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Acronyms

Acronym	Definition
CCGT	Combine Cycle Gas Turbine
CSP	Concentrated Solar Power
GT	Gas Turbine
OCGT	Open Cycle Gas Turbine
ST	Steam Turbine
TES	Thermal Energy Storage

1 DOCUMENT HISTORY

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2 REFERENCE SCENARIO: AVAILABLE COMMERCIAL SOLUTIONS

The object of this chapter is to compare the use of HYSOL with different commercial solutions for the solar field, in order to illustrate the advantages and issues of each one.

The main commercial solutions for the solar field are Parabolic Trough configuration using thermal oil as HTF and molten salt as TES fluid, and Tower configuration using molten salts both as HTF and TES fluid. Therefore, the possible commercial solutions are going to be divided in HYSOL Parabolic Trough solution and HYSOL Tower solution.

This chapter describes the main characteristics of each solution and the results obtained simulating their operation with the Matlab code developed by IDie, and finally they are going to be compared.

2.1 HYSOL Power Plant using a Solar Tower with Molten Salts

2.1.1 Description

The power block is composed by a steam turbine of 100 MW, a gas turbine of 80 MW, Hysol's Heat Recovery System (Exhaust gas / Molten salt) and Low Temperature Energy Recovery and Storage system. With this configuration, the Heat Recovery System produces enough hot molten salt to operate the steam turbine at minimum operation level when the gas turbine operates at nominal power.

2.1.2 Main Specifications

The main parameters of this configuration are shown in Table 1.

Table 1. HYSOL Tower Main Parameters

	CSP Tower
Steam Turbine Power (MW)	100
Gas Turbine Power (MW)	80
Power Plant Capacity (MW)	180
Solar Multiple	2.5
Storage capacity (hours)	14
Location	Southern Europe
Annual Receiver Energy (MWh_{th})	**1.110.200**[1]

[1] The annual receiver energy has been obtained with NREL's System Advisor Model.

2.1.3 Lay-out & drawings

HYSOL configuration using Tower is shown in Figure 1.

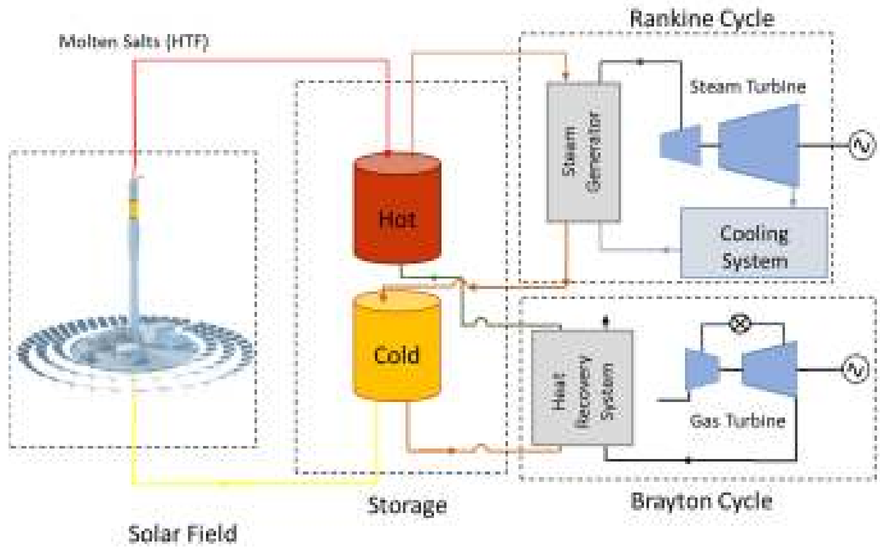

Figure 1. HYSOL Tower Configuration

2.1.4 Estimated Production and main results

With the main parameters shown in Table 1, a year operation has been simulated with the model developed by IDie using Matlab code. The results obtained are shown in Table 2

Table 2. HYSOL Tower Annual Results

	HYSOL Tower
Peak power	not limited[2]
Dispatchability[3]	48.5%
Solar fraction	31.3%
Annual Gross Energy Output (MWhe)	1.346.927

2.2 HYSOL Power Plant using a Parabolic Trough with Thermal Oil

2.2.1 Description

The power block is composed by a steam turbine of 100 MW, a gas turbine of 80 MW, Hysol's Heat Recovery System (Exhaust gas / Molten salt) and Low Temperature Energy Recovery and

[2] In order to provide firmness, HYSOL will typically have a nominal peak power lower than the addition of the turbines' individual powers (e.g., 100 + 80 MW will provide a firm power of 130-150 MW). For this simulation, however, the peak power is not limited to provide firmness.

[3] As explained in several publications, the figure used to compare dispatchability between different configurations is the efficiency (thermal to electricity) in the use of fuel.

Storage system. With this configuration, the Heat Recovery System produces enough hot molten salt to operate the steam turbine at minimum operation level when the gas turbine operates at nominal power.

2.2.2 Main Specifications

The main parameters of this configuration are shown in Table 3.

Table 3. HYSOL Parabolic Trough Main Parameters

	CSP Parabolic Trough
Steam Turbine Power (MW)	100
Gas Turbine Power (MW)	80
Power Plant Capacity (MW)	180
Solar Multiple	2.5
Storage capacity (hours)	14
Location	Southern Europe
Annual Receiver Energy (MWh_{th})	**887.050** [1]

2.2.3 Lay-out & drawings

HYSOL configuration using Parabolic trough is shown in Figure 2.

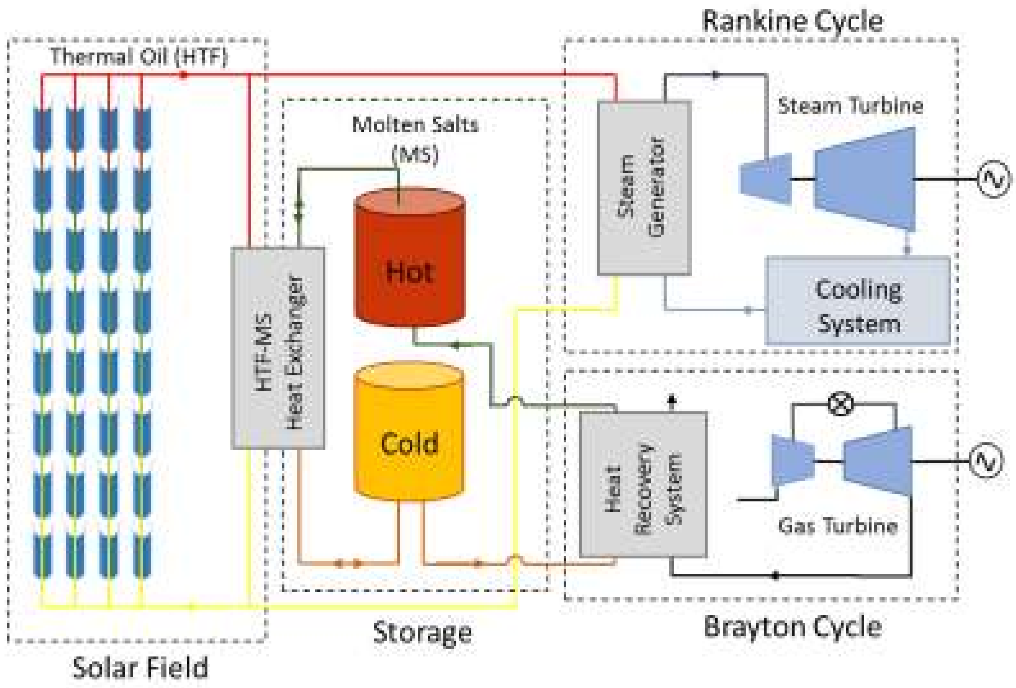

Figure 2. HYSOL Parabolic Trough Configuration

2.2.4 Estimated Production and main results

With the main parameters showed in Table 3, a year operation has been simulated with Matlab code developed by IDie. The results obtained are showed in Table 4.

Table 4. HYSOL Parabolic Trough Annual Results

	HYSOL Tower
Peak power	not limited
Dispatchability	45.3%
Solar fraction	28.8%
Annual Gross Energy Output (MWhe)	1.144.000

2.3 Results Comparison

The Tower solar field provides more energy throughout the year, with a higher Solar fraction and Dispatchability. However, these results are not caused by HYSOL but are instead a result of the intrinsic differences between both technologies:

- The definition of a Tower's solar multiple is strongly influenced by the location, and it usually results in a larger reflective area than for Parabolic Trough. As a consequence, for the same "peak" solar multiple, the average power reaching the receivers is higher in a tower than in a parabolic collector, causing a larger energy output and solar fraction.

- The peak temperature using Thermal Oil as HTF is below 400 ºC, while molten salts reach over 560 ºC. This makes the tower's Rankine cycle more efficient, therefore increasing the overall performance in the use of fuel that leads to a higher Dispatchability.

As far as HYSOL is concerned, both types of solar field can be used in a hybrid plant, and the choice will depend on additional techno-economic factors.

3 CSP POWER PLANTS RETROFITTING

The object of this chapter is to make a technical compatibility study with existing CSP facilities; a technical, legal and market study must be developed to identify a list of possible existing facilities where integration might be feasible. This task will help to adapt the developed technology not only for new projects but for existing ones, so that the economic benefits and impact of the project are boosted.

The retrofitting approach used for the comparison consists in calculating the amount of annual electric energy that can be produced with the solar field, then an extra fuel energy given by a combustion chamber is considered. The retrofitting configuration adds a gas turbine and HYSOL's heat recovery systems, dimensioned so that the annual fuel consumed is the same as in the combustion chamber; as HYSOL has a better fuel to electricity performance, the extra annual electric energy produced with fuel is higher but the fuel consumption is the same.

3.1 PARABOLIC TROUGH POWER PLANTS USING THERMAL OIL AS HTF

3.1.1 General Description of Parabolic Trough Power Plants

The main parameters of the CSP Parabolic Trough are shown in Table 5.

Table 5. CSP Parabolic Trough Power Plant main specifications

	CSP Parabolic Trough
Steam Turbine Power (MW)	50
Solar Multiple	2.1
Storage Hours	14
Location	Southern Europe
Annual Receiver Energy (MWh_{th})	**529.200**

3.1.2 Elements to be added/modified/replaced

+ Gas turbine (added)

Table 6 shows the gas turbine size that would consume the same amount of fuel as the non-retrofitted solution for various fuel energy percentages.

Table 6. Gas turbine power / Fuel energy percentage for Parabolic Trough

Existing solution fuel energy percentage	Annual Fuel consumption [tons]	Retrofitting solution gas turbine power [MW]
12%	4180	2.35

Existing solution fuel energy percentage	Annual Fuel consumption [tons]	Retrofitting solution gas turbine power [MW]
20%	6950	3.92
30%	10400	5.88
40%	13800	7.83

+ Exhaust Gas / Molten Salt Heat Recovery System (added)

The core of HYSOL, a heat recovery system transfers exhaust gas energy to the molten salt used as TES fluid.

+ Low Temperature Energy Recovery and Storage (added)

The Low Temperature Energy Storage recovers the thermal energy contained in the exhaust gas between the outlet temperature of the molten salt Heat Recovery System and a temperature suitable for stack release (100-150 ºC). This system can substitute the low pressure preheaters in the Rankine cycle, so the heat required in the steam generator system is lower for the same electricity output.

