NREL
NATIONAL RENEWABLE ENERGY LABORATORY

CSP and Natural Gas Hybrids

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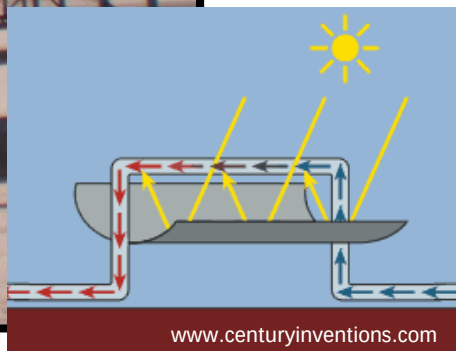
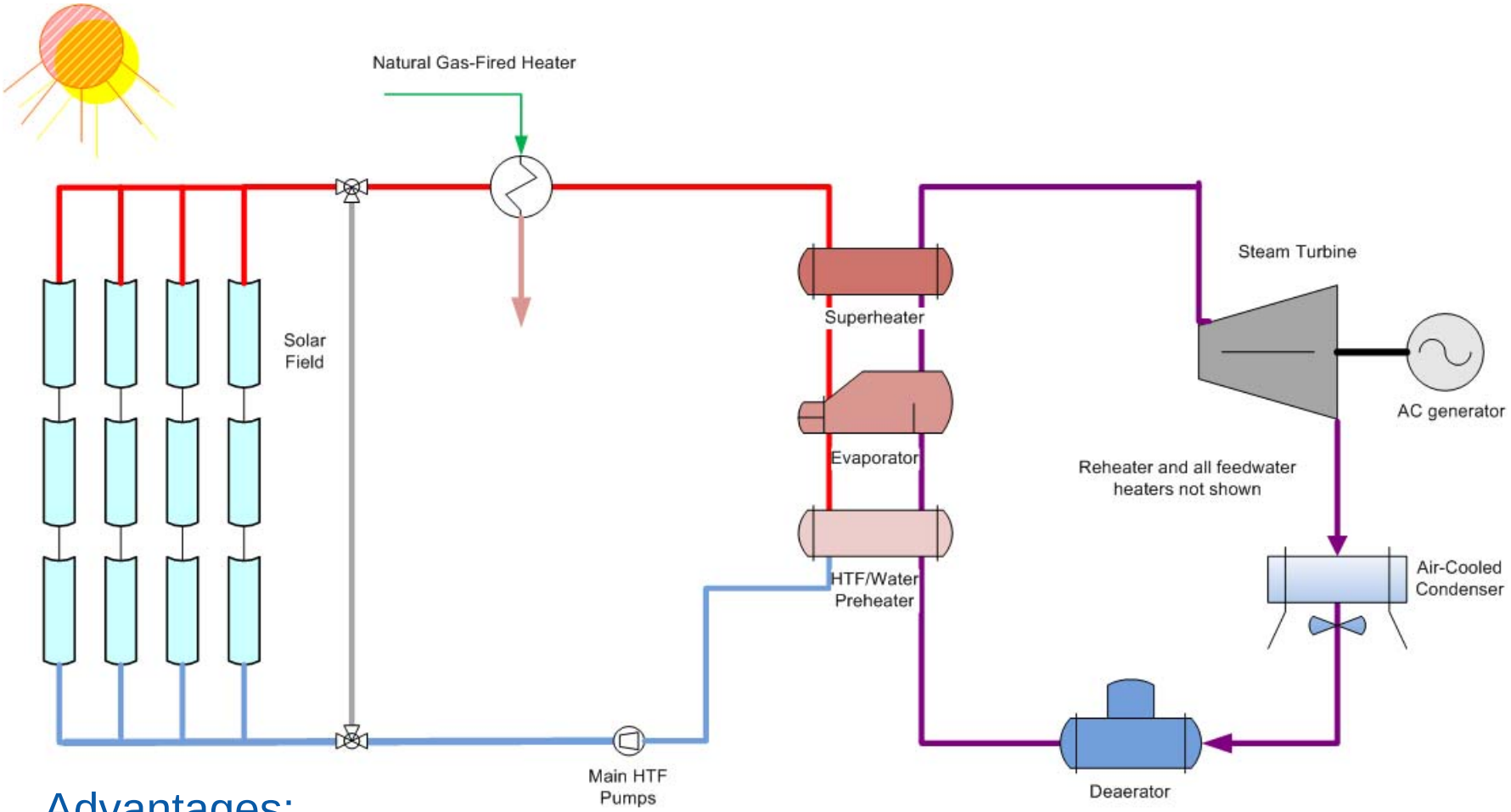
Parabolic Trough CSP



