Repowering of Old Power Stations

تطوير محطات توليد الطاقة القديمة

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Contents

Energy in Jordan

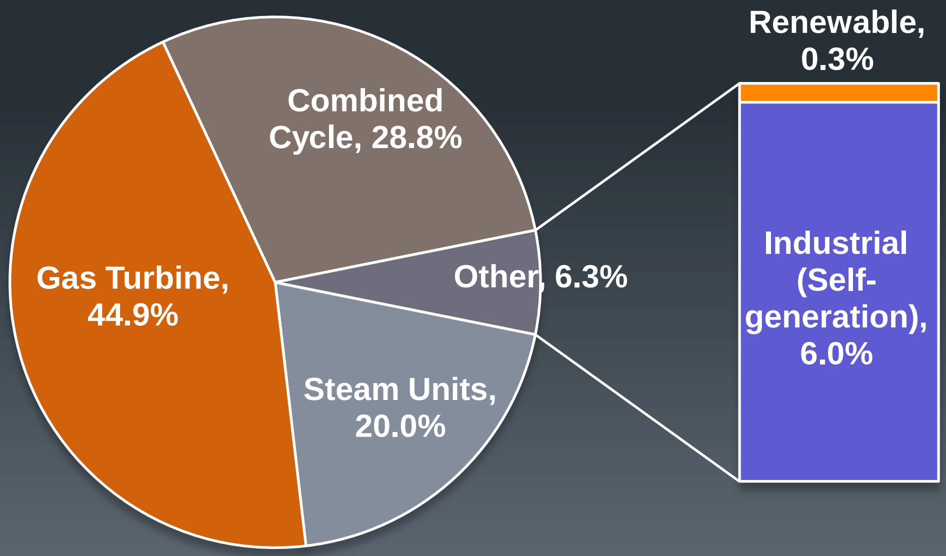
- **The most serious challenge of development in Jordan**

Lack of Conventional Energy Resources

Dependence on Imported Fossil-Fuel

Increasing Energy Demand

- **Till 2015, share of the renewable energies in total energy mix is less than 1%.**



Energy in Jordan

- Jordan has an ambitious target for current energy situation as mentioned in "Updated Master Strategy for Energy Sector in Jordan 2007 - 2020" presented by:

Reduce dependence on imported energy sources

Share of RE to reach 10% by 2020 (Solar and Wind Projects)

- Solar energy is one of the renewable resources that have high potentials in the country. Concentrated Solar Power (CSP) is one of proven solar technologies in worldwide and highly applicable in Jordan.

Scope of Work and Objectives

- In this study; integration of one of CSP technologies with existing fossil-fueled power plant (Steam cycle) to be presented.
- This integration presented by; substituting turbine's steam extractions for feedwater heaters in power plant by introducing a CSP technology.
- Importance of this work:
  1. Improve the performance of existing Rankine cycle
  2. Reduce fuel consumption and
  3. Reduce greenhouse gases (GHG) emissions.

Methodology

- The study will follow below main points:

Select a Local Existing Power Plant
The old 33 MW Unit at HTPP

↓

Study Different CSP Technologies & Conduct a Comparison Between Them

↓

Select One of CSP Technologies

↓

Develop a Simple Simulation Model Based on Energy and Mass Balance

↓

Conduct Technical, Economic and Environmental Aspects

What is CSP?

(a Brief Concept of CSP)

