Bioenergy Group

Chemical and Environmental Engineering Department

Opportunities of Hybridization of CSP Plants by Biomass Conversion

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Fluidized Bed Conversion of Biomass and Waste

(IEA FBC and IEA Bioenergy Task 33)

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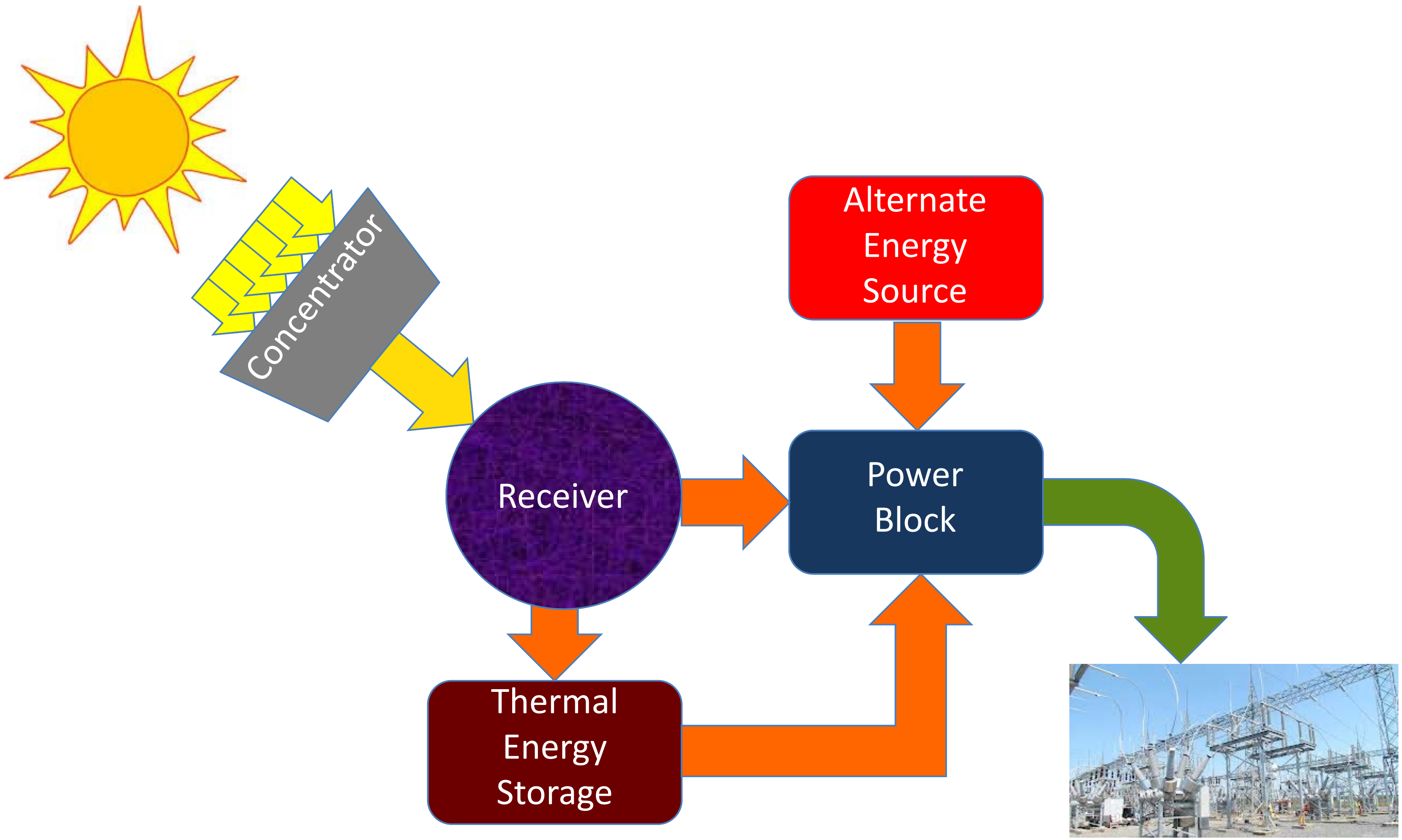
Concentrated Solar Thermal Power (CSP) Plant



CSP Technologies

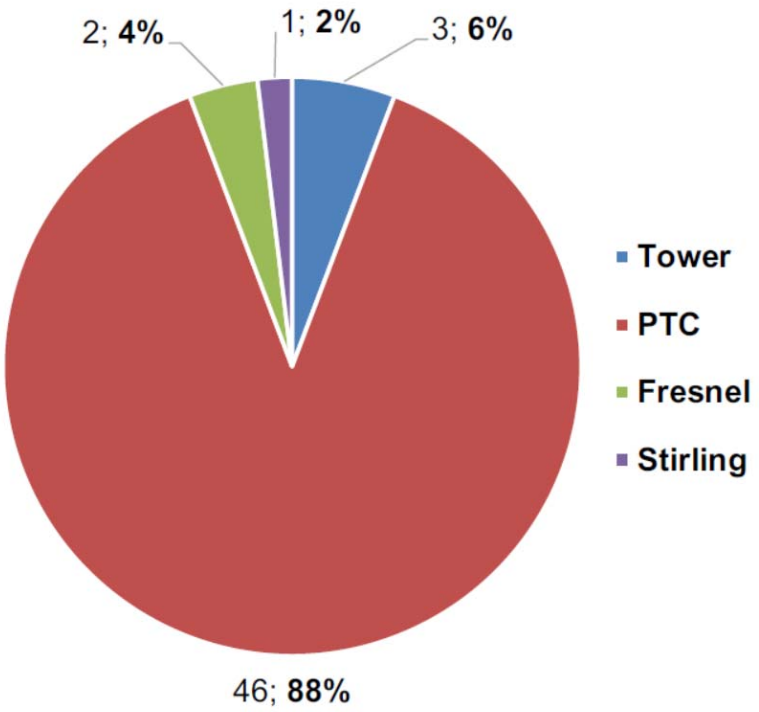
Parabolic Trough
(C ≈ 80, T ≈ 400 ºC)

Parabolic Dish
(C ≈ 2500, T ≈ 800 ºC)

Linear Fresnel Reflector
(C ≈ 50, T ≈ 300 – 500 ºC)

Power Tower
(C ≈ 600, T ≈ 10^2 – 10^3 K)

CSP in Spain



Solar to Power: The potential of CSP

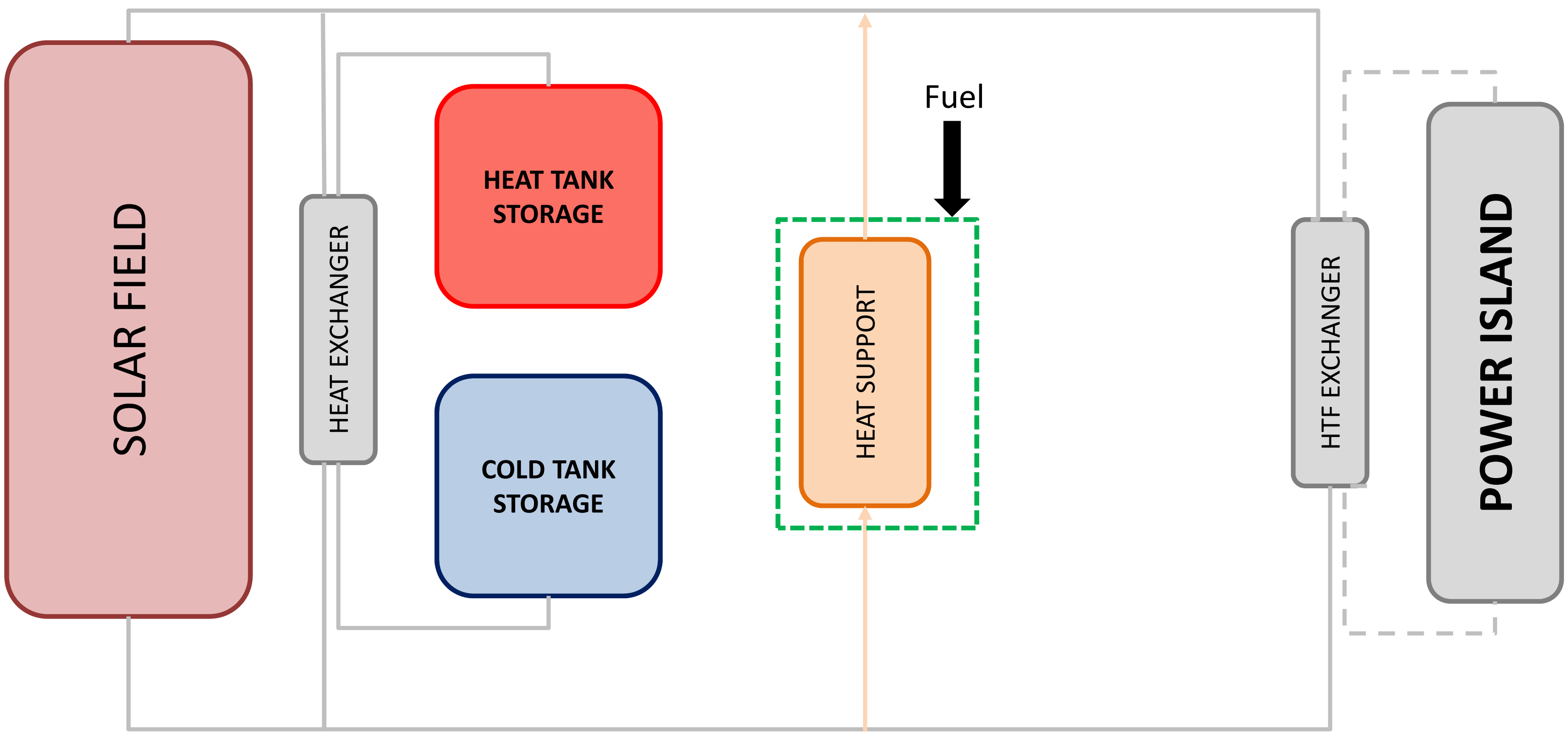
- Solar to power needs to provide **dispatchability**.