Typical CSP Plant (e.g. SEGS)



Advantages:

- Simple gas burner; easy implementation

Limitation:

- Gas thermal efficiency <37% (vs. >50% in combined cycle plant)

CSP / Natural Gas Hybrids

Commercial

1. Gas-burner backup
2. Integrated solar combined cycle (ISCC)
   - Substitute solar heat for duct burners (retrofit)
   - Oversize Heat Recovery Steam Generator (greenfield)

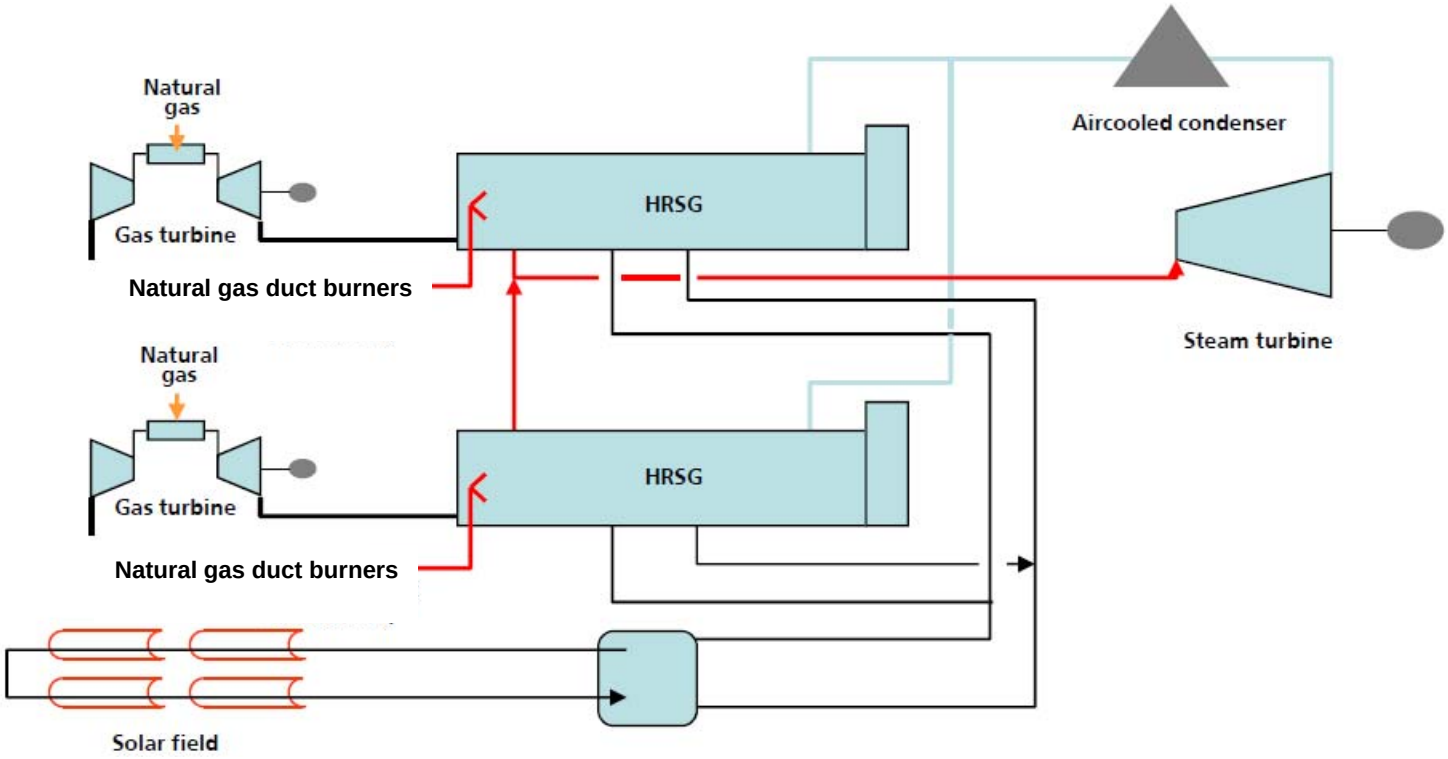
R&D

3. Solar preheated gas turbine
4. Solar steam injected gas turbine
5. Co-located CSP / gas turbine

Challenge:

To obtain high solar fraction with firm dispatchability and lowest possible cost.

