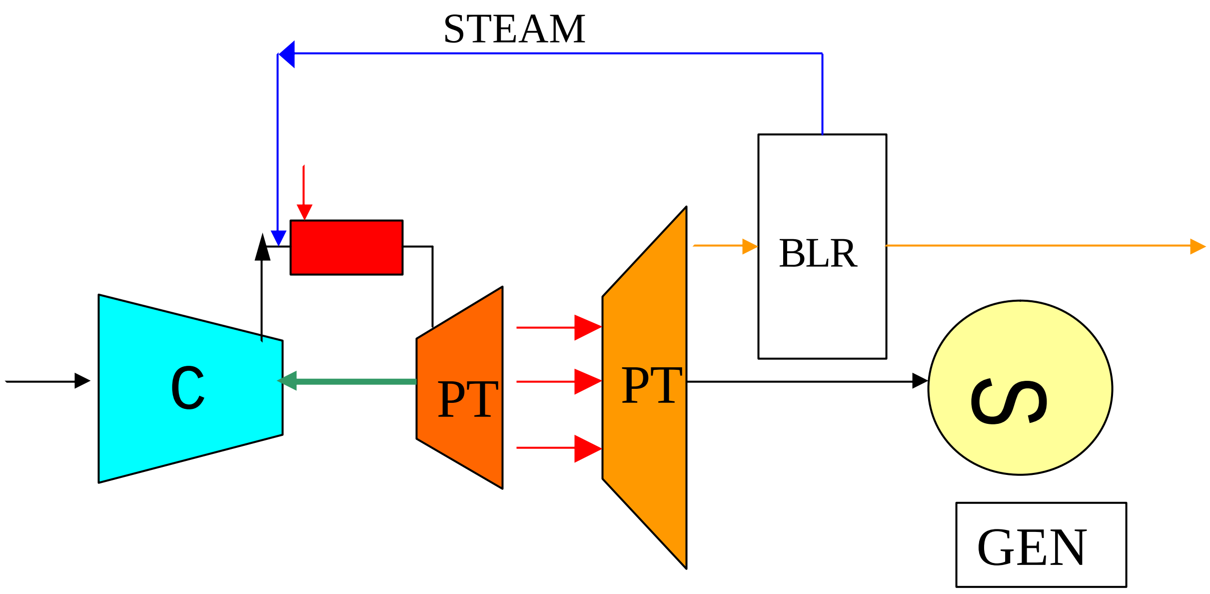
Efficiency: +5%

Power: -2%

Better part-load efficiency

Steam Injection ('STIG') cycle

"Poor man's Combined Cycle" (no steam turbine)