  Two options:

  1. **Fuel-based backup** (**hybridization**)
  2. **Thermal Energy Storage** (TES)
- CSP can ideally adapted for both options
- CSP competes with PV with storage (batteries) to guarantee dispatchability

  (PV is cheaper without storage but more expensive with batteries, which should be actually the basis for comparison)

Options of dispatchability



HYBRIDIZATION WITH BIOMASS KEEP THE OVERALL SYSTEM RENEWABLE

2. Concept Solar-Biomass Hybridization

Pros / Cons

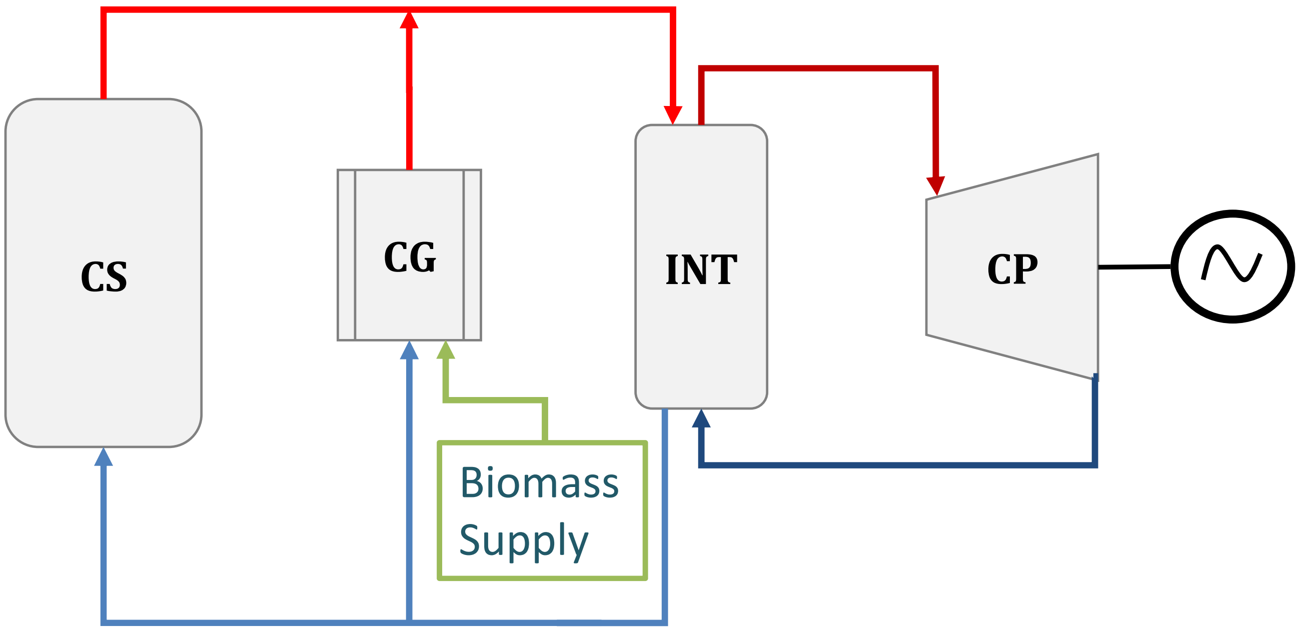
- 100% Renewable Energy Plants
- Full Dispatchability
- Fuel Saving (vs Standalone Biomass Plant)
- Increased Capacity Factor (vs Standalone CSP Plant)
- Distributed power: CSP plants in regions with: (i) moderate DNI (≥1700 kWh/m^2/y) and (ii) moderate biomass resources

- Increased O&M Costs
- Biomass Availability
- Effect of Biomass on Solar Plant (dust, smoke…)

3. Hybridization Strategies

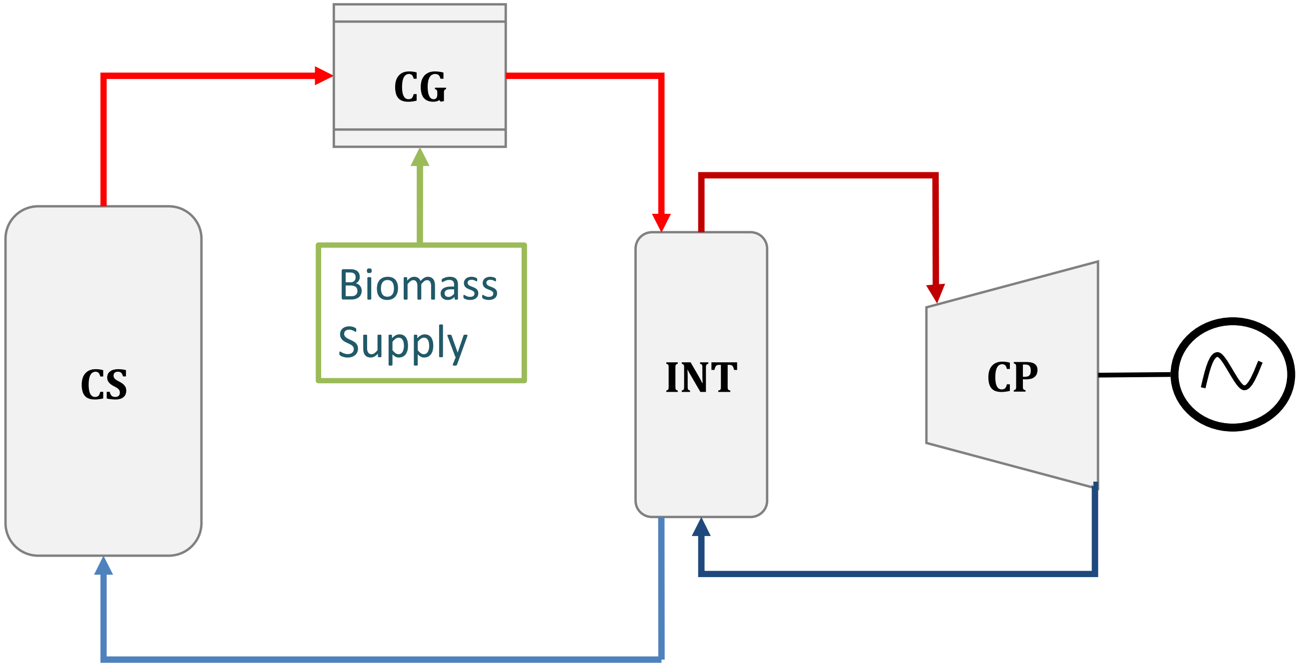
1. Biomass in Parallel with Solar Field
2. Biomass in Series with Solar Field
3. Biomass in Parallel with Solar Steam Generator, Power Block
4. Biomass in Series with Solar Steam Generator, Power Block
5. Combination of the 2 above
6. Hybridization at Solar Receiver (gasification only)
7. Combined Cycle (gasification only)