Integrated Solar Combined Cycle (ISCC)



Advantages:

- Shares infrastructure (power block, transmission, O&M staff, etc.)
- Good solar-to-electric efficiency

Limitations:

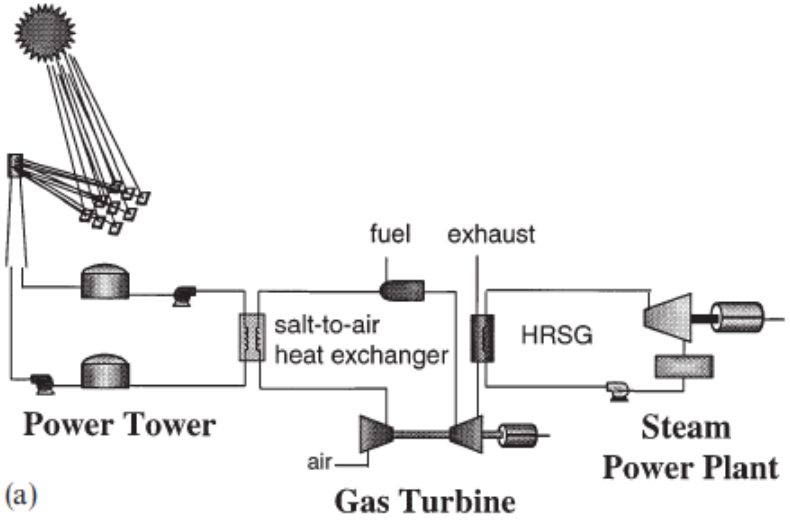
- Maximum of ~15% solar contribution at design point
- Less than 5% annual average solar contribution

Graphic: Abener 2010

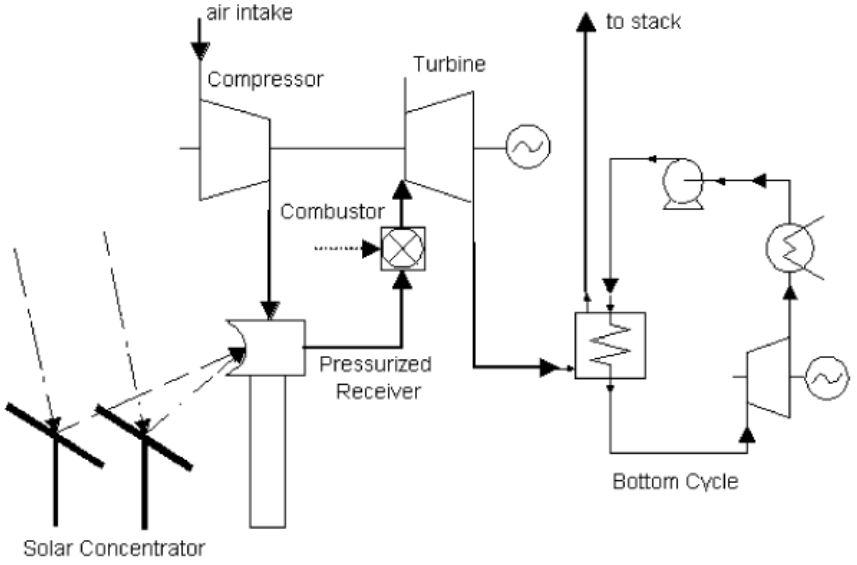
75 MW solar-augment ISCC Plant in Florida

Solar Preheat to Gas Turbine

Solar energy used to preheat compressed air feeding a gas turbine.
Solar integration can be through salt HTF (left) or direct air heating (right):