C S P

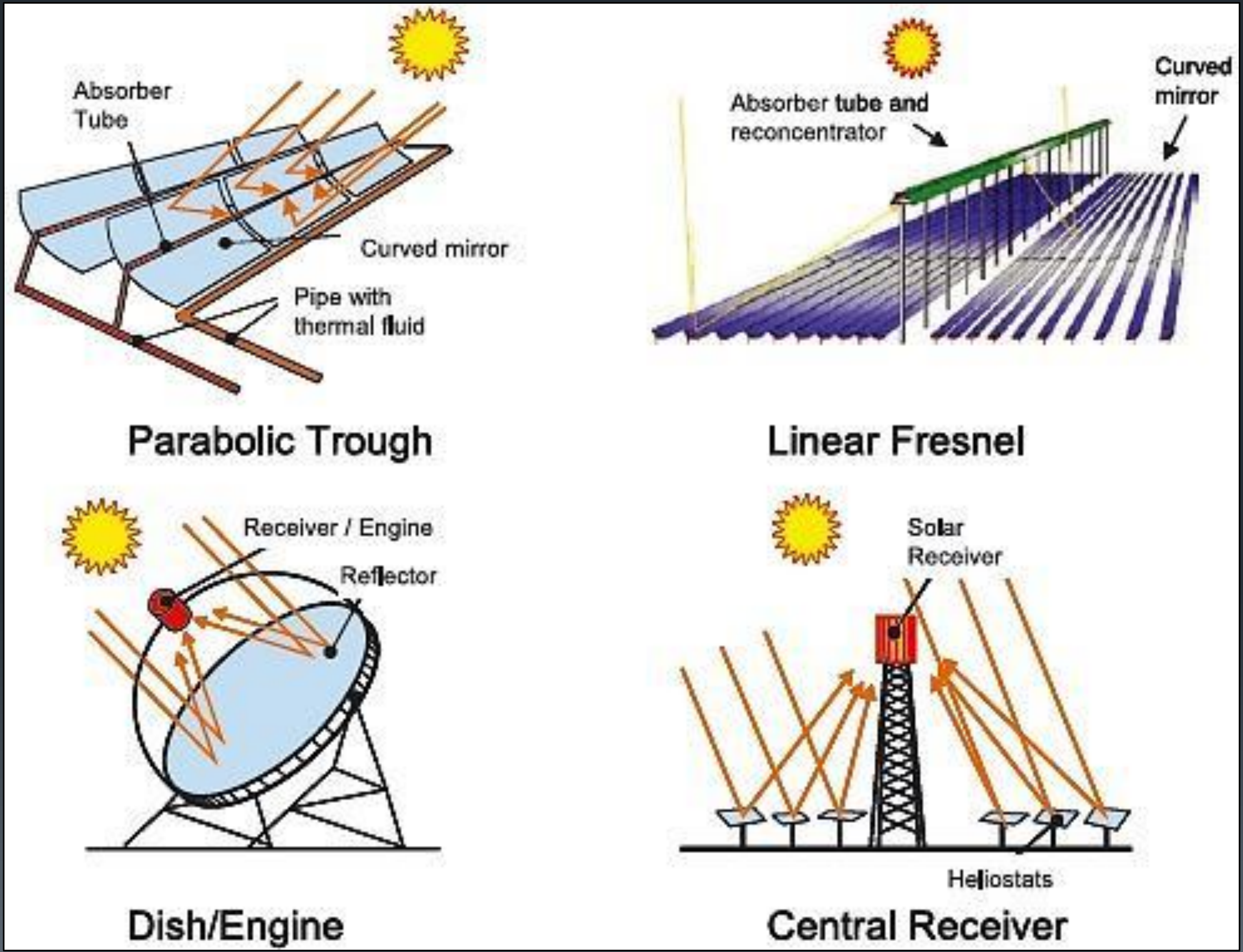
Concentrated **Solar** **Power**

- **CSP is one of renewable solar energy technologies.**
- **CSP technology simply is reflectors/absorber combination:**