Cost: +30%

Efficiency: +4%

Power: +24%

Better part-load efficiency+ NOx

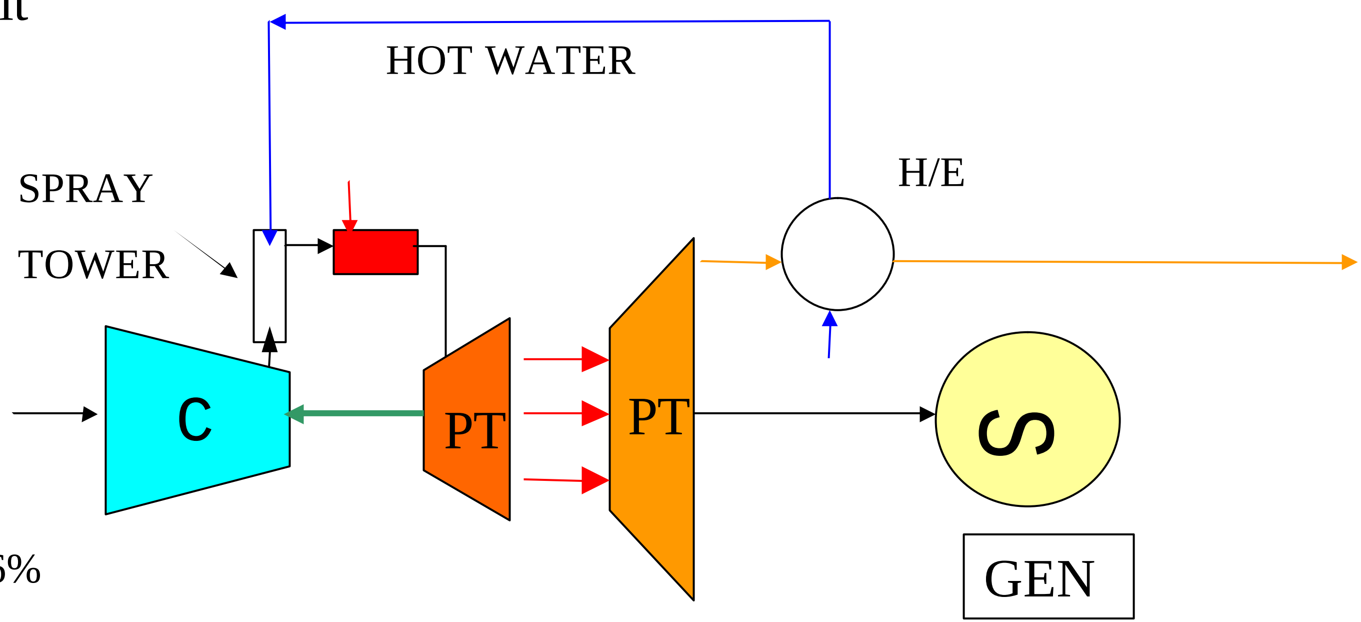
HAT (Humid Air turbine) cycle concept (EPRI)