NREL 1995; Kolb 1998

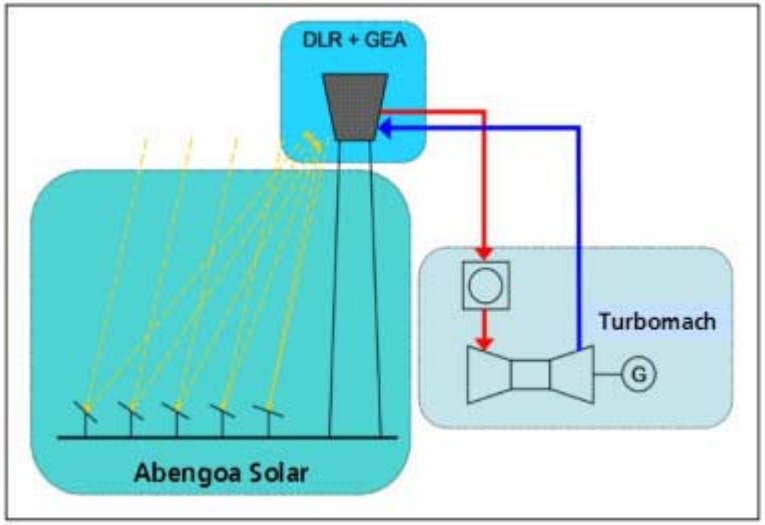


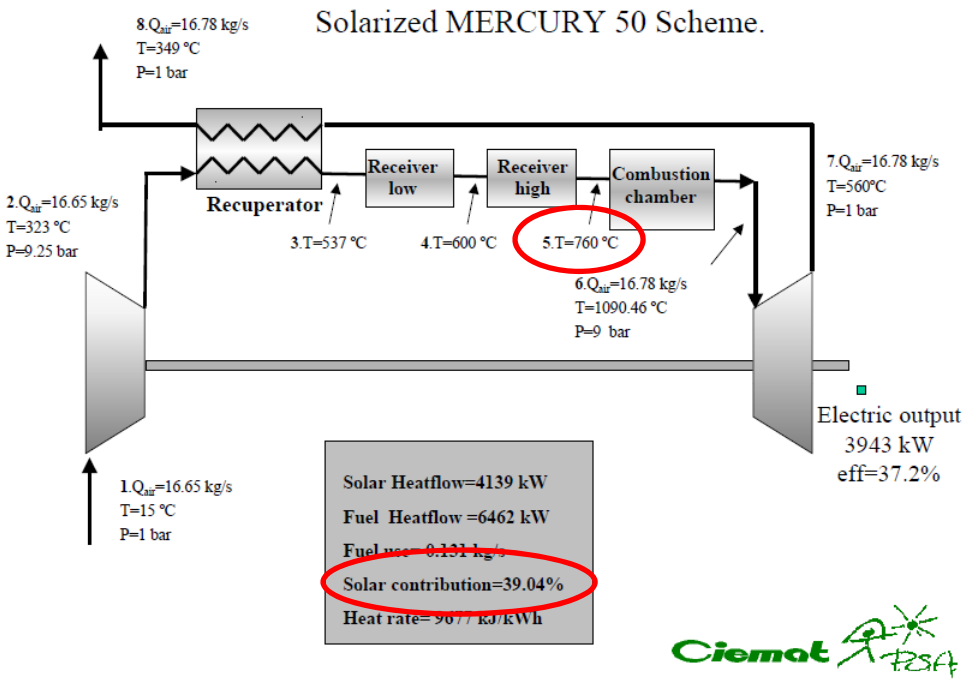
Schwarzbozl et al. 2006

Solar Preheat to Gas Turbine

EU Solugas demonstration project

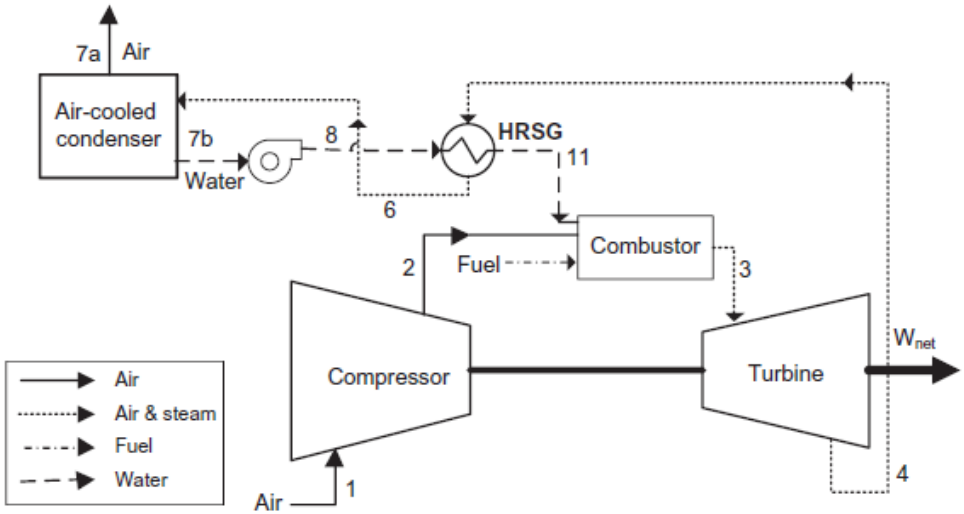
1. Solar-energy heats pressurized air to 650°C.
2. The heated air is fed into the combustion chamber of a 4.6 MWe industrial gas turbine.
3. Later testing to look at solar temperatures of 800°C to 1000°C