  Reflectors >>> **Mirrors (Flat or curved mirrors)**

  Absorber >>> **Dark receiver (Tube or cavity)**

Four CSP Technologies



Comparison of CSP Technologies

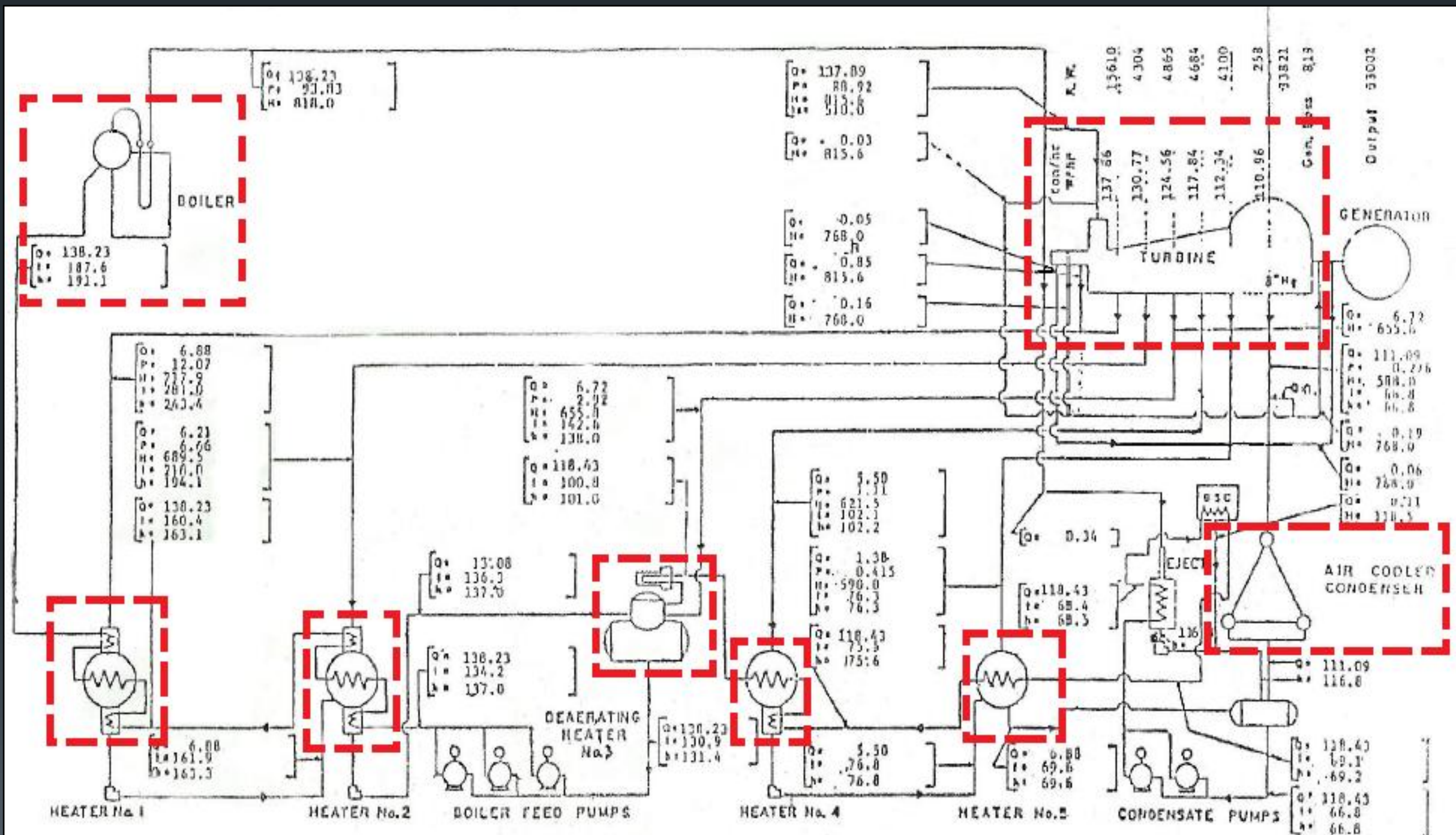
	PTC	LFR	CRS	DE
Tracking	2D, one-axis		3D, two-axis	
Capacity (MW)	Up to 360	Up to 40	Up to 400	Up to 1.5
Working Fluid	Water/Oil	Water	Water/Oil/Air	H_2/He
Fluid Temp. Range (℃)	150 - 550	150 - 450	300 - 1000	250 - 700
Concentration Ratio	30 - 80		200 - 1000	1000 - 3000
Maturity	Commercially Proven			Pilot Projects
Relative Cost	Low	Very low	High	Very High
Storage	Yes	Shot-term	Yes	Not yet
Integration with fossil fuel PP	Yes and direct		Yes	Not planned
Example	SEGS / USA (354 MW)	Puerto Errado / Spain (31.4 MW)	Ivanpah SEGS / USA (392 MW)	Maricopa / USA (1.5 MW)

Selected CSP Technology

- Parabolic trough collector (PTC) with direct steam generation was the selected CSP technology; since PTC has below advantages:

1	Commercially proven CSP technology
2	Low cost (capital and O&M) with respect to CRS and DE
3	Low relative area required
4	Possibility of direct steam generation (DSG)
5	Providing temperatures and pressures close to those required by FWHs