Recovers more heat (therefore more H_2O mass flow boost) than STIG

Avoids boiler insurance+ manning problems

Spray tower is very large (NOT to scale!) + complex H/E system

NOT yet built



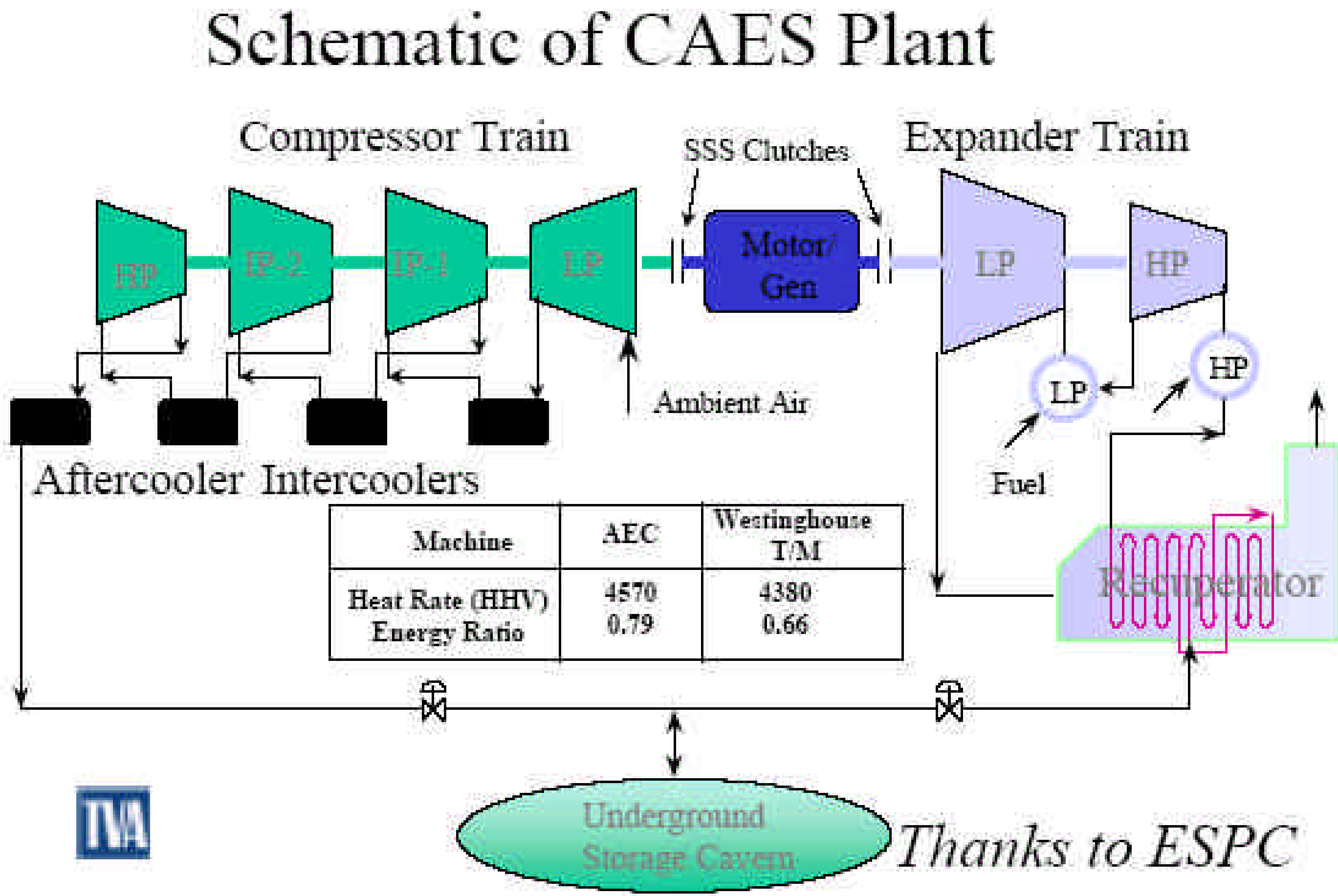
Cost: +25%

Efficiency: +6%

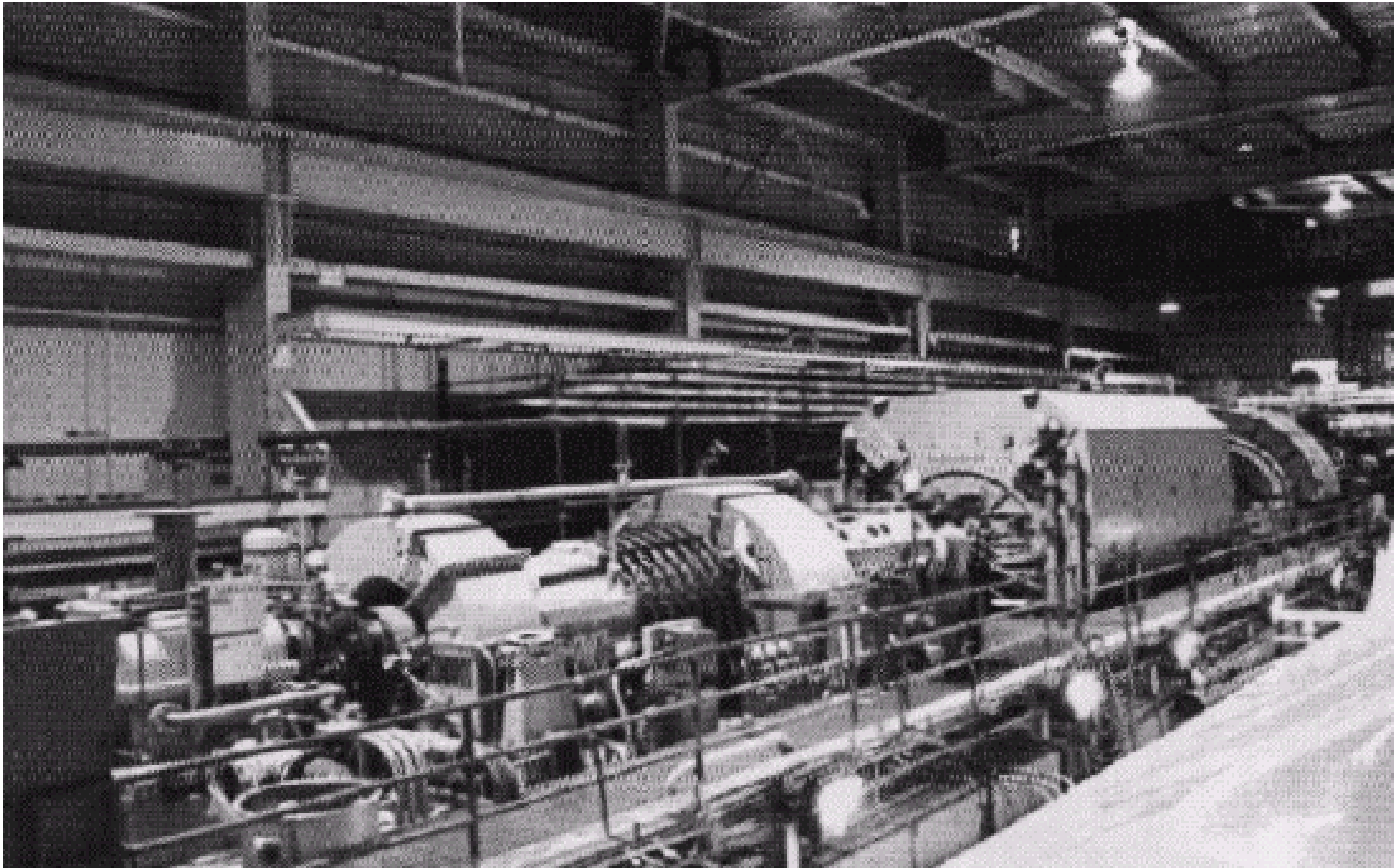
POWER: +30%

Better part-load efficiency +NOx

Compressed Air Energy Storage (CAES)



Machine	AEC	Westinghouse T/M
Heat Rate (HHV)	4570	4380
Energy Ratio	0.79	0.66



Thanks to ESPC

AEC 110 MW CAES Plant Turbomachinery Train

CAES Features

- 15 min startup from cold
- rapid load ramping
- Superior part-load efficiency (only 15% penalty at 25% load)
- Uses only 30-40% of normal fuel rate during gen. Period
- Good spinning reserve capability