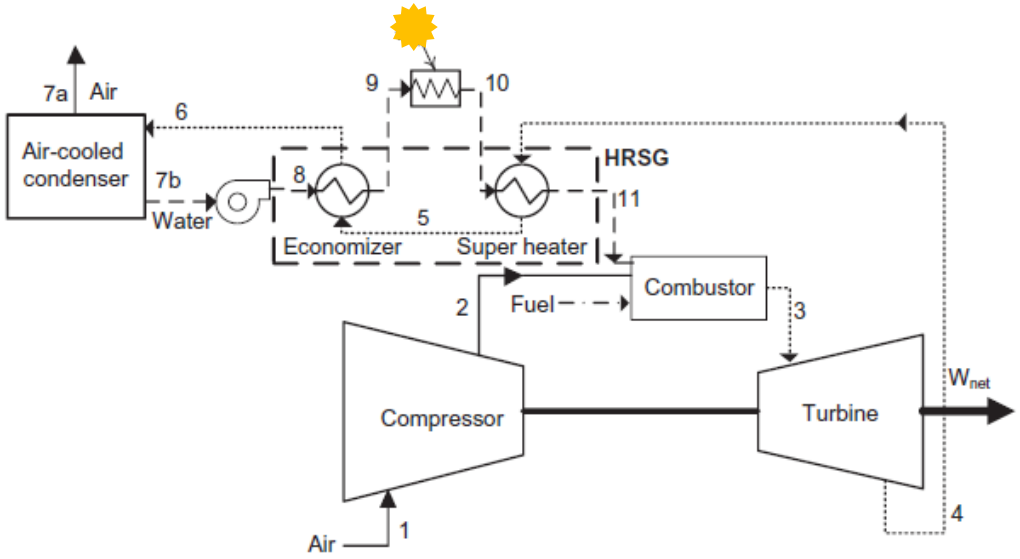


Solar Steam Injected Gas Turbine

Conventional STIG Cycle

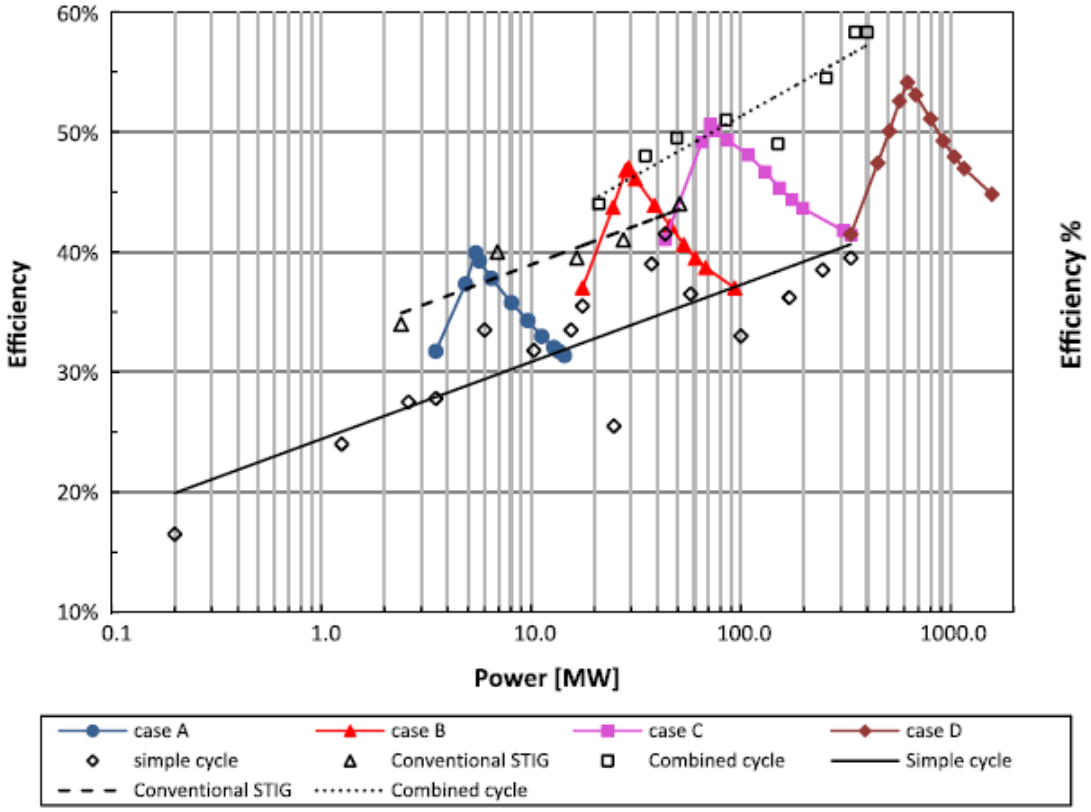