Existing Steam (Rankine) Cycle for 33 MW Unit at HTPP



Heat balance diagram for 33 MW unit at HTPP

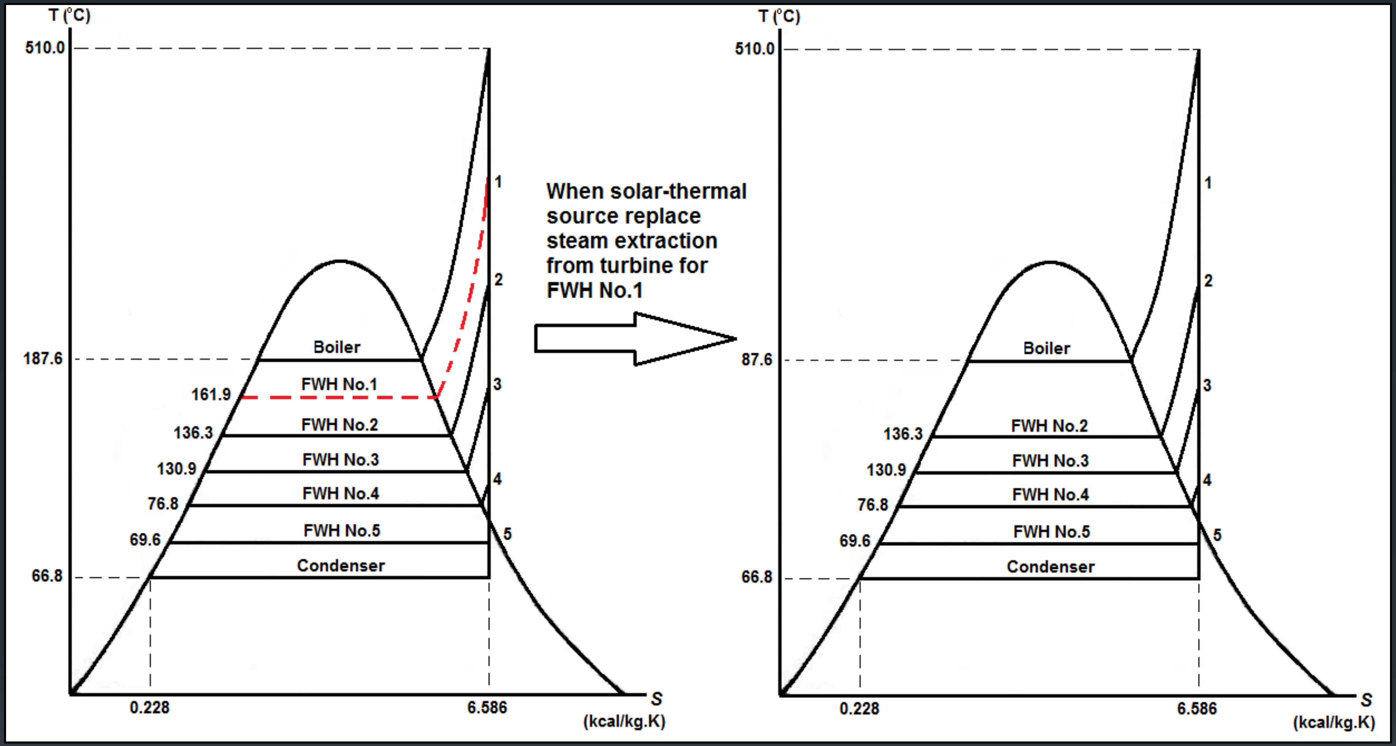
Assumed Replacement Options

- **Six scenarios were assumed for FWHs solar replacement, this options summarized as in below table:**

No. of Option	Replacement Option	Steam Bleed Saved (ton/h)	Thermal Energy Rate (kcal/h)
1	FWH #1	6.88	4,939,152
2	FWH #1+2	13.09	9,220,947
3	FWH #1+2+3	19.81	13,627,923
4	FWH #4+5	6.88	4,232,450
5	FWH #5	1.38	814,200
6	All FWHs	26.69	17,860,373

Results:

- When first replacement done; this is how will the cycle affected:



- As no steam extraction to be occurred from turbine for FWH#1 then, more work output available for generator, as well as the efficiency of current cycle will be increased, and same procedure done for all FWHs replacement scenarios.

Results:

- **Replacement of FWH #1:**

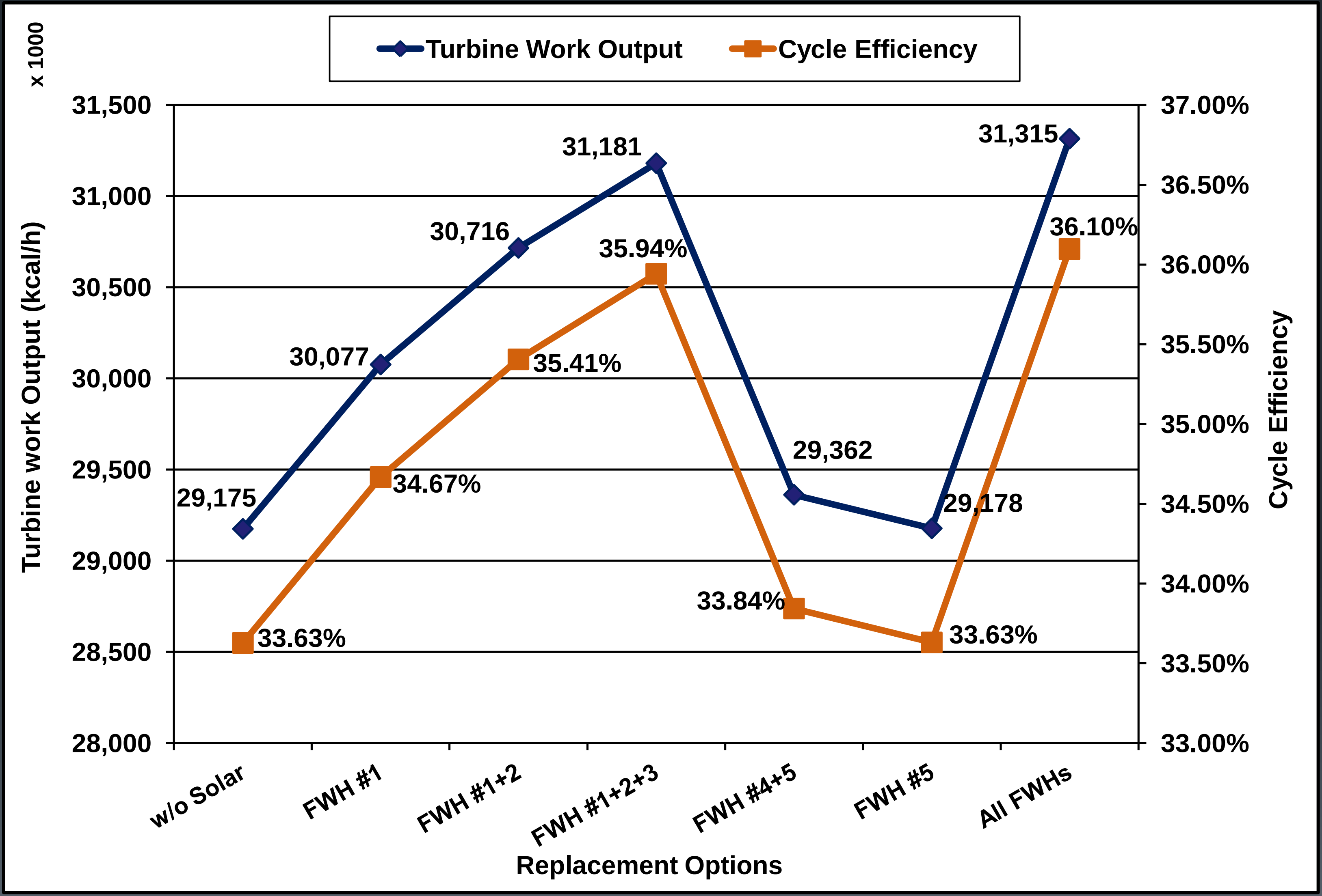
	Before Solar	After Solar	Addition
Work output (kcal/h)	29,175,210	30,076,590	901,380 ↑
Cycle Efficiency	33.63%	34.67%	1.04% ↑

- **And table below shows the conclusion of all replacement options:**

Replacement Option	Steam Bleed Saved (ton/h)	Thermal Energy Rate (kcal/h)	$\dot{W}_{Turbine}$ (kcal/h)	Cycle Efficiency η (%)
w/o Solar	0	---	29,175,210	33.63%
FWH #1	6.88	4,939,152	30,076,590	34.67%
FWH #1+2	13.09	9,220,947	30,716,004	35.41%
FWH #1+2+3	19.81	13,627,923	31,180,881	35.94%
FWH #4+5	6.88	4,232,450	29,362,220	33.84%
FWH #5	1.38	814,200	29,177,970	33.63%
All FWHs	26.69	17,860,373	31,315,484	36.10%

Results:

Turbine Output Work and Cycle Efficiency for Each Option



Simulation a CSP System

- **System Advisor Model (SAM)** by NREL was used as a **simulation tool** for optimizing PTC system.
- **Solar irradiation data** available at the Hashemite University were used and **weather data** were obtained by Atmospheric Science Data Center (administered by NASA) for selected power plant location.
- **SAM provides:**