Biomass Boiler in parallel to Solar Field (C1)



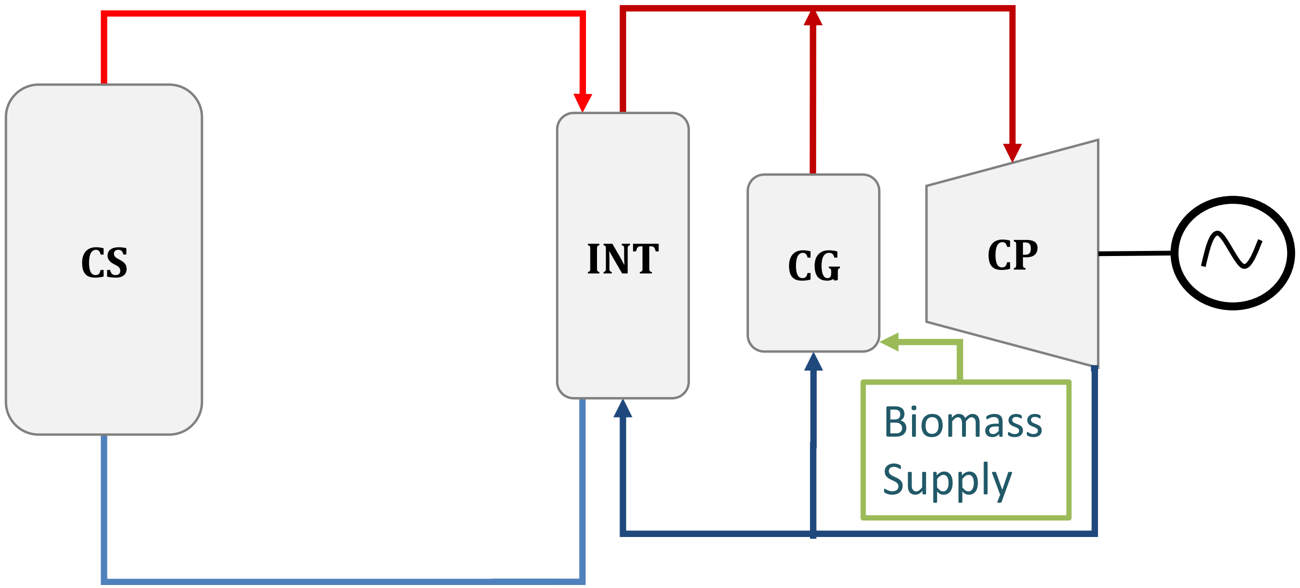
* CS=Solar Field; CG=Biomass Conversor; INT=Heat Exchanger (Steam Generator); CP=Power Block

Biomass Boiler in series to Solar Field (C2)



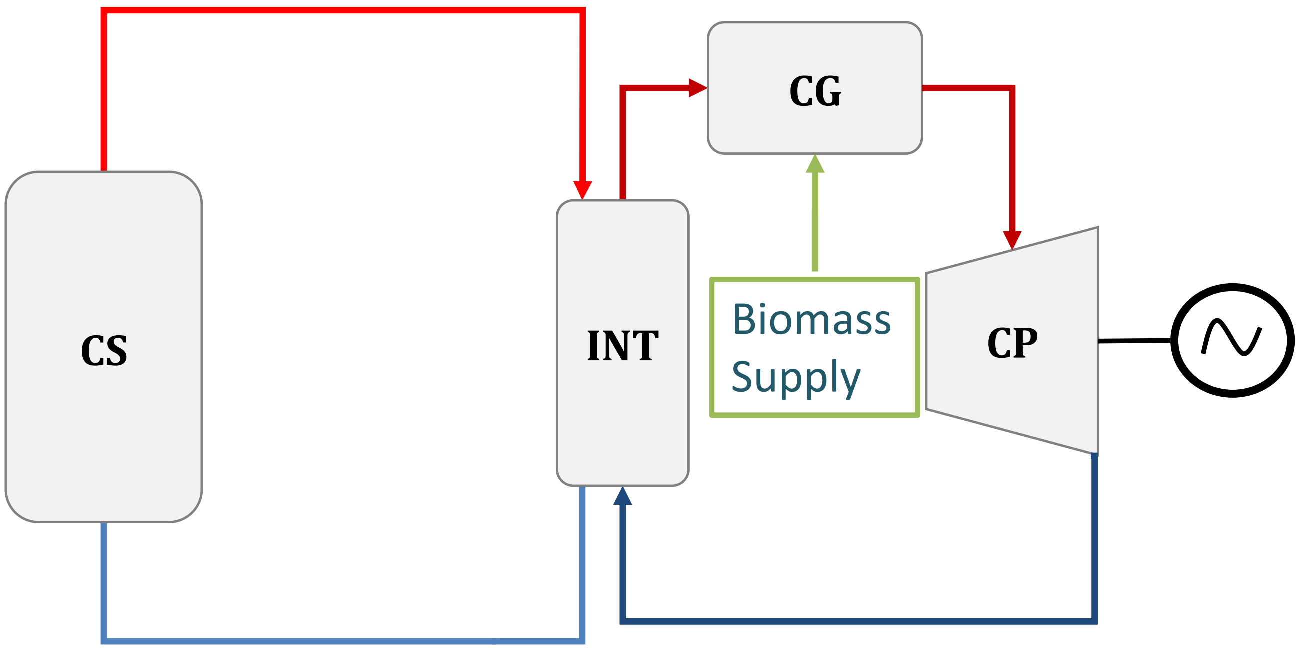
* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator); CP=Power Block

Biomass Boiler in Parallel with Solar Steam Generator (C3)



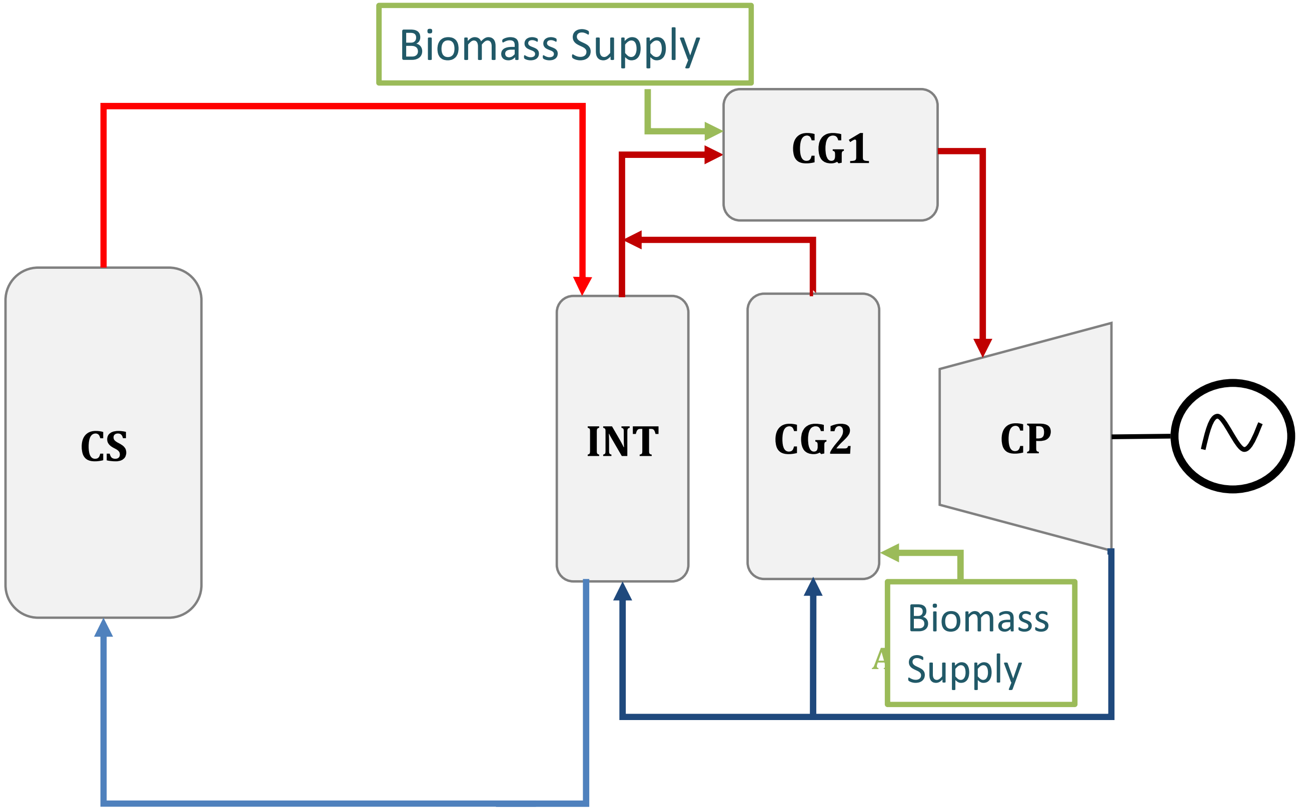
* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator); CP=Power Block