+ Gas-fueled HTF heaters (removed)

Gas-fueled heaters are used in CSP plants for maintenance purposes (anti-freeze) and to increase production.

3.1.3 Estimated costs

This module shows the investment and operation & maintenance costs in each configuration tested to compare the effect of the retrofitting in the costs.

- Existing (no retrofitting) solutions in Parabolic Trough:
    - 12% Energy from fuel:

Table 7. CSP Parabolic Trough Power Plant CAPEX (12% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	Combustion Chamber	0.3 M$
			ST	17.1 M$
			Air-Cooled Condenser	6.0 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	17.5 M$
			Contingencies (7 % Solar)	19.8 M$

	Indirect Cost	EPC and Owner Cost (10% Direct Cost)	30.2 M$
	Total Cost		**332.4 M$**

Table 8. CSP Parabolic Trough Power Plant OPEX (12% Energy from Fuel)

OPEX	Water consumption	$ 367,290
	Insurance	$ 332,366
	Spare parts	$ 2,137,681
	Land rental	$ 68,535
	Staff	$ 2,469,911
	Municipal tax	$ 166,183
	Total Cost	**$ 5,541,966**

- 20% Energy from fuel:

Table 9. CSP Parabolic Trough Power Plant CAPEX (20% Energy from Fuel)

CAPEX	Direct Cost	Power Block	Combustion Chamber	0.5 M$
			ST	17.1 M$
			Air-Cooled Condenser	6.4 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	17.5 M$
			Contingencies (7 % Solar)	19.8 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		30.3 M$
	Total Cost			**333.2 M$**

Table 10. CSP Parabolic Trough Power Plant OPEX (20% Energy from Fuel)

OPEX	Water consumption	$ 367,290
	Insurance	$ 333,151
	Spare parts	$ 2,169,757
	Land rental	$ 68,535
	Staff	$ 2,469,911
	Municipal tax	$ 166,576
	Total Cost	**$ 5,575,219**

- 30% Energy from fuel:

Table 11. CSP Parabolic Trough Power Plant CAPEX (30% Energy from Fuel)

CAPEX	Direct Cost	Power Block	Combustion Chamber	0.8 M$
			ST	17.1 M$
			Air-Cooled Condenser	7.0 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	17.5 M$
			Contingencies (7 % Solar)	19.9 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		30.4 M$
	Total Cost			**334.1 M$**

Table 12. CSP Parabolic Trough Power Plant OPEX (30% Energy from Fuel)

OPEX	Water consumption	$ 367,290
	Insurance	$ 334,133
	Spare parts	$ 2,174,666
	Land rental	$ 68,535
	Staff	$ 2,469,911
	Municipal tax	$ 167,067
	Total Cost	**$ 5,581,601**

- 40% Energy from fuel:

Table 13. CSP Parabolic Trough Power Plant CAPEX (40% Energy from Fuel)

CAPEX	Direct Cost	Power Block	Combustion Chamber	1.1 M$
			ST	17.1 M$
			Air-Cooled Condenser	7.6 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	17.5 M$
			Contingencies (7 % Solar)	19.9 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		30.5 M$
	Total Cost			**335.1 M$**

Table 14. CSP Parabolic Trough Power Plant CAPEX (40% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 335,115
	Spare parts	$ 2,179,576
	Land rental	$ 10
	Staff	$ 2,469,911
	Municipal tax	$ 167,558
	Total Cost	**$ 5,519,459**

The overall costs for existing solutions are summarized in Table 15. The price of fuel considered is 8 US$/MMBtu.

Table 15. CSP Parabolic Trough Power Plant Costs, summary

	12%	20%	30%	40%
Investment	332.4 M$	333.2 M$	334.1 M$	335.1 M$
O&M	5.5 M$	5.6 M$	5.6 M$	5.5 M$
Fuel Costs	0.8 M$	1.3 M$	1.9 M$	2.6 M$

- Retrofitting solutions:
    - 12% Energy from fuel:

Table 16. Retrofitted CSP Parabolic Trough Power Plant CAPEX (12% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	GT	1.3 M$
			Combustion Chamber	0.3 M$
			ST	17.1 M$
			Air-Cooled Condenser	6.3 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
			Pumps and HRSG HYSOL	1.0 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	18.5 M$
			Contingencies (7 % Solar)	20.0 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		30.6 M$
	Total Cost			**336.6 M$**

Table 17. Retrofitted CSP Parabolic Trough Power Plant OPEX (12% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290

	Insurance	$ 336,629
	Spare parts	$ 2,187,147
	Land rental	$ 68,535
	Staff	$ 2,469,911
	Municipal tax	$ 168,315
	Total Cost	**$ 5,597,826**

- 20% Energy from fuel:

Table 18. Retrofitted CSP Parabolic Trough Power Plant CAPEX (20% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	GT	1.8 M$
			Combustion Chamber	0.5 M$
			ST	17.1 M$
			Air-Cooled Condenser	6.9 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
			Pumps and HRSG HYSOL	1.5 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	18.9 M$
			Contingencies (7 % Solar)	20.2 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		30.8 M$
	Total Cost			**339.3 M$**

Table 19. Retrofitted CSP Parabolic Trough Power Plant OPEX (20% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 339,298
	Spare parts	$ 2,200,489
	Land rental	$ 68,535
	Staff	$ 2,469,911
	Municipal tax	$ 169,649
	Total Cost	**$ 5,615,171**

- 30% Energy from fuel:

Table 20. Retrofitted CSP Parabolic Trough Power Plant CAPEX (30% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	GT	2.8 M$
			Combustion Chamber	0.8 M$

			ST	17.1 M$
			Air-Cooled Condenser	7.7 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
			Pumps and HRSG HYSOL	2.3 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	19.7 M$
			Contingencies (7 % Solar)	20.4 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		31.2 M$
	Total Cost			**343.4 M$**

Table 21. Retrofitted CSP Parabolic Trough Power Plant OPEX (30% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 343,428
	Spare parts	$ 2,221,140
	Land rental	$ 68,535
	Staff	$ 2,469,911
	Municipal tax	$ 171,714
	Total Cost	**$ 5,642,017**

- 40% Energy from fuel:

Table 22. Retrofitted CSP Parabolic Trough Power Plant CAPEX (40% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	GT	3.7 M$
			Combustion Chamber	1.1 M$
			ST	17.1 M$
			Air-Cooled Condenser	8.4 M$
			Pumps and heat exchanger (Rankine)	4.4 M$
			Pumps and HRSG HYSOL	3.0 M$
		Solar	Receiver system	30.8 M$
			Thermal energy storage	105.5 M$
			Solar collector field + site improvement	100.8 M$
		Others	Balance of Plant	20.4 M$
			Contingencies (7 % Solar)	20.7 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		31.6 M$
	Total Cost			**347.4 M$**

Table 23. Retrofitted CSP Parabolic Trough Power Plant OPEX (40% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 347,408
	Spare parts	$ 2,241,041
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 173,704
	Total Cost	**$ 5,690,734**

The overall costs for retrofitted solutions are summarized in Table 24. The price of fuel considered is 8 US$/MMBtu.

Table 24. Retrofitted CSP Parabolic Trough Power Plant Costs, summary

	12%	20%	30%	40%
Investment	336.6 M$	339.3 M$	343.4 M$	347.4 M$
O&M	5.6 M$	5.6 M$	5.6 M$	5.7 M$
Fuel Costs	0.8 M$	1.3 M$	1.9 M$	2.6 M$

- Retrofitting elements marginal cost:

Table 25. Retrofitted CSP Parabolic Trough Power Plant Components Costs, summary

	12%	20%	30%	40%
Investment	4.3 M$	6.1 M$	9.3 M$	12.3 M$
O&M	0.1 M$	0.0 M$	0.1 M$	0.2 M$
Fuel Costs	0.0 M$	0.0 M$	0.0 M$	0.0 M$

3.1.4 Cost Analysis

Figure 3 shows that the LCOE for the retrofitted solution is lower than for the basic solution, and the higher annual fuel consumption, the higher this LCOE difference due to the higher fuel efficiency that is obtained in the retrofitted solution.

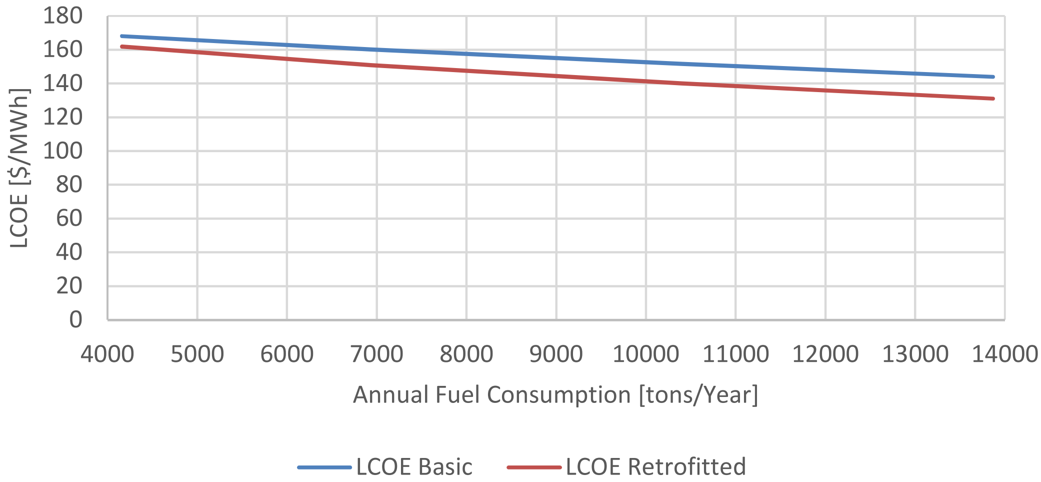

Figure 3. LCOE Retrofitted Vs Existing (Parabolic Trough Retrofitting)

An additional analysis has been carried out in order to reflect the legal situation of Spanish CSP plants. Nowadays, CSP plants are paid a premium tariff for the electricity coming from solar, but receive only the market price for the electricity generated using gas. The systems installed in these plants reach a low gas-to-electricity performance[4] (~35%), so their generation with gas is not competitive. This makes CSP plants incapable of providing firmness, as generating with gas causes a loss of profit.

A marginal analysis has been carried out, calculating the apparent LCOE of the additional energy generated with a HYSOL retrofit, considering the additional investment and operation cost. Assuming a plant lifetime of 25 years, two scenarios have been simulated: a retrofit implemented on the fifth operation year, and on the tenth operation year. Figure 4 shows the comparison between the basic solution's LCOE (red line) and the retrofitting components marginal LCOE.

[4] There are two main reasons for these plants having gas-using systems but with such low performance:

- They have gas-using systems because, when these plants were developed, they were allowed to generate 12 to 15% of their annual output using gas while receiving the premium tariff for all their production (so they were profitable even having a low performance).
- They chose gas furnaces (instead of gas turbines with heat recovery, similar to HYSOL) because Spanish Electric Sector regulations stablish that the nominal power of a plant is the added power of all the installed generators (even if they don't operate simultaneously), and there was a cap (50 MW) for the nominal power of plants to be eligible to receive the premium tariff.

Therefore, a 50 MW steam turbine with auxiliary gas furnaces was the logical technical solution at the moment.