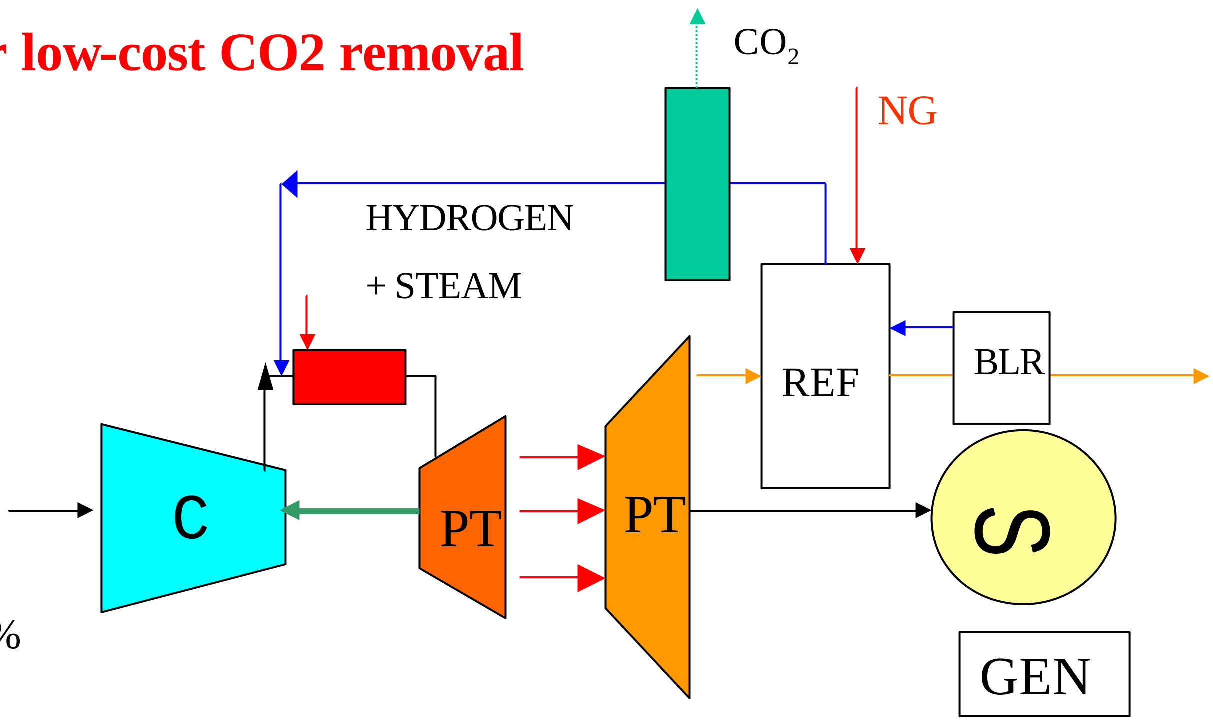
Chemically Recuperated Gas Turbine (CRGT cycle)

Highly advanced R&D concept (complex)

Boiler but no steam turbine

Process expertise required

Prospect for low-cost CO2 removal



Cost: +30%

Efficiency: +9%

Power: +30%

The Joker In The Pack: Carbon Capture + Storage (CCS)

- **WILL** CCS be required for gas-fired plant, or only for coal ?
- **What** % CCS required for coal?
  - c. 90% ?
  - NG CCGT equivalence (c. 60%)?
  - Pre-capture (IGCC) or post-capture?
- Post-capture for CCGT: high % eff'y drop for GT (back-pressure)
- Pre-capture: reform NG into H2 +remove CO2 (CRGT cycle) (**fully-proven** technology elements)
  - demo should be funded (BP Peterhead debacle)

Squaring the circle: IGCC

- Integrated Gasification-Combined Cycle (IGCC)
- Fuels: Coal, pet.coke, heavy resid. oil
- Combines resource availability/ low price of solid fuels with low emissions of gas ("coal cleaning" technique)
- Perceived reliability/ complexity/ commercial issues
- Cost **without** CCS: 15-20% higher than PC coal
- CCS penalty **much lower** than for PC, and **fully-proven*** "pre-capture" technology
  - CCS **demo'd on full scale** at Great Plains, USA since 1997 (>2M tonnes CO2 **sold** + sequestered)
- **"The way to go" for coal +CCS new-build for the low-CO2 era**
- Gov't currently **only** funding PC **post**-capture demo option

IGCC performance

- Efficiency 43-45% LHV (and proportionate CO2 reduction if no CCS)
- S removal 99+% + saleable product (S or H_2SO_4)
- **Proven** CO2 removal 85-90+% + saleable product (CO2 for oil/gas-field EOR)
  - actual gas volume treated = 1/180th!
- Water use 1/3 - Site **<u>independent of</u>** large rivers
- NOx emissions <1/20th (10-25 ppmv)
- Hg emissions –neglig.
- Dust emissions (main combustion) NEGATIVE!
- Solid waste – saleable slag aggregate (low leaching)
- Liquid waste – small volume, on-site cleanup
- Flexible coal/NG feed (startup, peaking, fuel balancing)
- **Retrofittable** to existing PC sites