Biomass Boiler in series to Solar Steam Generator (C4)



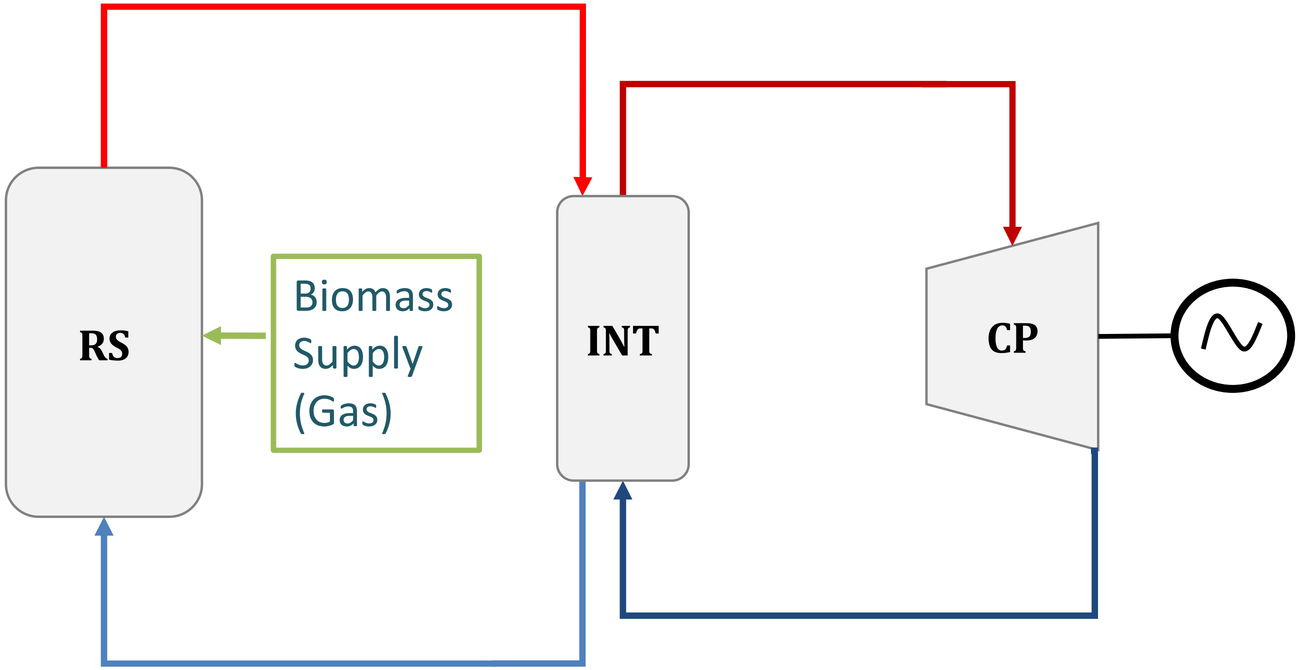
* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator);
CP=Power Block

Biomass Boilers in parallel + series to Solar Steam Generator (C5)



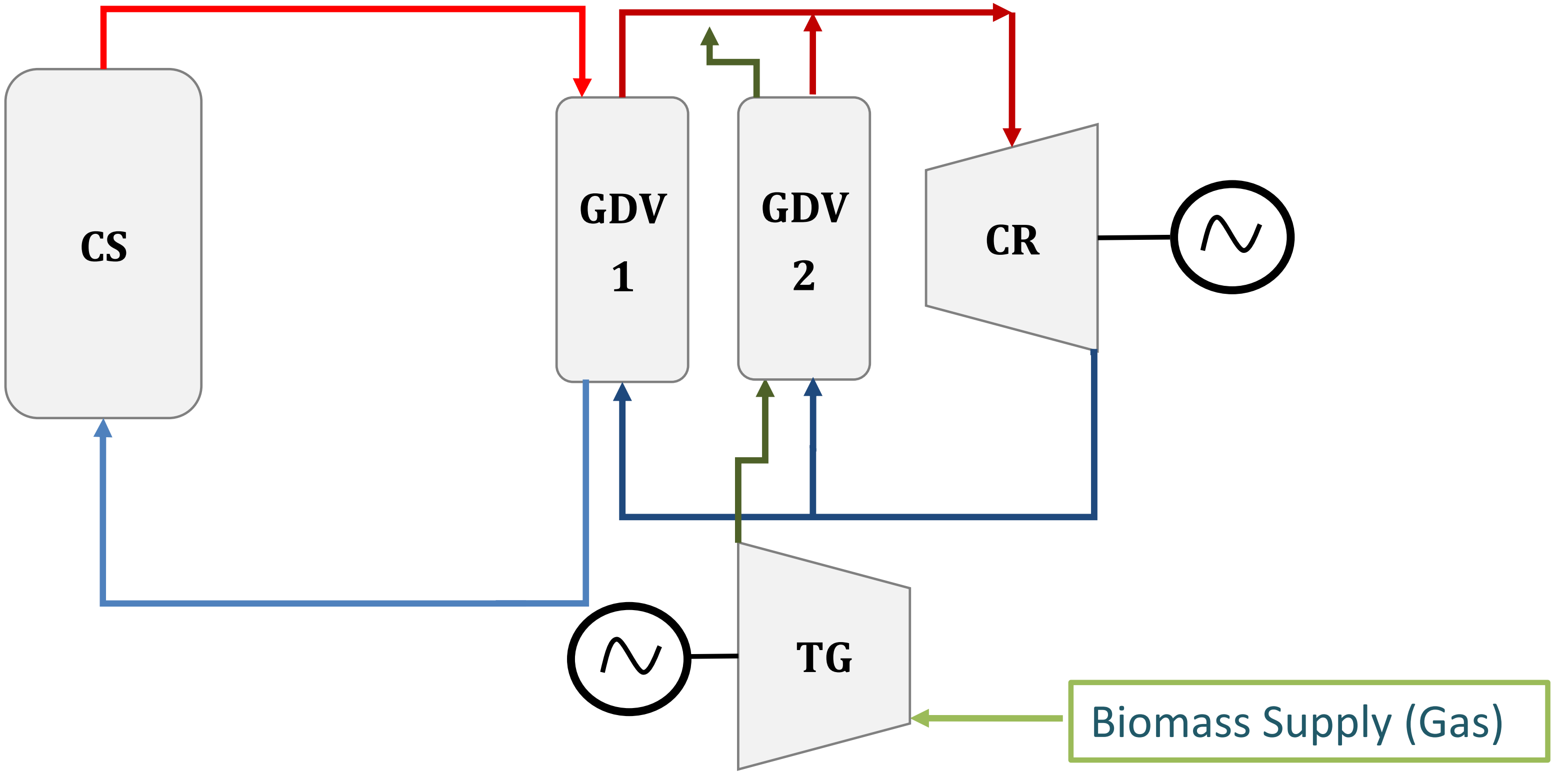
* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator);
CP=Power Block

Hybrid Receiver (C6)