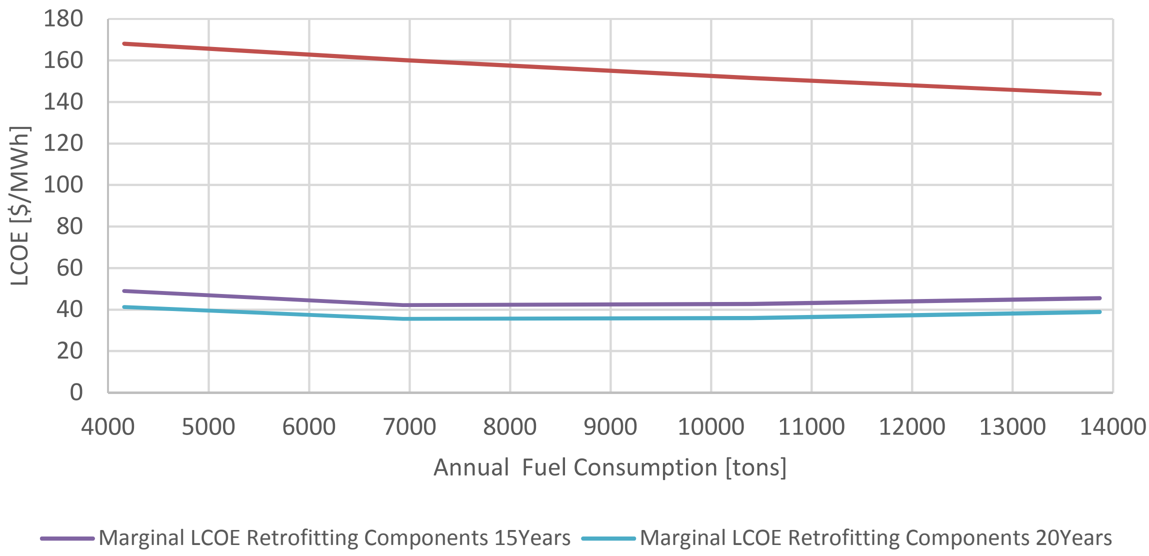

Figure 4. Marginal LCOE in Parabolic Trough Retrofitting

The retrofitting components have a marginal LCOE in the range of 35 to 45 $/MWh, which is near the pool price in Spain, so it could be a competitive solution to provide firm energy. Legal barriers might still prevent the retrofitting, though.

3.1.5 Comparison of production profiles

The retrofitting solution will increase the annual energy production by getting a higher fuel energy efficiency and better power plant operation adaptability to different demands and fuel prices.

Figure 5 shows that the higher the annual fuel consumption, the higher the annual energy production we have, and the difference between both productions is also greater with the fuel consumption, because the retrofitted solution has a higher fuel energy efficiency.

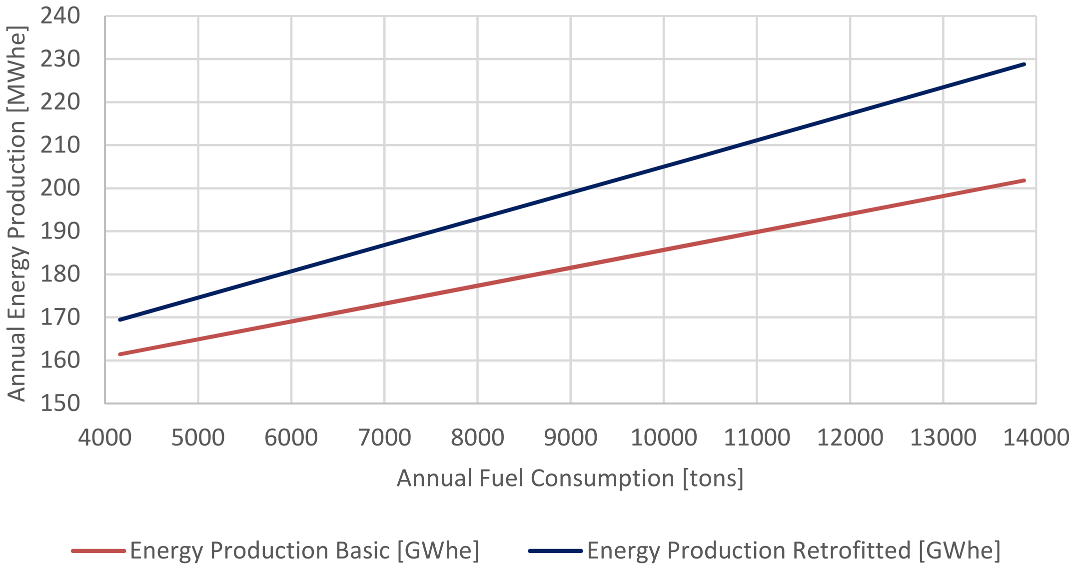

Figure 5. Annual Energy Production Comparison (Parabolic Trough Retrofitting)

As an example, for an annual energy production of 190,000 MWhe, the retrofitted solution needs 7500 tons of fuel per year, while the conventional solution needs 11000 tons, which means a fuel consumption difference of nearly 33%.

The following points show a weekly energy production profile for each retrofitting solution described. The week shown illustrates days with both abundant and scarce solar resource.

- 12% Energy from fuel:

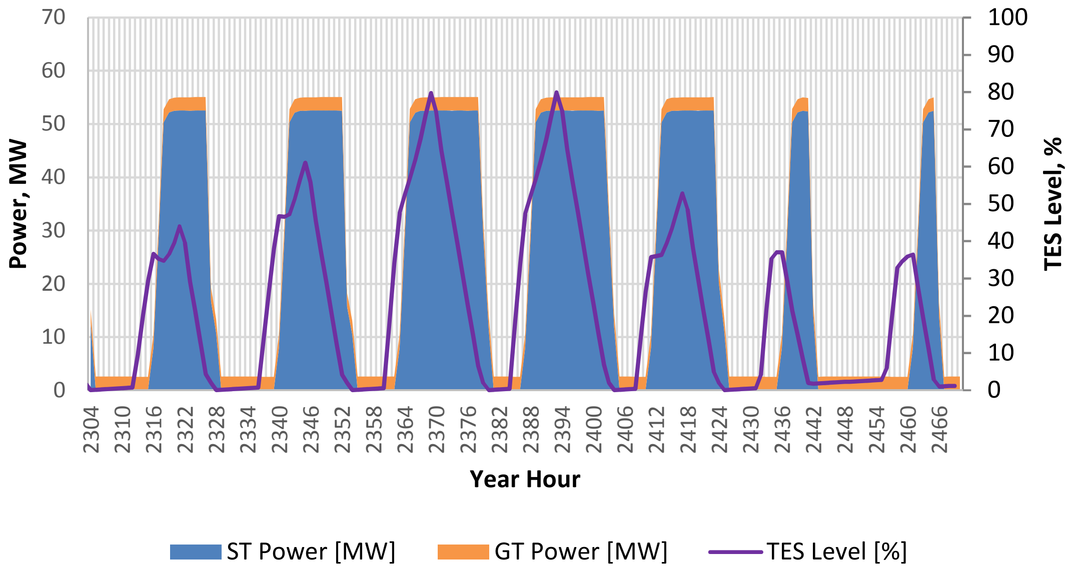

Figure 6. Retrofitted CSP Parabolic Trough Weekly production profile (12% energy from fuel)

- 20% Energy from fuel:

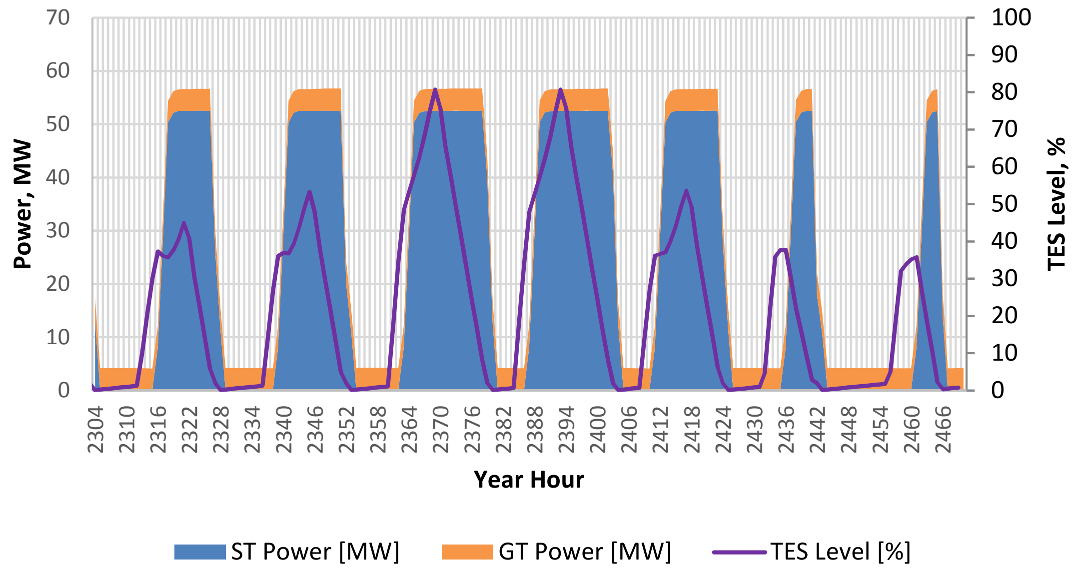

Figure 7. Retrofitted CSP Parabolic Trough Weekly production profile (20% energy from fuel)

- 30% Energy from fuel:

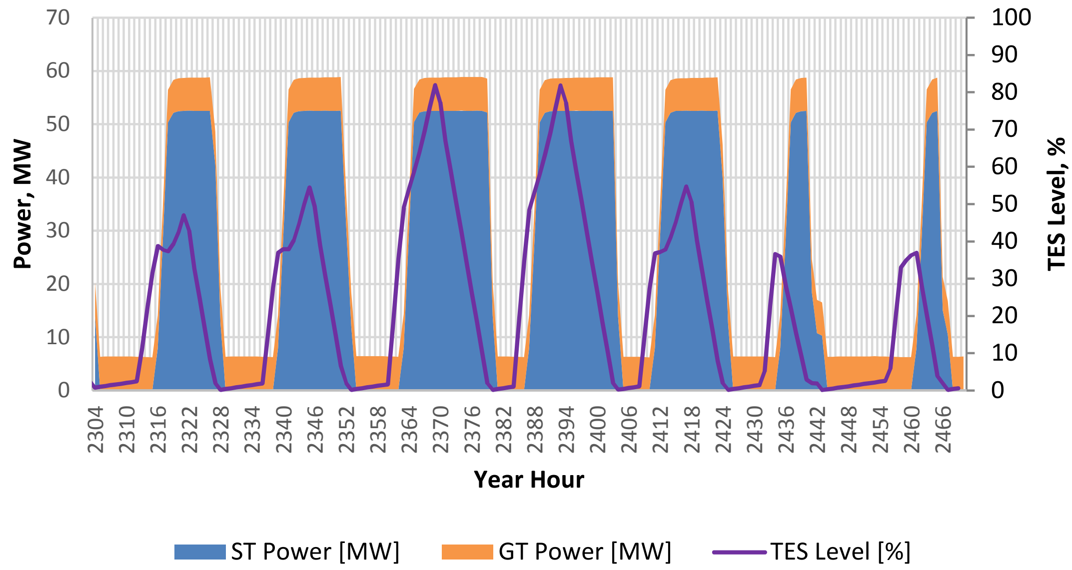

Figure 8. Retrofitted CSP Parabolic Trough Weekly production profile (30% energy from fuel)