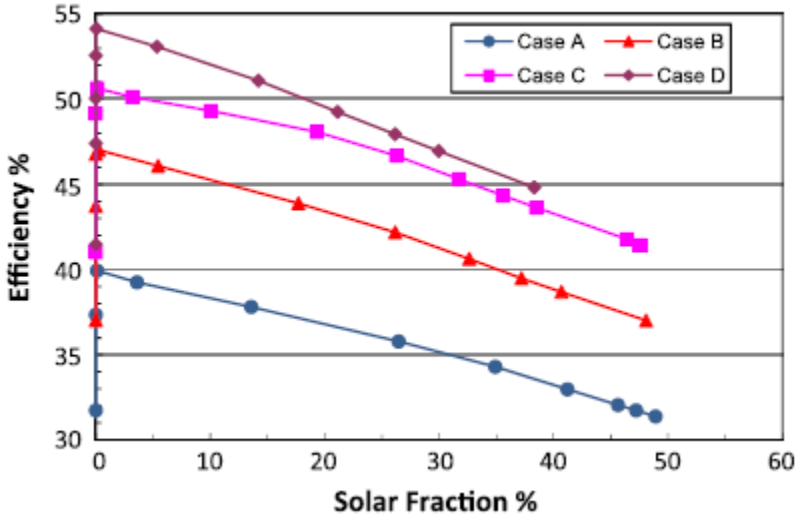
Solar STIG Cycle



Livshits and Kribus 2012

Solar Steam Injected Gas Turbine

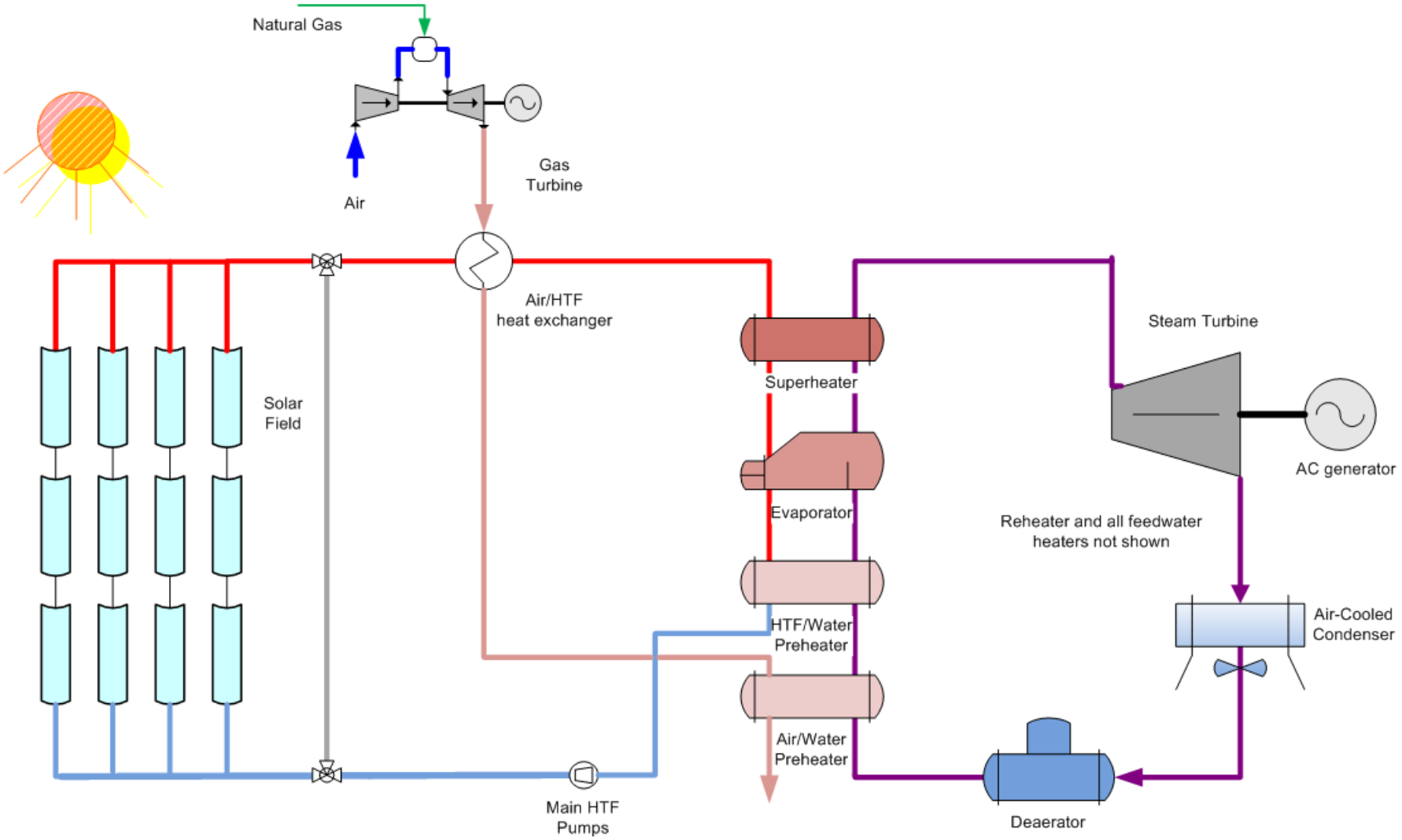