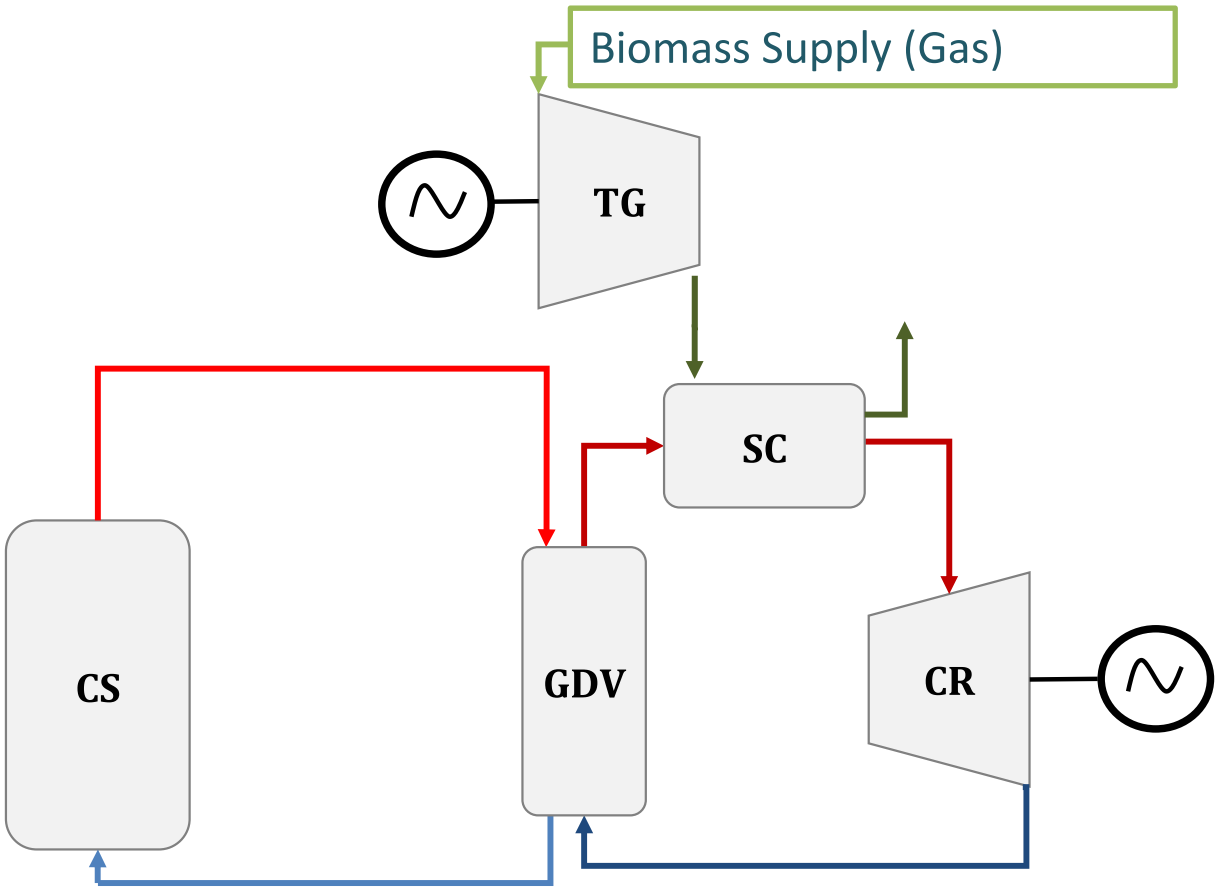
* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator); CP=Power Block

Combined Cycle (a) (C7)



* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator);
CR=Rankine Cycle; TG=Gas Turbine

Combined Cycle (b) (C8)



* CS=Solar Field; CG=Biomass Convertor; INT=Heat Exchanger (Steam Generator); CR=Rankine Cycle; TG=Gas Turbine

Comparison of Configurations

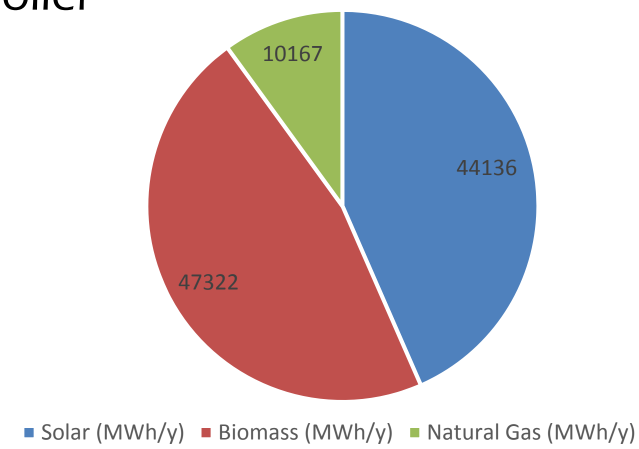
FEATURES	C1	C2	C3	C4	C5	C6	C7	C8
Off-Sun Generation	X	-	X	-	X	X	X	X
Increase Power Block Efficiency	-	X	-	X	X	-/X	-	X
Decouple Solar and Biomass Resources	X	-	X	-	-	X/-	X	-
Easy Integration in Current STE Plants	X	-	X	-	-	X/-	-	-
Increase Biomass to Electric Efficiency	-	-	X	X	X	X/-	X	X
Low Technology Risk	X	X	X	X	X	-	-	-
Stable Solar receiver operation	-	-	-	-	-	X/-	-	-

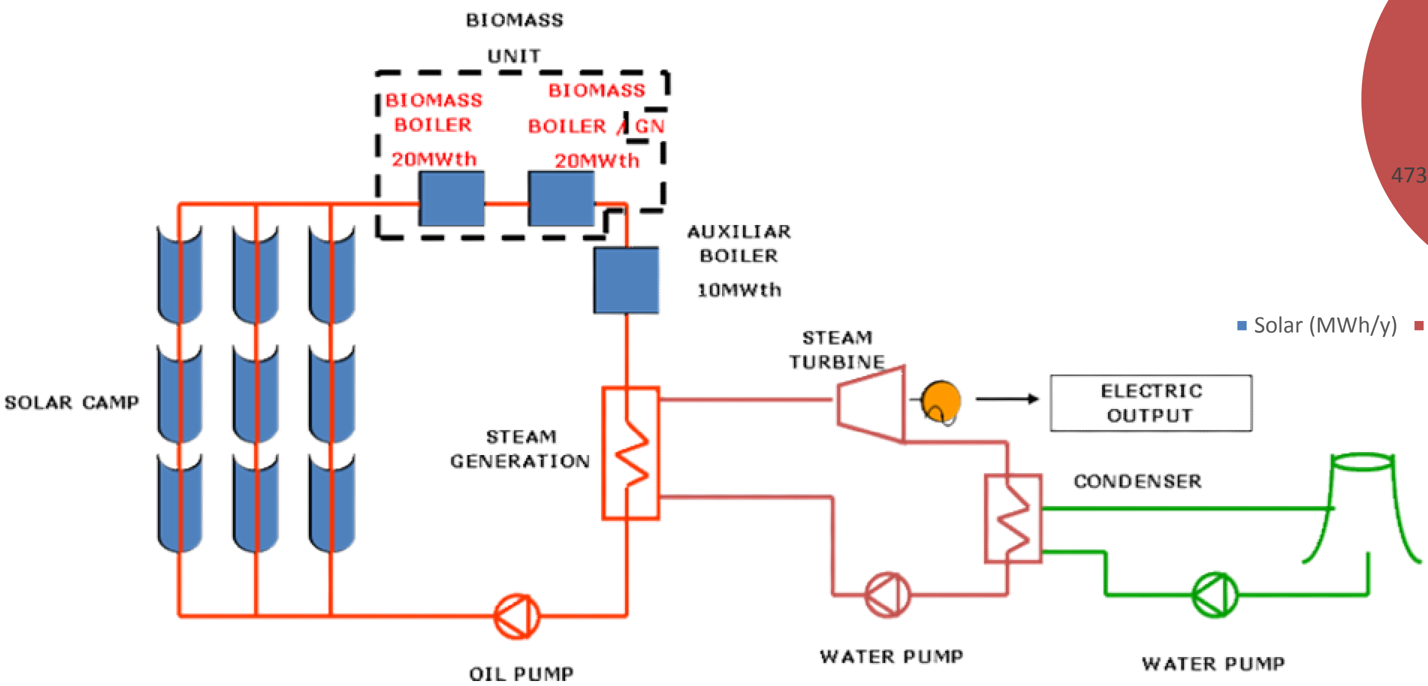
AG5 AG6 AG7

4. Commercial experience

First CSP-Biomass Power Plant: Borges Termosolar, Lleida, Spain

- **Solar field:** 183 120 m^2 aperture area
- **Back-up block:** 20 MWth biomass boiler, 20 MWth dual biomass and natural gas boiler,10 MWth natural gas auxiliary boiler
- **Electric block:** 22,5 MWe steam turbine generator