- 40% Energy from fuel:

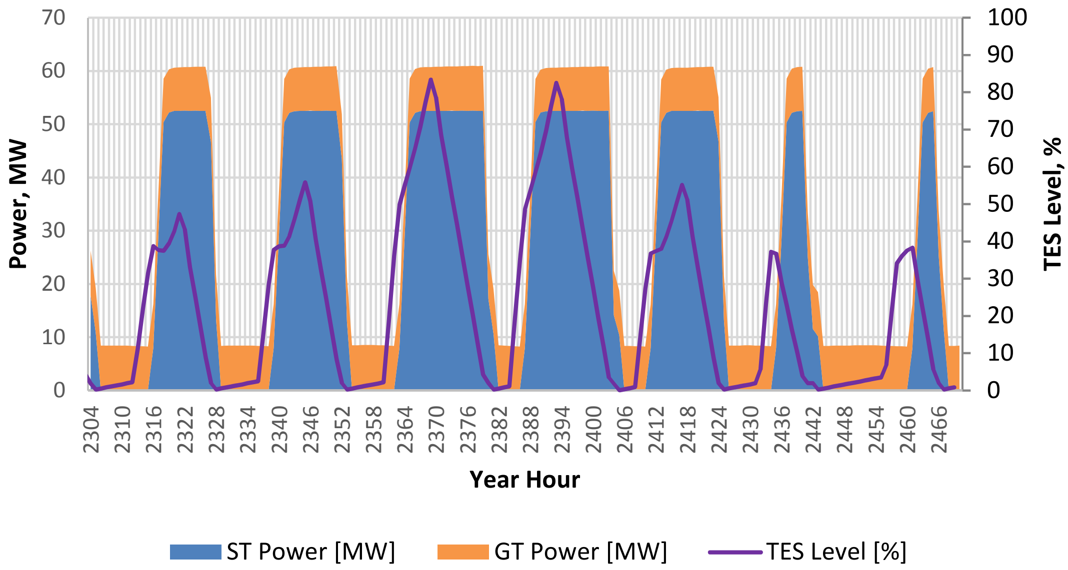

Figure 9. Retrofitted CSP Parabolic Trough Weekly production profile (40% energy from fuel)

As shown in Figure 6, Figure 7, Figure 8 and Figure 9, the increase of energy from fuel also produces a slight increase in the steam turbine energy production because of the heat recovery system and the low temperature energy storage, it is, HYSOL.

3.2 Solar Tower Power Plants using Molten Salts as HTF

3.2.1 General Description of Solar Tower Power Plants

The main parameters of the CSP Tower are shown in Table 26.

Table 26. CSP Tower Power Plant main specifications

	CSP Tower
Steam Turbine Power (MW)	100
Solar Multiple	2.5
Storage Hours	14
Location	Southern Europe
Annual Receiver Energy (MWh_{th})	**1,110,200**

3.2.2 Elements to be added/modified/replaced

+ Gas turbine (added)

Table 27 show the gas turbine power that consume the same fuel tan the no retrofitted solution with the fuel energy percentage that is shown.

Table 27. Gas turbine power / Fuel energy percentage for Tower

Existing solution fuel energy percentage	Annual Fuel consumption [tons]	Retrofitting solution gas turbine power [MW]
12%	12760	6.7
20%	23400	12.4
30%	40110	21.2
40%	62400	33

+ Exhaust Gas / Molten Salt Heat Recovery System (added)

The core of HYSOL, a heat recovery system transfers exhaust gas energy to the molten salt used as TES fluid.

+ Low Temperature Energy Recovery and Storage (added)

The Low Temperature Energy Storage recovers the thermal energy contained in the exhaust gas between the outlet temperature of the molten salt Heat Recovery System and a temperature suitable for stack release (100-150 ºC). This system can substitute the low pressure preheaters in the Rankine cycle, so the heat required in the steam generator system is lower for the same electricity output.

+ Gas-fueled HTF heaters (removed)

Gas-fueled heaters are used in CSP plants for maintenance purposes (anti-freeze) and to increase production.

3.2.3 Estimated costs

This module shows the investment and operation & maintenance costs in each configuration tested to compare the effect of the retrofitting in the costs.

- Existing (no retrofitting) solutions in Tower:
  - 12% Energy from fuel:

Table 28. CSP Tower Power Plant CAPEX (12% Energy from Fuel)

<table>
<tr><td rowspan="6">CAPEX</td><td rowspan="6">Direct Cost</td><td rowspan="4">Power Block</td><td>Combustion Camber</td><td>1.0 M$</td></tr>
<tr><td>ST</td><td>34.3 M$</td></tr>
<tr><td>Air-Cooled Condenser</td><td>10.6 M$</td></tr>
<tr><td>Pumps and heat exchanger (Rankine)</td><td>8.8 M$</td></tr>
<tr><td rowspan="2">Solar</td><td>Receiver system</td><td>67.9 M$</td></tr>
<tr><td>Thermal energy storage</td><td>105.5 M$</td></tr>
</table>

			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	35.0 M$
			Contingencies (7 % Solar)	39.1 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		59.8 M$
	Total Cost			**658.4 M$**

Table 29. CSP Tower Power Plant OPEX (12% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 658,364
	Spare parts	$ 4,628,249
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 329,182
	Total Cost	**$ 8,544,375**

- 20% Energy from fuel:

Table 30. CSP Tower Power Plant CAPEX (20% Energy from Fuel)

CAPEX	Direct Cost	Power Block	Combustion Camber	1.1 M$
			ST	34.3 M$
			Air-Cooled Condenser	10.6 M$
			Pumps and heat exchanger (Rankine)	8.8 M$
		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	35.0 M$
			Contingencies (7 % Solar)	39.1 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		59.8 M$
	Total Cost			**658.5 M$**

Table 31. CSP Tower Power Plant OPEX (20% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 658,464
	Spare parts	$ 4,628,748

	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 329,232
	Total Cost	**$ 8,545,024**

- 30% Energy from fuel:

Table 32. CSP Tower Power Plant CAPEX (30% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	Combustion Camber	1.2 M$
			ST	34.3 M$
			Air-Cooled Condenser	10.6 M$
			Pumps and heat exchanger (Rankine)	8.8 M$
		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	35.0 M$
			Contingencies (7 % Solar)	39.1 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		59.8 M$
	Total Cost			**658.6 M$**

Table 33. CSP Tower Power Plant OPEX (30% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 658,619
	Spare parts	$ 4,629,521
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 329,309
	Total Cost	**$ 8,546,029**

- 40% Energy from fuel:

Table 34. CSP Tower Power Plant CAPEX (40% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	Combustion Camber	1.4 M$
			ST	34.3 M$
			Air-Cooled Condenser	10.6 M$
			Pumps and heat exchanger (Rankine)	8.8 M$

		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	35.0 M$
			Contingencies (7 % Solar)	39.1 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		59.8 M$
	Total Cost			**658.8 M$**

Table 35. CSP Tower Power Plant OPEX (40% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 658,824
	Spare parts	$ 4,630,548
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 329,412
	Total Cost	**$ 8,547,365**

The overall costs for existing solutions are summarized in Table 36. The price of fuel considered is 8 US$/MMBtu.

Table 36. Tower Power Plant Costs, summary

	12%	20%	30%	40%
Investment	658.4 M$	658.5 M$	658.6 M$	658.8 M$
O&M	8.5 M$	8.5 M$	8.5 M$	8.5 M$
Fuel Costs	2.3 M$	2.6 M$	3.0 M$	3.4 M$

- Tower Power Plant Retrofitted costs:
    - 12% Energy from fuel:

Table 37. Retrofitted CSP Tower Power Plant CAPEX (12% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	Combustion Camber	1.0 M$
			GT	3.0 M$
			ST	34.3 M$
			Air-Cooled Condenser	11.3 M$
			Pumps and heat exchanger (Rankine)	8.8 M$
			Pumps and HRSG HYSOL	2.5 M$

		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	37.3 M$
			Contingencies (7 % Solar)	39.7 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		60.7 M$
	Total Cost			**668.4 M$**

Table 38. Retrofitted CSP Tower Power Plant OPEX (12% Energy from Fuel)

OPEX	**Water consumption**	$ 367,290
	Insurance	$ 668,409
	Spare parts	$ 4,678,471
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 334,204
	Total Cost	**$ 8,609,664**

- 20% Energy from fuel:

Table 39. Retrofitted CSP Tower Power Plant CAPEX (20% Energy from Fuel)

CAPEX	**Direct Cost**	**Power Block**	Combustion Camber	1.1 M$
			GT	5.6 M$
			ST	34.3 M$
			Air-Cooled Condenser	11.9 M$
			Pumps and heat exchanger (Rankine)	8.8 M$
			Pumps and HRSG HYSOL	4.6 M$
		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	39.3 M$
			Contingencies (7 % Solar)	40.2 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		61.5 M$
	Total Cost			**677.1 M$**

Table 40. Retrofitted CSP Tower Power Plant OPEX (20% Energy from Fuel)

OPEX	Water consumption	$ 367,290
	Insurance	$ 677,054
	Spare parts	$ 4,721,695
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 338,527
	Total Cost	**$ 8,665,856**

- 30% Energy from fuel:

Table 41. Retrofitted CSP Tower Power Plant CAPEX (30% Energy from Fuel)

CAPEX	Direct Cost	Power Block	Combustion Camber	1.2 M$
			GT	9.5 M$
			ST	34.3 M$
			Air-Cooled Condenser	12.9 M$
			Pumps and heat exchanger (Rankine)	8.8 M$
			Pumps and HRSG HYSOL	7.8 M$
		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	42.4 M$
			Contingencies (7 % Solar)	41.0 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		62.7 M$
	Total Cost			**690.4 M$**

Table 42. Retrofitted CSP Tower Power Plant OPEX (30% Energy from Fuel)

OPEX	Water consumption	$ 367,290
	Insurance	$ 690,401
	Spare parts	$ 4,788,431
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 345,200
	Total Cost	**$ 8,752,613**

- 40% Energy from fuel:

Table 43. Retrofitted CSP Tower Power Plant CAPEX (40% Energy from Fuel)

CAPEX	Direct Cost	Power Block	Combustion Camber	1.4 M$
			GT	14.8 M$
			ST	34.3 M$
			Air-Cooled Condenser	14.1 M$
			Pumps and heat exchanger (Rankine)	8.8 M$
			Pumps and HRSG HYSOL	12.1 M$
		Solar	Receiver system	67.9 M$
			Thermal energy storage	105.5 M$
			Tower	29.2 M$
			Heliostat field + site improvement	267.3 M$
		Others	Balance of Plant	46.6 M$
			Contingencies (7 % Solar)	42.0 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		64.3 M$
	Total Cost			**708.3 M$**

Table 44. Retrofitted CSP Tower Power Plant OPEX (40% Energy from Fuel)

OPEX	Water consumption	$ 367,290
	Insurance	$ 708,296
	Spare parts	$ 4,877,909
	Land rental	$ 91,380
	Staff	$ 2,469,911
	Municipal tax	$ 354,148
	Total Cost	**$ 8,868,933**

The overall costs for existing solutions are summarized in Table 45. The price of fuel considered is 8 US$/MMBtu.