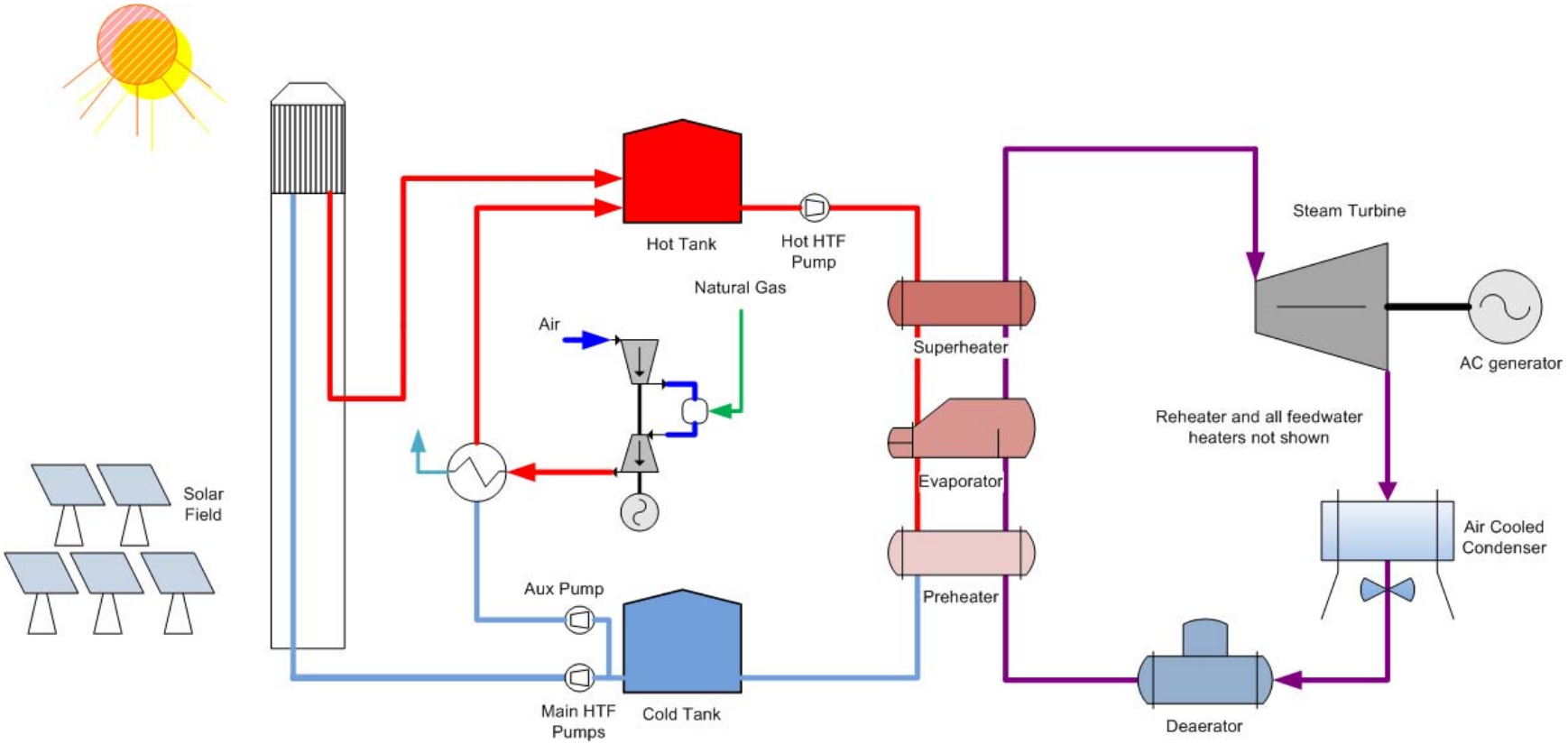
Efficiency benefits occur by using fossil exhaust to heat steam. Adding solar steam boosts power, but not overall efficiency.