Folie 18

AG5	Alberto Gomez; 22.10.2017
AG6	Alberto Gomez; 22.10.2017
AG7	Alberto Gomez; 22.10.2017

Borges: Comparison with Standalone CSP and PV

Borges:
22,5 MWe
102 000 MWh/y

→

Standalone CSP:
50 MWe
110 000 MWh/y

	CSP Borges	PV Plant Same Location	Comments	
Energy Production (MWh/year)	98.000	98.000	Comparison criteria: same electrical production	
Installed Power (MW)	22,5	77,94		
Running Hours (per year)	6354	1283	(equivalent hours)	
Required Surface (Ha)	70	130-135		
Efficiency (kWh/MW installed)	4.356	1.257	3,464	Ratio
Investment (M€)	150	117	22,0%	Price diff.
Back Up required	NO	YES	Extra Investmet required	
Dispatchability	YES	NO		
Supports Grid stability	YES	NO		

Borges: some data

- ✓ Energy production with very low or no solar radiation
- ✓ Designed to achieve 50% turbine's workload at nights, avoiding sharply efficiency decreases. Turbine efficiency 37% at full load
- ✓ Biomass consumption: 66 000 t/y (45% moisture)
- ✓ DNI: 1800 kWh/m^2/y
- ✓ 6500 h/y operation → CP: 0,74
- ✓ Cost: 153 M€

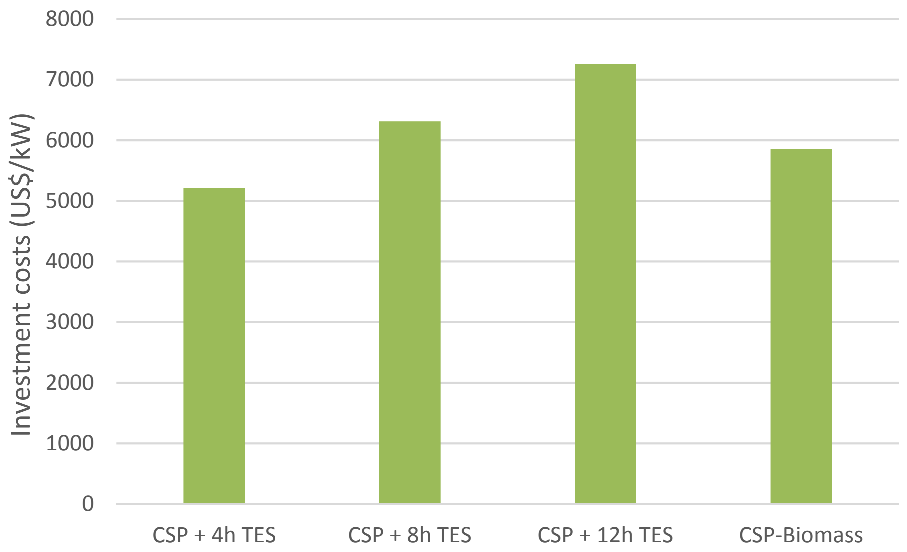
5. CSP-biomass hybridization vs Standalone CSP plants

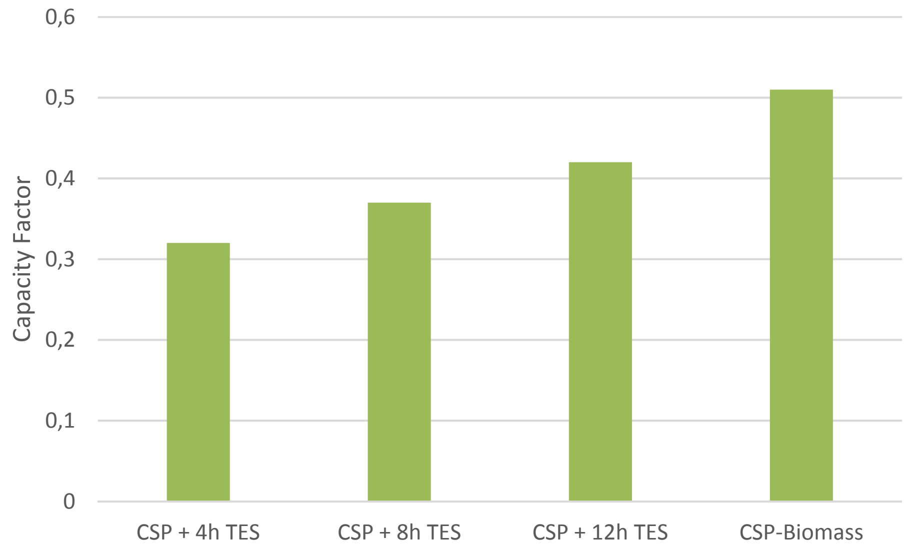
- **Lower investment cost (CAPEX):**

  Biomass Standalone$_{CAPEX}$ < **CSP-Biomass$_{CAPEX}$** < CSP Standalone $_{CAPEX}$

- **Higher capacity factor (CF)**

  CSP Standalone $_{CF}$ < **CSP-Biomass$_{CF}$** < Biomass Standalone$_{CF}$



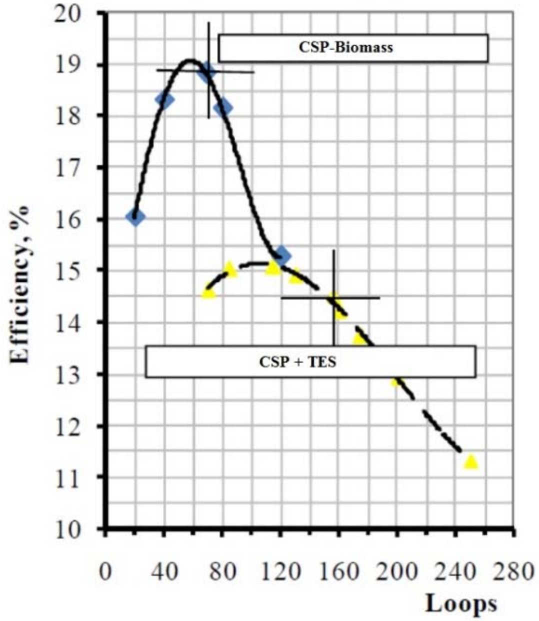


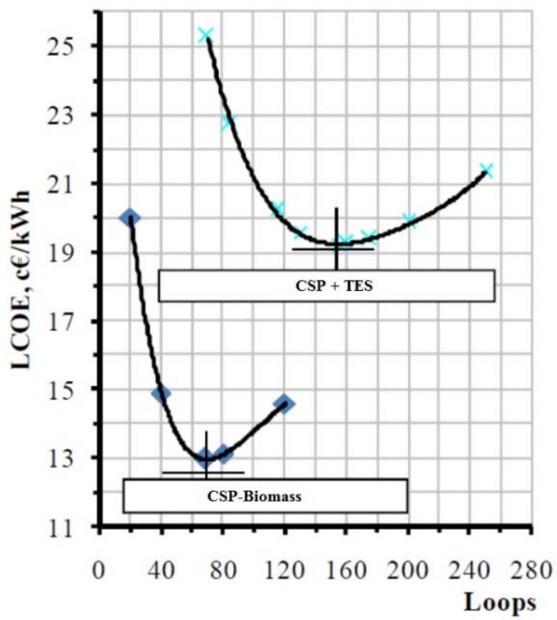
CSP-biomass hybridization vs Standalone CSP plants

- Higher dispatchability
- Lower solar multiple (less solar field's area required)
- Higher power generation
- Lower LCOE
- Higher thermodynamic efficiency due to continuous turbine operation at higher loads