Table 45. Retrofitted CSP Tower Power Plant Costs, summary

	12%	20%	30%	40%
Investment	668.4 M$	677.1 M$	690.4 M$	708.3 M$
O&M	8.6 M$	8.7 M$	8.8 M$	8.9 M$
Fuel Costs	2.3 M$	2.6 M$	3.0 M$	3.4 M$

- Retrofitting elements marginal cost:

Table 46. CSP Tower Power Plant Retrofitting Components Costs, summary

	12%	20%	30%	40%
Investment	10.0 M$	18.6 M$	31.8 M$	49.5 M$
O&M	0.1 M$	0.1 M$	0.2 M$	0.3 M$
Fuel Costs	0.0 M$	0.0 M$	0.0 M$	0.0 M$

3.2.4 Cost Analysis

Figure 10 shows that the LCOE for the retrofitted solution is lower than for the basic solution, and the higher the annual fuel consumption, the higher this LCOE difference due to the higher fuel efficiency that is obtained in the retrofitted solution.

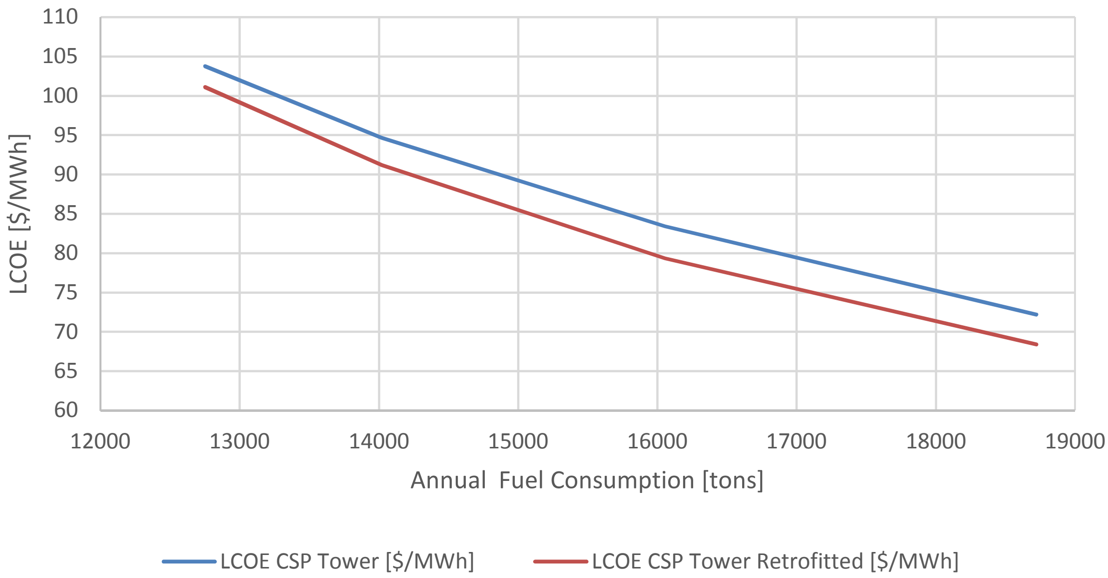

Figure 10. LCOE Retrofitted Vs Existing (Tower Retrofitting)

An additional analysis has been carried out in order to reflect the legal situation of Spanish CSP plants. Nowadays, CSP plants are paid a premium tariff for the electricity coming from solar, but receive only the market price for the electricity generated using gas. The systems installed in these plants reach a low gas-to-electricity performance[5] (~35%), so their generation with gas is

[5] There are two main reasons for these plants having gas-using systems but with such low performance:

- They have gas-using systems because, when these plants were developed, they were allowed to generate 12 to 15% of their annual output using gas while receiving the premium tariff for all their production (so they were profitable even having a low performance).
- They chose gas furnaces (instead of gas turbines with heat recovery, similar to HYSOL) because Spanish Electric Sector regulations stablish that the nominal power of a plant is the added power of all the installed generators (even if they don't operate simultaneously), and there was a cap (50 MW) for the nominal power of plants to be eligible to receive the premium tariff.

Therefore, a 50 MW steam turbine with auxiliary gas furnaces was the logical technical solution at the moment.

not competitive. This makes CSP plants incapable of providing firmness, as generating with gas causes a loss of profit.

A marginal analysis has been carried out, calculating the apparent LCOE of the additional energy generated with a HYSOL retrofit, considering the additional investment and operation cost. Assuming a plant lifetime of 25 years, two scenarios have been simulated: a retrofit implemented on the fifth operation year, and on the tenth operation year. Figure 11 shows the comparison between the basic solution's LCOE (red line) and the retrofitting components marginal LCOE.

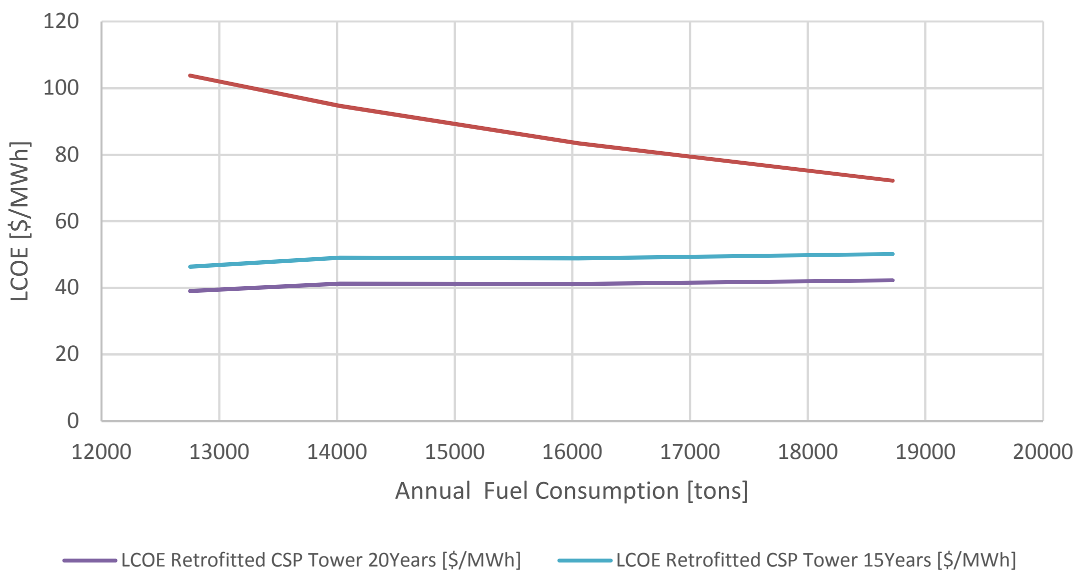

Figure 11. Marginal LCOE Retrofitting Components Vs Basic (Tower Retrofitting)

The retrofitting components have a marginal LCOE in the range of 40 to 50 $/MWh, which is near the pool price in Spain, so it could be a competitive solution to provide firm energy. Legal barriers might still prevent the retrofitting, though.

3.2.5 Comparison of production profiles

The retrofitting solution will increase the annual energy production by getting a higher fuel energy efficiency and better power plant operation adaptability to different demands and fuel prices.

Figure 12 shows that the higher the annual fuel consumption, the higher the annual energy production we have, and the difference between both productions is also greater with the fuel consumption, because the retrofitted solution has a higher fuel energy efficiency.

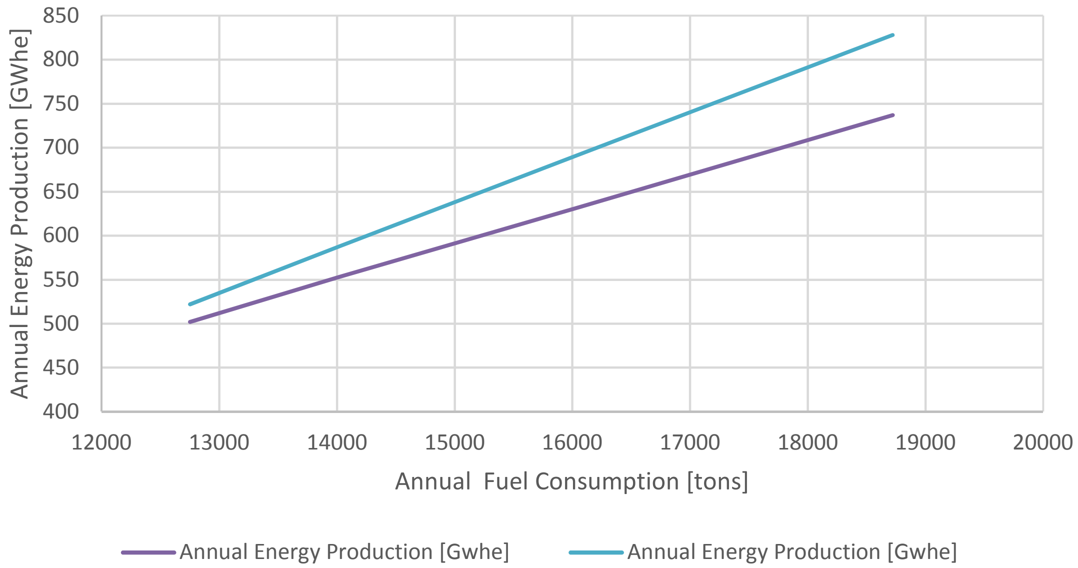

Figure 12. Annual Energy Production Comparison (Tower Retrofitting)

As an example, for an annual energy production of 650,000 MWhe, the retrofitted solution needs 15200 tons of fuel per year, while the conventional solution need 16500 tons, which means a fuel consumption difference of nearly 8%. The difference is smaller than for Parabolic Trough retrofit because the base performance in the use of fuel is higher in Tower due to the higher Rankine cycle temperature.

The following points show a weekly energy production profile for each retrofitting solution described. The week shown illustrates days with both abundant and scarce solar resource.

- 12% Energy from fuel:

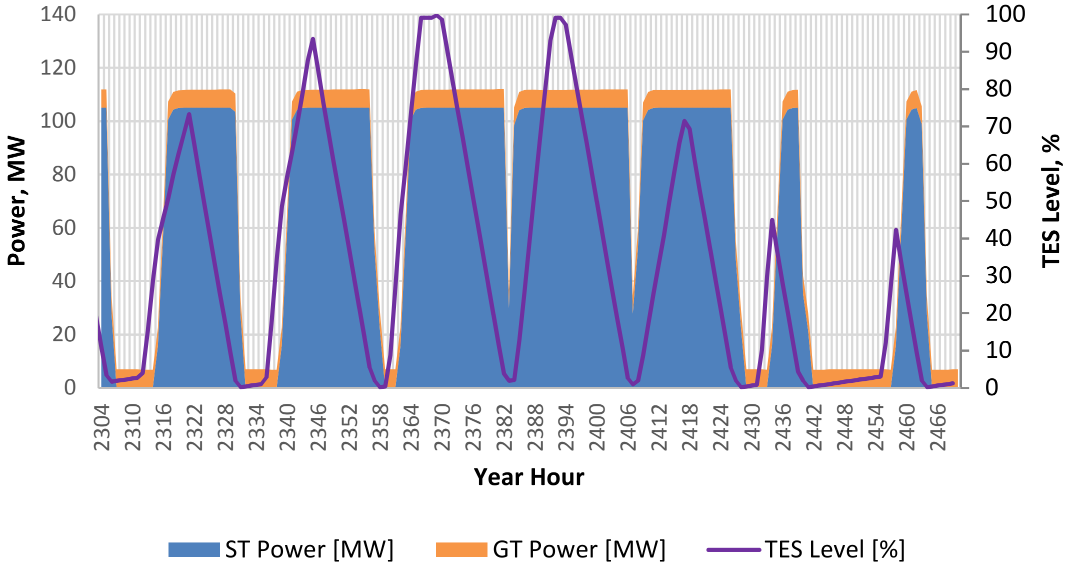

Figure 13. Retrofitted CSP Tower Weekly production profile (12% Energy from Fuel)