Livshits and Kribus 2012

Co-located Gas Turbine / CSP (oil HTF)



Co-located Gas Turbine / CSP (salt HTF)



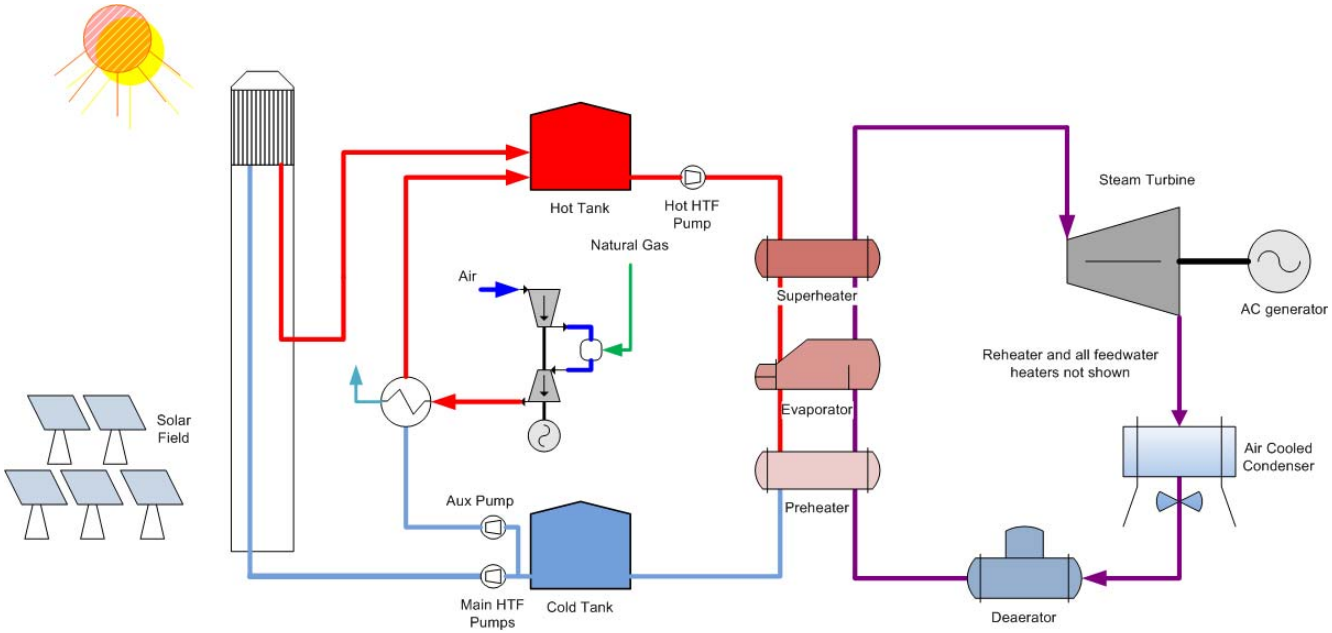
Torresol Energy 20 MW Gemasolar Seville, Spain

The Basic Question:

PV + NGCC

OR

CSP / NG Hybrid



Conclusions

1. Virtually all CSP plants have some gas integration
2. The challenge for CSP/gas hybrids is to integrate the two heat sources such that both reap benefits
   - Benefits must outweigh issues associated with greater system complexity
3. ISCC can save gas and offset gas turbine power degradation during hot weather; however, solar fraction is low.
4. Some novel hybrid configurations promise high efficiency with high solar fraction, but these are yet to be proven.
5. Co-located systems have clear, albeit small, advantages and low risk.
6. Lower CSP system costs are necessary for broad market competitiveness

CSP / Gas Hybrids

Hybrid Type	Benefits	Limitations
Gas back-up	• Low risk, proven technology • >50% solar fraction • Improves dispatchability	• Poor gas heat rate • Little benefit to CSP costs
ISCC	• Low risk, proven technology • Good solar-to-electric efficiency • Reduces CSP cost (shared power block)	• <10% solar fraction • Retrofits limited to plants with duct burners
Solar preheat to Gas Turbine	• >50% solar fraction at design point (at high temperature) • Can run combined cycle power block	• High temps present materials issues
Solar STIG	• Up to 50% solar fraction • Only low-grade CSP collectors required	• Efficiency drops as solar fraction increases • Requires efficient dry-cooling to recover water
Co-located CSP / Gas Turbine	• Low risk, proven technology (oil trough) • Improves CSP efficiency (oil trough) • Improves heat rate of co-located peaker • >50% solar fraction	• LCOE benefits on the order of 5%