CSP+TES & CSP-Biomass modelling

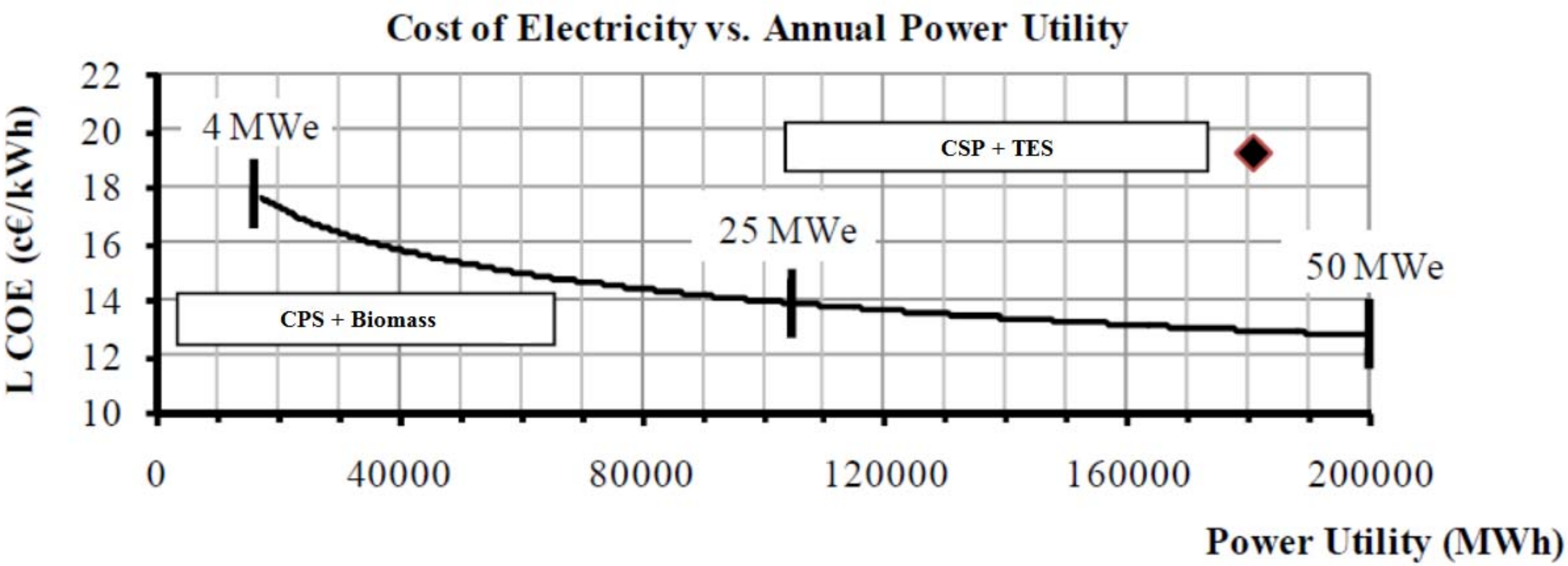
180 GWh Power Generation





CSP-biomass hybridization vs Standalone CSP plants

✓Capital requirements profitable even in small and medium sized plants (if compared with CSP standalone)



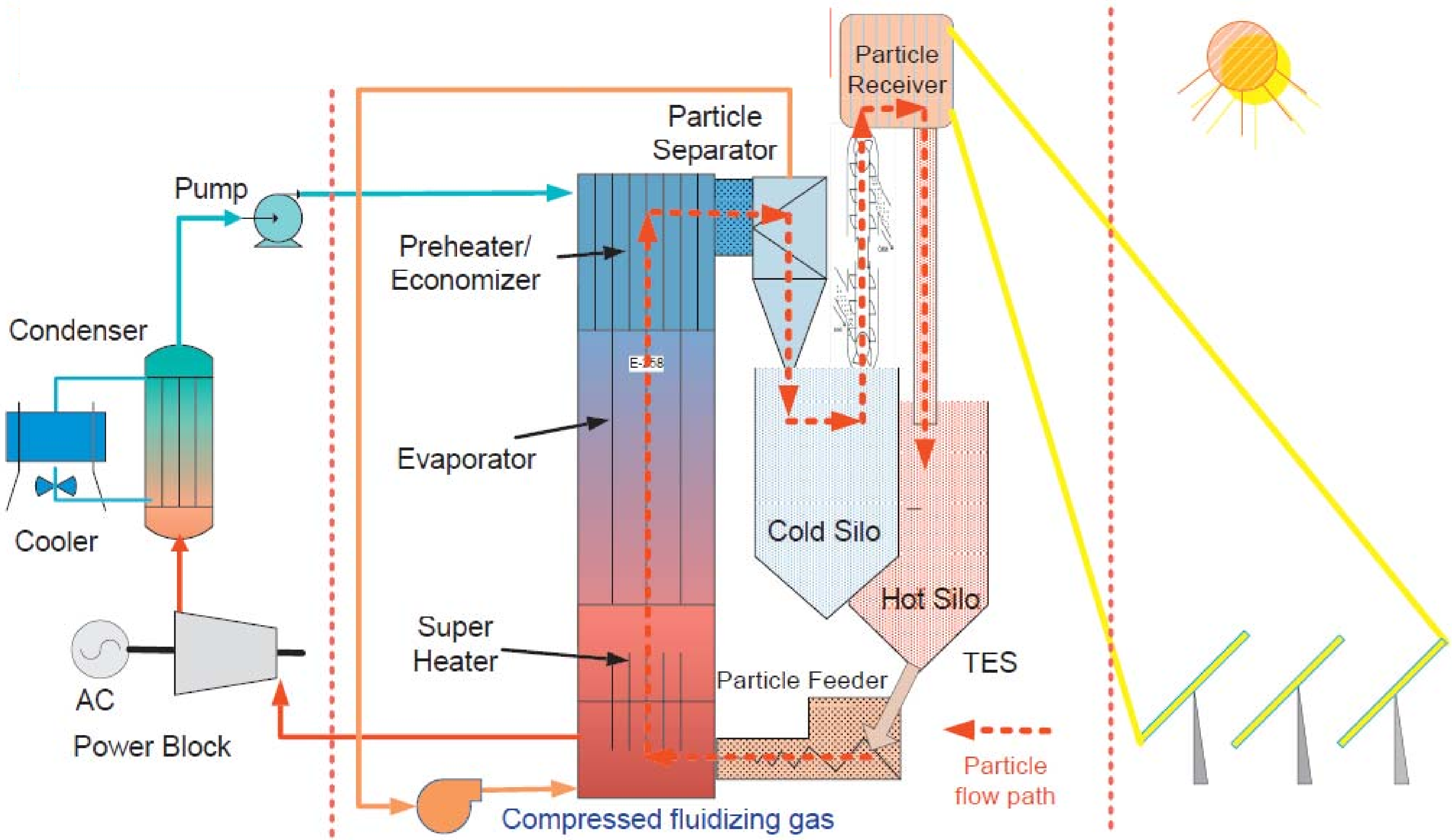
Gasification (vs Combustion)

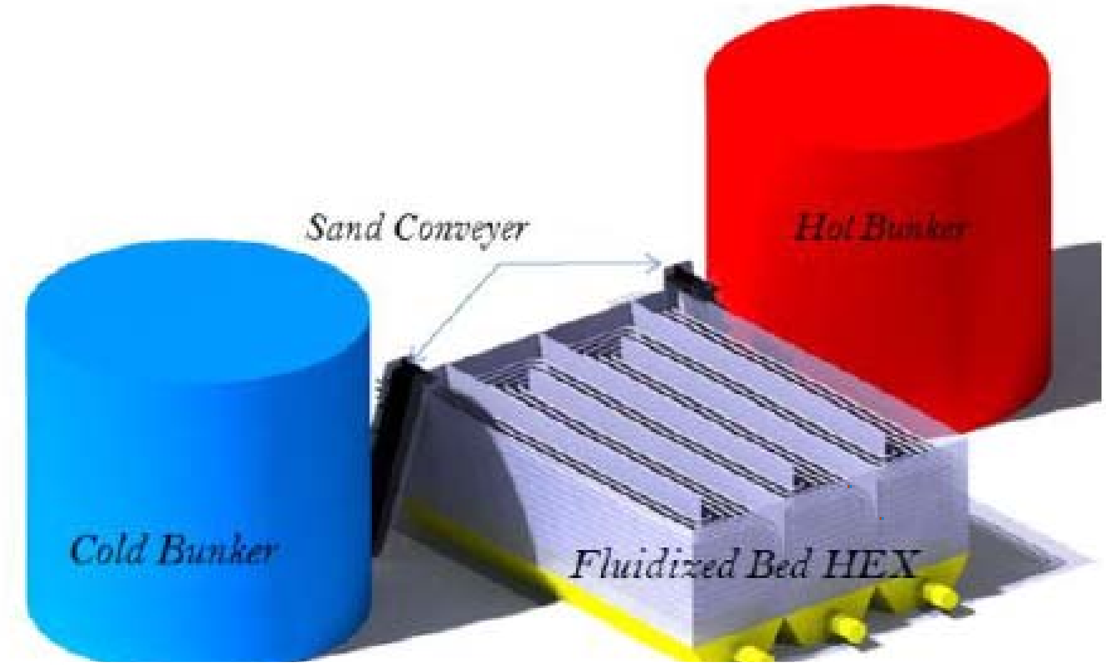
- Enables high-efficient hybridization (hybrid receiver, CC)
- More flexibility in “ready-to-hybridized” applications:
  - ✓ Easier performance during transients
  - ✓ Syngas storage
  - ✓ More efficient and controlled burning
- Enables syngas cleaning (waste feedstocks)