- 20% Energy from fuel:

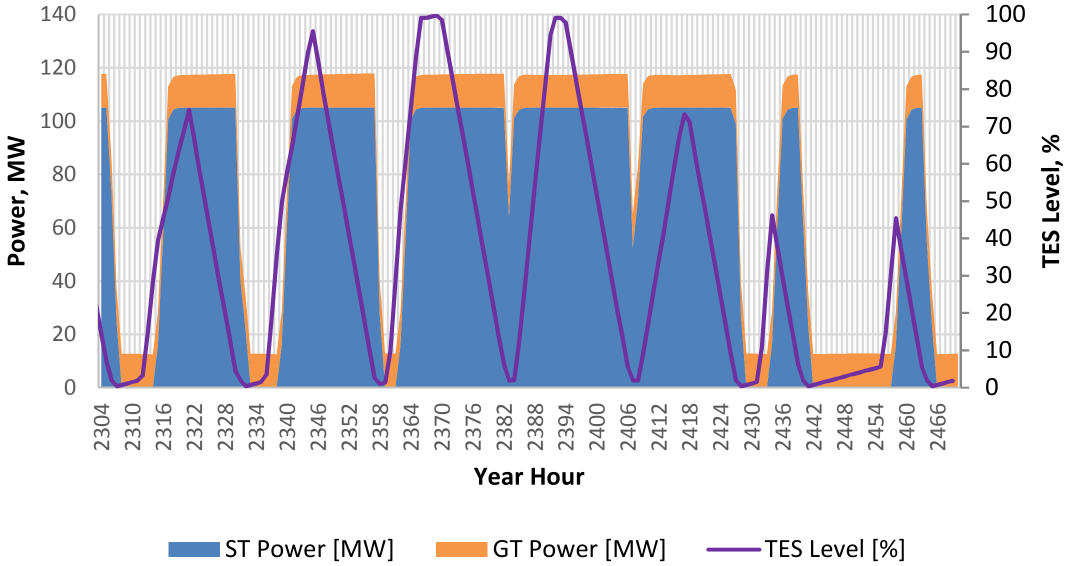

Figure 14. Retrofitted CSP Tower Weekly production profile (20% Energy from Fuel)

- 30% Energy from fuel:

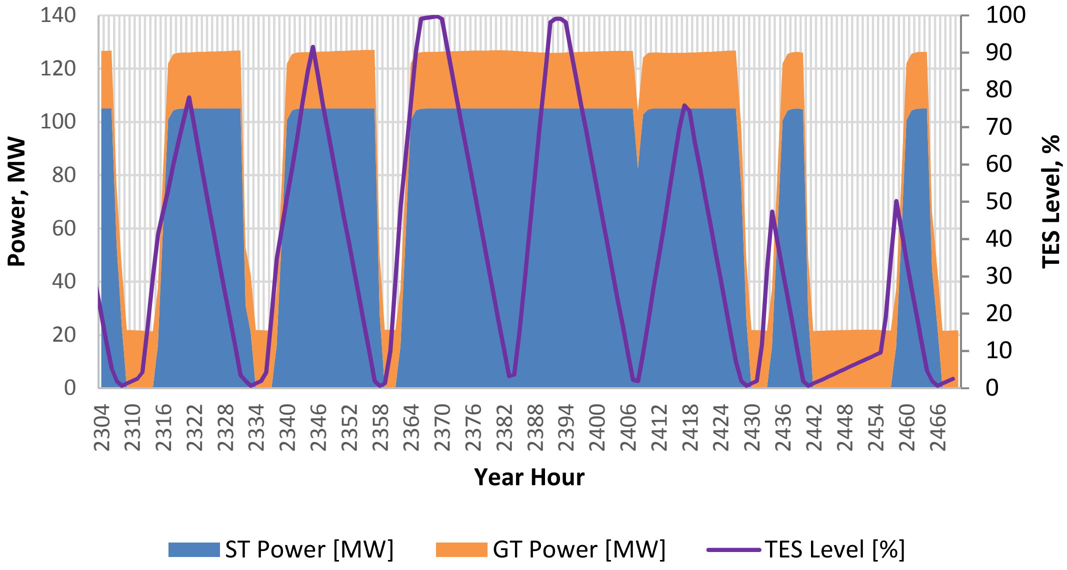

Figure 15. Retrofitted CSP Tower Weekly production profile (30% Energy from Fuel)

- 40% Energy from fuel:

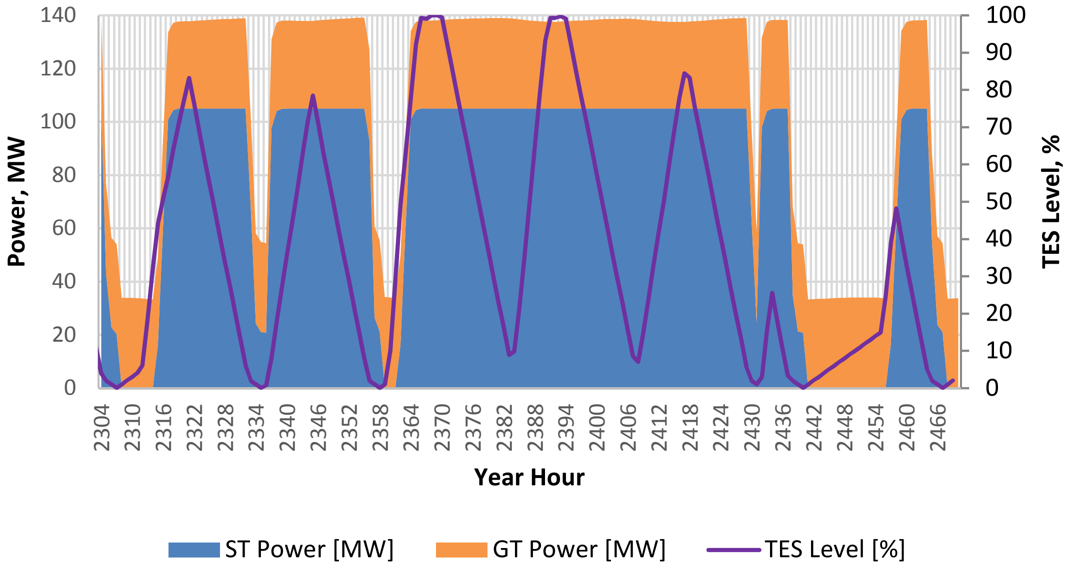

Figure 16. Retrofitted CSP Tower Weekly production profile (40% Energy from Fuel)

As shown in Figure 13, Figure 14, Figure 15 and Figure 16, the increase of energy from fuel also produces a significant increase in the steam turbine energy production because of the heat recovery system and the low temperature energy storage, it is, HYSOL.

3.3 Conclusions on CSP Plant Retrofitting

Retrofitting existing CSP plants using HYSOL is technically feasible, because no major modifications are required in the actual equipment of the plant, and it would increase their economic performance, as it would lower the unit cost of generation with gas by increasing the gas-to-electricity efficiency.

Existing CSP plants were built during early stages of the technologies' learning curve, so their LCOE is higher than the market price. HYSOL's use of gas has a cost and efficiency close to those of a combined cycle, so it brings the overall plant's LCOE closer to the market price (which is often marked by the price offered by combined cycles).

A differential or marginal cost analysis is carried out in order to assess the economic feasibility of the retrofit, with a special focus on the Spanish market situation. Results show that investing in a HYSOL retrofit could render the use of gas in these plants profitable again, so they could contribute to the stability of the grid by providing firm energy. Legal barriers still apply, though.

All these conclusions apply to both Parabolic Trough and Tower CSP plants, although the efficiency improvement is more noticeable in Parabolic Trough because their base performance is lower.

4 OCGT AND CCGT: MOVING TO SOLAR ENERGY AS MAIN PRIMARY SOURCE

The object of this chapter is to make a technical compatibility study with existing power facilities using natural gas, namely Open Cycle Gas Turbines (OCGT) and Combined Cycles (CCGT); a technical, legal and market study must be developed to identify a list of possible existing facilities where integration might be feasible. This task will help to adapt the developed technology not only for new projects but for existing ones, so that the economic benefits and impact of the project are boosted.

The retrofitting approach used for the comparison with OCGT consists in calculating, for a theoretical plant operating as a baseload in Morocco[6], the steam turbine that would better suit its conditions for closing the cycle considering the inclusion of a 100 MWe CSP Tower solar field (which is, for the moment, the technical size limit for towers). A 155 MW gas turbine is proposed, as it is a frequent size for OCGT plants, and it has the particular property of providing approximately 55 MWe in the form of exhaust gases, so that the steam turbine used in the cycle will have the same nominal power as the gas turbine (55 + 100). This maximizes the operation flexibility of the plant. The retrofit of the OCGT plant will include the incorporation of solar field, TES, HYSOL's heat recovery systems and steam turbine, and a post-combustor to increase the exhaust gas temperature.

In order to make the results readily comparable, the CCGT approach considered the same gas turbine used in the OCGT plant, but already including the 55 MW steam turbine powered by the exhaust gas heat recovery boiler. This plant would be retrofitted by incorporating the 100 MWe solar field and TES, and replacing the existing heat recovery boiler and 55 MW steam turbine with HYSOL's heat recovery systems and a 155 MW steam turbine.

4.1 OCGT: CLOSING CYCLES IN A SUSTAINABLE, CLEAN AND EFFICIENT WAY

4.1.1 General Description of Open Cycle Gas Turbine

The Open Cycle Gas Turbine used as a base case is a theoretical 155 MW gas turbine located in Casablanca (Morocco).

Table 47. OCGT main parameters

	OCGT
Gas Turbine Power (MW)	155
Location	Morocco
Exhaust gases Temperature (ºC)	430

[6] Morocco was chosen for the comparison due to the existence in the country of OCGT plants, and its recent trend toward CSP implementation.

4.1.2 Elements to be added/modified/replaced

- Steam turbine (added)

A Steam Turbine with 155 MW power is added, 100 MW because of the solar field and 55 MW because of the heat recovery system.

- Solar Field (added)

It consists of a heliostats field and a receiver with a solar multiple of 2.5, so assuming a steam turbine efficiency of 40%, we will need 625 MWth of peak design power.

- Thermal Energy Storage, TES (added)

A thermal storage is designed with a capacity to supply molten salts during 14 hours to the steam generator system without any solar field contribution.

- Exhaust Gas / Molten Salt Heat Recovery System (added)

The core of HYSOL, a heat recovery system transfers exhaust gas energy to the molten salt used as TES fluid.

- Low Temperature Energy Recovery and Storage (added)

The Low Temperature Energy Storage recovers the thermal energy contained in the exhaust gas between the outlet temperature of the molten salt Heat Recovery System and a temperature suitable for stack release (100-150 ºC). This system can substitute the low pressure preheaters in the Rankine cycle, so the heat required in the steam generator system is lower for the same electricity output.

4.1.3 Estimated costs

This module shows the investment and operation & maintenance costs in each configuration tested to compare the effect of the retrofitting in the costs. The price of fuel considered is 8 US$/MMBtu for the base case, although a sensitivity analysis is carried out.

- Existing OCGT costs:

Table 48. OCGT CAPEX

<table>
<tr><td rowspan="4">CAPEX</td><td rowspan="2">Direct Cost</td><td>Power Block</td><td>GT (155 MW)</td><td>67 M$</td></tr>
<tr><td>Others</td><td>Contingencies (7%)</td><td>2 M$</td></tr>
<tr><td>Indirect Cost</td><td colspan="2">EPC and Owner Cost (10% Direct Cost)</td><td>7 M$</td></tr>
<tr><td colspan="3">Total Cost</td><td>76 M$</td></tr>
</table>

Table 49. OCGT OPEX

OPEX	Water consumption[7]	~ 0 $
	Insurance	76,452 $
	Spare parts	382,260 $
	Land rental[7]	~ 0 $
	Staff	1,816,580 $
	Municipal tax	38,226 $
	Total Cost	**2,313,517 $**

Table 50. OCGT Costs

Investment	76.5 M$
O&M	2.3 M$
Fuel Costs	104.6 M$

- OCGT Retrofitted costs:

Table 51. Retrofitted OCGT CAPEX

CAPEX	Direct Cost	Power Block	GT (155 MW)	67 M$
			ST (155 MW)	53 M$
			Air-Cooled Condenser	32 M$
			Pumps and heat exchanger (Rankine)	14 M$
			Pumps and HRSG HYSOL	59 M$
		Solar	Receiver system	68 M$
			Thermal energy storage	105 M$
			Tower	29 M$
			Heliostat field + site improvement	267 M$
		Others	Balance of Plant	107 M$
			Contingencies (7 % Solar)	56 M$
	Indirect Cost	EPC and Owner Cost (10% Direct Cost)		86 M$
	Total Cost			**944 M$**

Table 52. Retrofitted OCGT OPEX

OPEX	Water consumption	367,290 $
	Insurance	944,238 $
	Spare parts	6,057,617 $
	Land rental	91,380 $

[7] Water consumption and land rental costs have been considered negligible for gas turbines

	Staff	2,469,911 $
	Municipal tax	472,119 $
	Total Cost	**10,402,554 $**

Table 53. Retrofitted OCGT Costs

Investment	944.2 M$
O&M	10.4 M$
Fuel Costs	135.6 M$

- OCGT Retrofitting components marginal costs:

Table 54. OCGT Retrofitting Components Costs

Investment	867.8 M$
O&M	8.1 M$
Fuel Costs	31.0 M$

4.1.4 Cost Analysis

The LCOE of gas-based power plants is strongly influenced by the fuel cost. Switching to CSP-based power is not competitive against low fuel prices; the moment of the retrofitting is also important. A marginal analysis has been carried out, calculating the apparent LCOE of the additional energy generated with a HYSOL retrofit, considering the additional investment and operation cost. Assuming a plant lifetime of 25 years, two scenarios have been simulated: a retrofit implemented on the fifth operation year, and on the tenth operation year. Figure 17 shows the comparison between the basic solution's LCOE (red line) and the retrofitting components marginal LCOE.

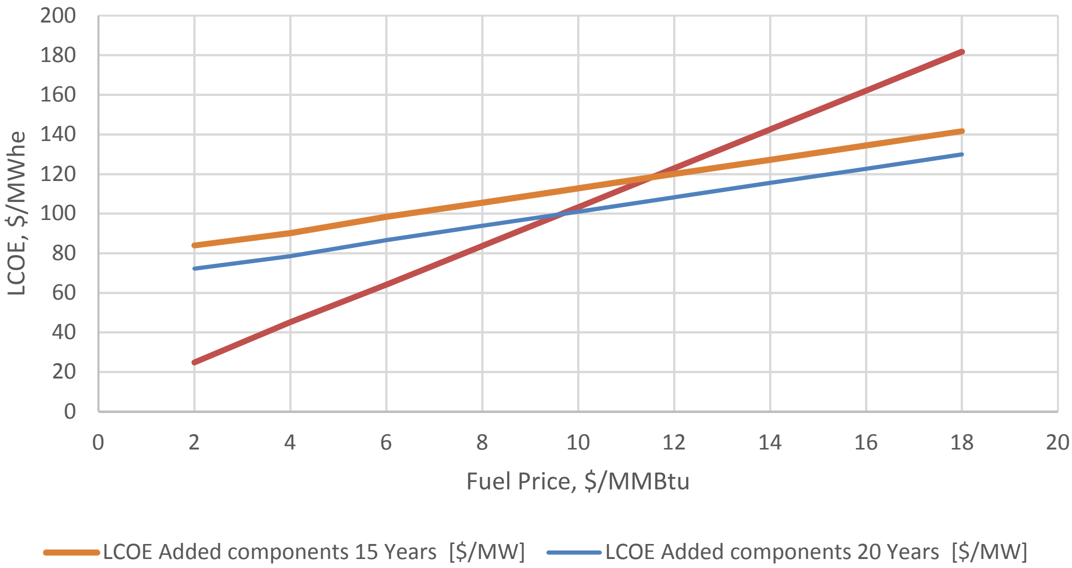

Figure 17. OCGT & Retrofitting components LCOE-Fuel Price

HYSOL's retrofit could be profitable if the fuel price is between 10 and 12 US$/MMBtu, for the scenarios considered. Please note that these figures could be analyzed as "equivalent fuel price", it is, the market price of fuel should be modified considering externalities, CO2 credits or similar.

4.1.5 Comparison of production profiles

The retrofitting solution will increase the annual energy production because of the solar contribution, but also by getting a higher fuel energy efficiency (in the case of OCGT), and better power plant operation adaptability to different demands and fuel prices thanks to the use of Thermal Energy Storage.

The following points show a weekly energy production profile for each retrofitting solution described. The week shown illustrates days with both abundant and scarce solar resource.

- OCGT weekly production profile:

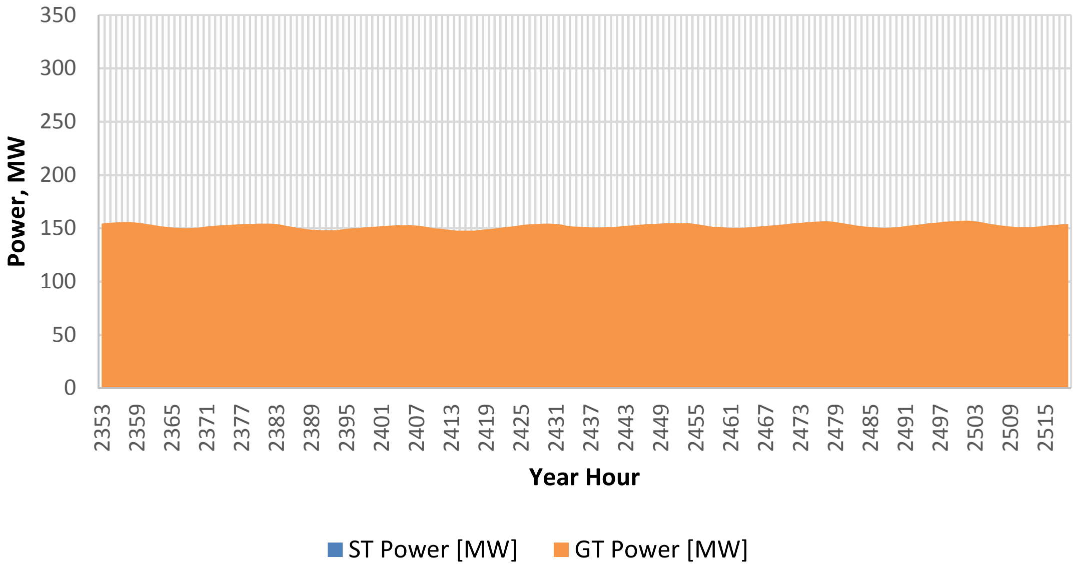

Figure 18. OCGT Weekly production profile

- OCGT Retrofitted weekly production profile:

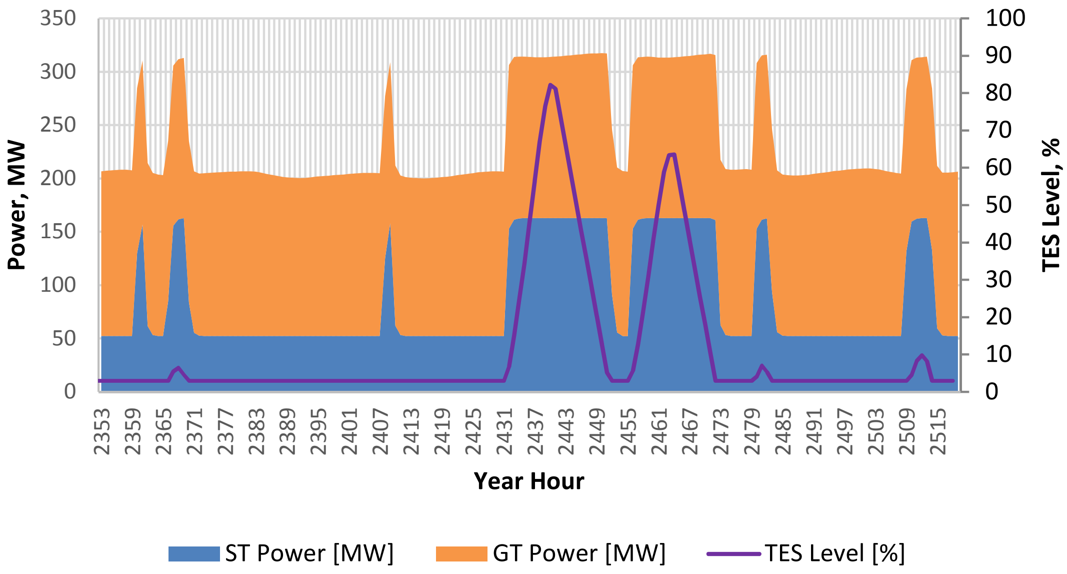

Figure 19. Retrofitted OCGT Weekly production profile

4.2 CCGT: USING EXISTING CONFIGURATIONS TO INCLUDE A HYSOL POWER PLANT

4.2.1 General Description of Combined Cycle Gas Turbine

The Combined Cycle Gas Turbine used as a base case is a theoretical 210 MW (155 MW gas turbine + 55 MW steam turbine) located in Casablanca (Morocco).

Table 55. OCGT main parameters

	CCGT
Gas Turbine Power (MW)	155
Steam Turbine Power (MW)	55
Location	Morocco
Exhaust gases Temperature (ºC)	430

4.2.2 Elements to be added/modified/replaced

+ Steam turbine (added)

A Steam Turbine with 155 MW power is installed, replacing the existing 55 MW unit to incorporate the 100 MW of solar.

+ Solar Field (added)

It consists of a heliostats field and a receiver with a solar multiple of 2.5, so assuming a steam turbine efficiency of 40%, we will need 625 MWth of peak design power.

+ Thermal Energy Storage, TES (added)

A thermal storage is designed with a capacity to supply molten salts during 14 hours to the steam generator system without any solar field contribution.

+ Exhaust Gas / Molten Salt Heat Recovery System (replaced)

The existing heat recovery steam boiler will be replaced with the core of HYSOL, a heat recovery system transfers exhaust gas energy to the molten salt used as TES fluid.