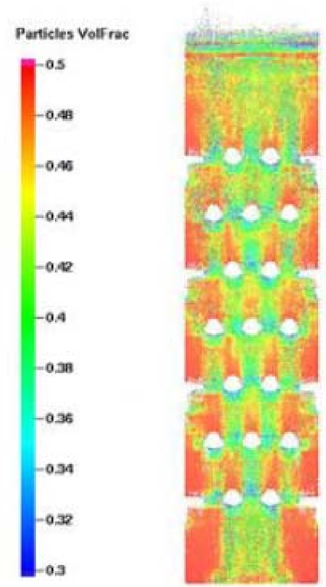
7. Potential of FB technology in hybridization

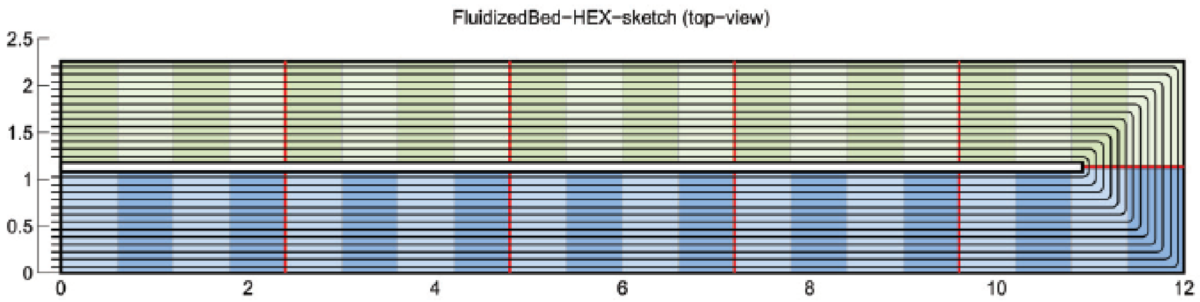
- FB convertor (boliler and gasifier) (FBC)
- FB heat exchangers (FBEx)
- FB Thermal Energy Storage (FB-TES)
- Combinations

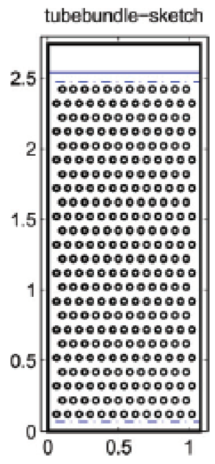
FBEx: Solid Particle Receiver-based CSP system (NREL)



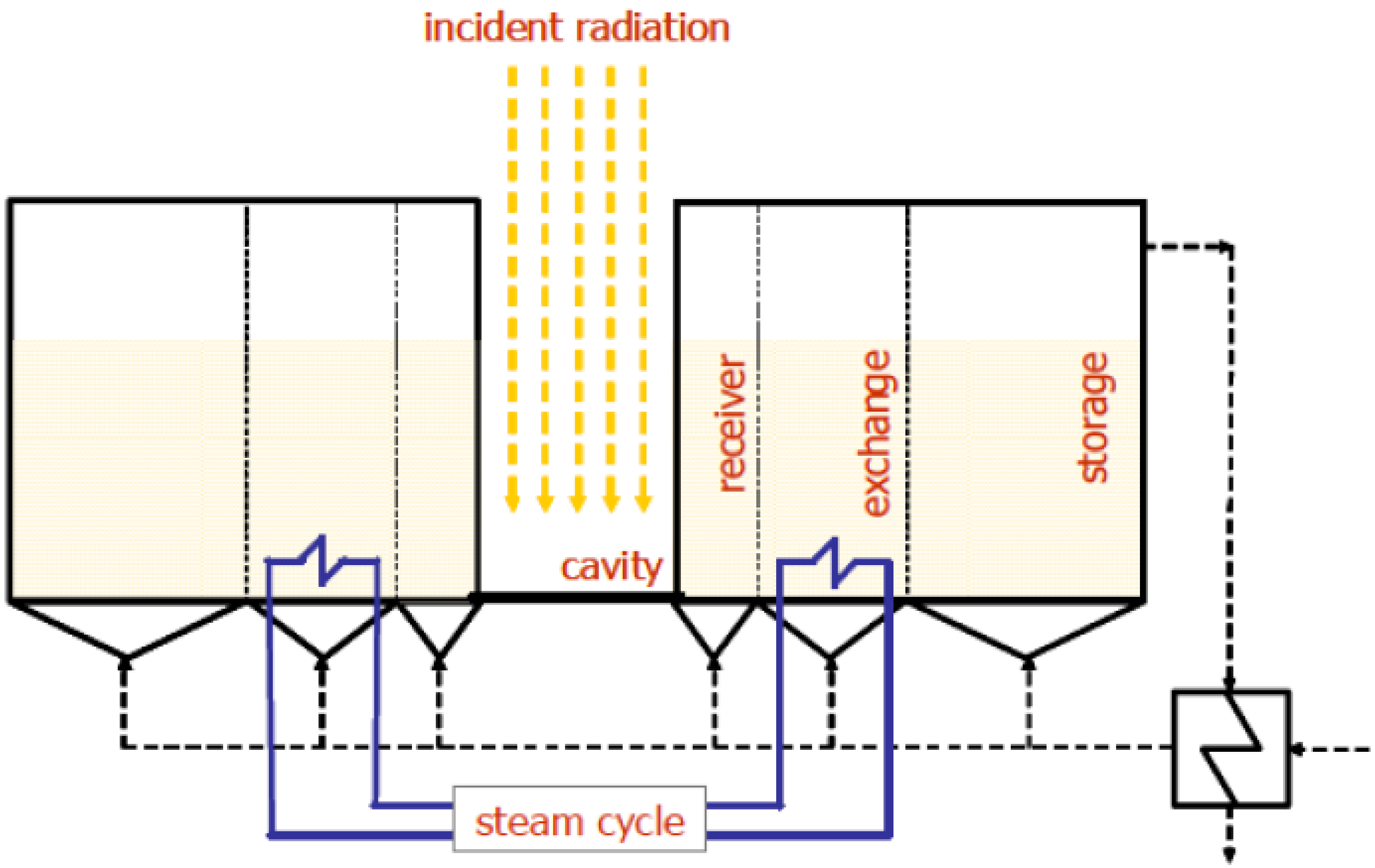

Sand Conveyer
Hot Bunker
Cold Bunker
Fluidized Bed HEX


Particles VolFrac
0.5
0.48
0.46
0.44
0.42
0.4
0.38
0.36
0.34
0.32
0.3


FluidizedBed-HEX-sketch (top-view)
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12


tubebundle-sketch
2.5
2
1.5
1
0.5
0
0
0.5
1

Compartmented Fluid Bed Receiver (IRC, 2013)



Conclusions

1. Solar-biomass hybridization is a promising concept (only one plant at commercial scale)
2. Storage or backup fuel is necessary to garantee dispatchability. CSP-biomass hybrid is more competitive tan PV with batteries
3. Different alternatives of CSP hybridization with biomass, both based on combustion and gasification of biomass
4. Integration in current parabolic trough technology is straightforward and seems to be feasible
5. Challenges for advanced, more efficient concepts remain huge. Development of gasification seems to play a key role
6. Advanced design in development for both TES and hybrid integration

Thank you

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