+ Low Temperature Energy Recovery and Storage (added)

The Low Temperature Energy Storage recovers the thermal energy contained in the exhaust gas between the outlet temperature of the molten salt Heat Recovery System and a temperature suitable for stack release (100-150 ºC). This system can substitute the low pressure preheaters in the Rankine cycle, so the heat required in the steam generator system is lower for the same electricity output.

4.2.3 Estimated costs

This module shows the investment and operation & maintenance costs in each configuration tested to compare the effect of the retrofitting in the costs. The price of fuel considered is 8 US$/MMBtu for the base case, although a sensitivity analysis is carried out.

- Existing CCGT costs:

Table 56. CCGT CAPEX

[illegible]	**Direct Cost**	**Power Block**	GT (155 MW)	67 M$

			ST (55 MW)	19 M$
			Air-Cooled Condenser	22 M$
			Pumps and heat exchanger (Rankine)	5 M$
			Pumps and HRSG	28 M$
		Solar	Receiver system	0 M$
			Thermal energy storage	0 M$
			Tower	0 M$
			Heliostat field + site improvement	0 M$
		Others	Balance of Plant	72 M$
			Contingencies (7 % Solar)	11 M$
	Indirect Cost	**EPC and Owner Cost (10% Direct Cost)**		22 M$
	Total Cost			245 M$

Table 57. CCGT OPEX

OPEX	**Water consumption**	35,930 $
	Insurance	245,173 $
	Spare parts	1,225,867 $
	Land rental[8]	~ 0 $
	Staff	2,151,213 $
	Municipal tax	122,587 $
	Total Cost	**3,780,769 $**

Table 58.CCGT Costs

Investment	245.2 M$
O&M	3.8 M$
Fuel Costs	104.6 M$

- CCGT Retrofitted costs:

Table 59. Retrofitted CCGT CAPEX

CAPEX	**Direct Cost**	**Power Block**	GT (MW)	67 M$
			ST (MW)	53 M$
			Air-Cooled Condenser (MWth)	32 M$
			Pumps and heat exchanger (Rankine)	14 M$
			Pumps and HRSG HYSOL (MWth)	87 M$
		Solar	Receiver system (MWth)	68 M$

[8] Land rental costs have been considered negligible for combined cycles

			Thermal energy storage (h)	105 M$
			Tower (m) - SM=2.47	29 M$
			Heliostat field + site improvement (m2)	267 M$
		Others	Balance of Plant (MW)	107 M$
			Contingencies (% Solar Tower)	58 M$
	Indirect Cost	**EPC and Owner Cost (% Direct Cost)**		89 M$
	Total Cost			977 M$

Table 60. Retrofitted CCGT OPEX

OPEX	**Water consumption**	367,290 $
	Insurance	976,695 $
	Spare parts	6,219,903 $
	Land rental	91,380 $
	Staff	2,469,911 $
	Municipal tax	488,348 $
	Total Cost	**10,613,525 $**

Table 61. Retrofitted CCGT Costs

Investment	976.7 M$
O&M	10.6 M$
Fuel Costs	135.6 M$

- CCGT Retrofitting components marginal costs:

Table 62. CCGT Retrofitting Components costs

Investment	731.5 M$
O&M	6.8 M$
Fuel Costs	31.0 M$

4.2.4 Cost Analysis

The LCOE of gas-based power plants is strongly influenced by the fuel cost. Switching to CSP-based power is not competitive against low fuel prices; the moment of the retrofitting is also important. A marginal analysis has been carried out, calculating the apparent LCOE of the additional energy generated with a HYSOL retrofit, considering the additional investment and operation cost. Assuming a plant lifetime of 25 years, two scenarios have been simulated: a retrofit implemented on the fifth operation year, and on the tenth operation year. Figure 20 shows the comparison between the basic solution's LCOE (red line) and the retrofitting components marginal LCOE.

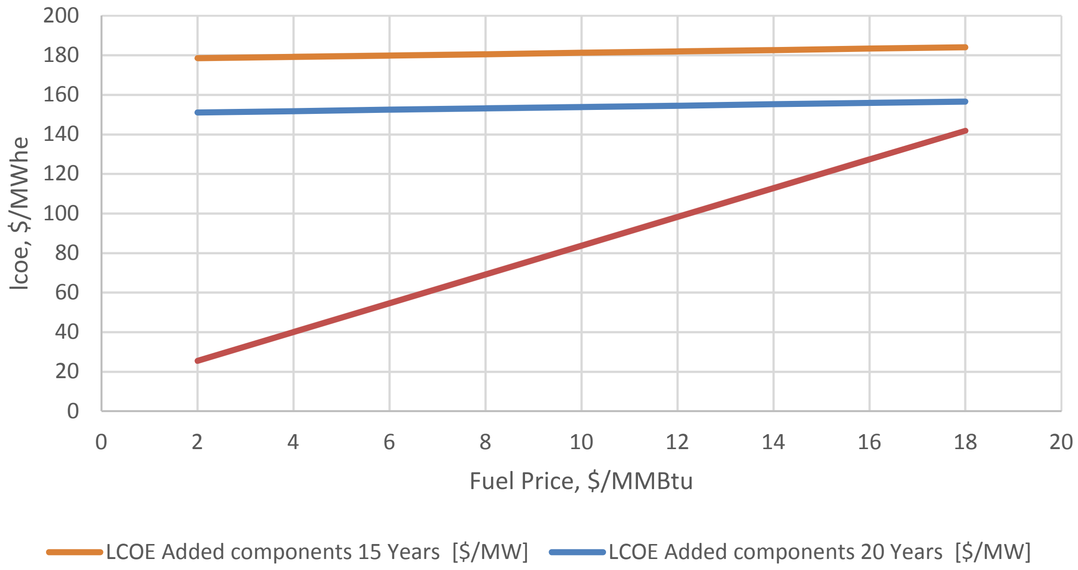

Figure 20. CCGT & Retrofitting components LCOE-Fuel Price

HYSOL's retrofit of a CCGT would not be profitable for any of the fuel prices or the scenarios considered. Please note that these figures could be analyzed as "equivalent fuel price", it is, the market price of fuel should be modified considering externalities, CO2 credits or similar.

4.2.5 Comparison of production profiles

The retrofitting solution will increase the annual energy production because of the solar contribution, and better power plant operation adaptability to different demands and fuel prices thanks to the use of Thermal Energy Storage. In the case of CCGT, the fuel energy efficiency would not be significantly changed.

The following points show a weekly energy production profile for each retrofitting solution described. The week shown illustrates days with both abundant and scarce solar resource.

- CCGT weekly production profile:

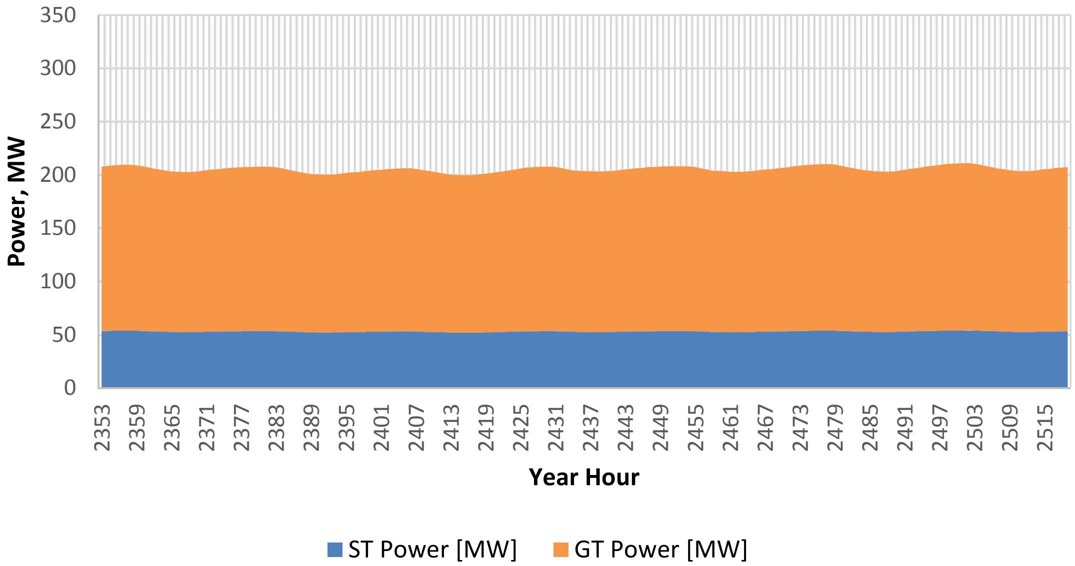

Figure 21. CCGT Weekly production profile

- CCGT Retrofitted weekly production profile:

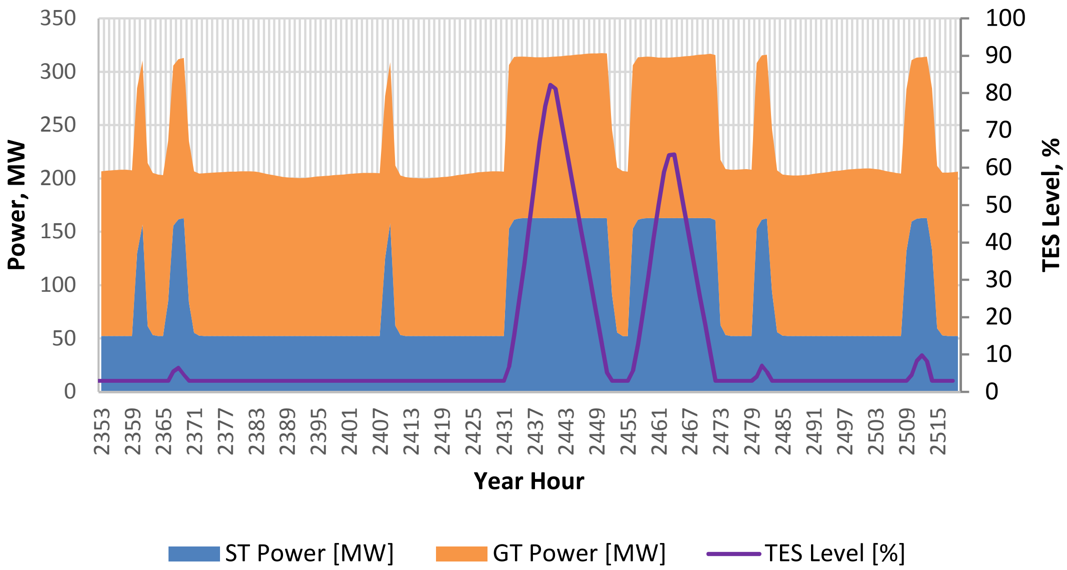

Figure 22. Retrofitted CCGT Weekly production profile

4.3 Conclusions on Gas-Based Plant Retrofitting

Retrofitting existing gas-based plants (OCGT and CCGT) using HYSOL is technically feasible, although major modifications are required in the actual equipment of the plant in the case of CCGT. Also, the likelihood of finding enough available flat ground surrounding an existing OCGT or CCGT for a solar field is low; relocating the existing gas turbine would be a somehow more feasible solution.

The effect of HYSOL's retrofit on the existing plants' economic performance would be positive only for high fuel prices, although for this comparison an "equivalent fuel price" should be used, it is, the market price of fuel should be modified considering externalities, CO2 credits or similar.

The case of CCGT is especially disadvantageous, and HYSOL's retrofit of a CCGT would not be profitable for any of the fuel prices deemed "reasonably likely" in this analysis, regardless of the scenario considered.

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