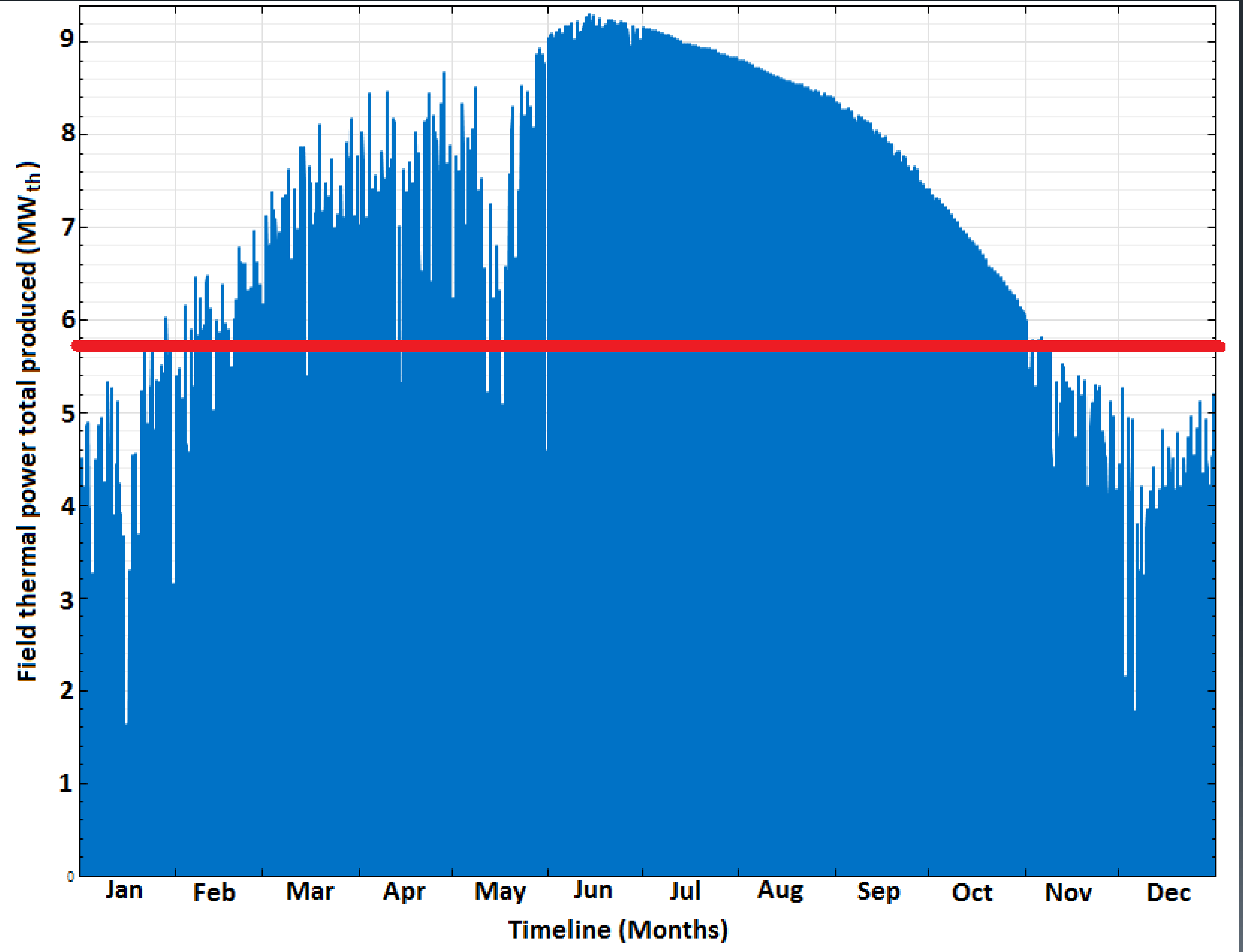
1. Required solar field aperture area (in m^2)
2. System active hours (8670 hours in the year)
3. Out-of-service days (365 days in the year)

Results of Simulation for FWH#1

	Input Parameters			Output of PTC		
Replacement Option	Solar Multiple (SM)	Required Thermal Power Output (MW_{th})	Steam Output/Input Temperatures (°C)	Solar Field Aperture (m^2)	Active Hours (hour)	Out of Service Days
FWH#1	1.50	5.74	300/160	13,160	2,043	91

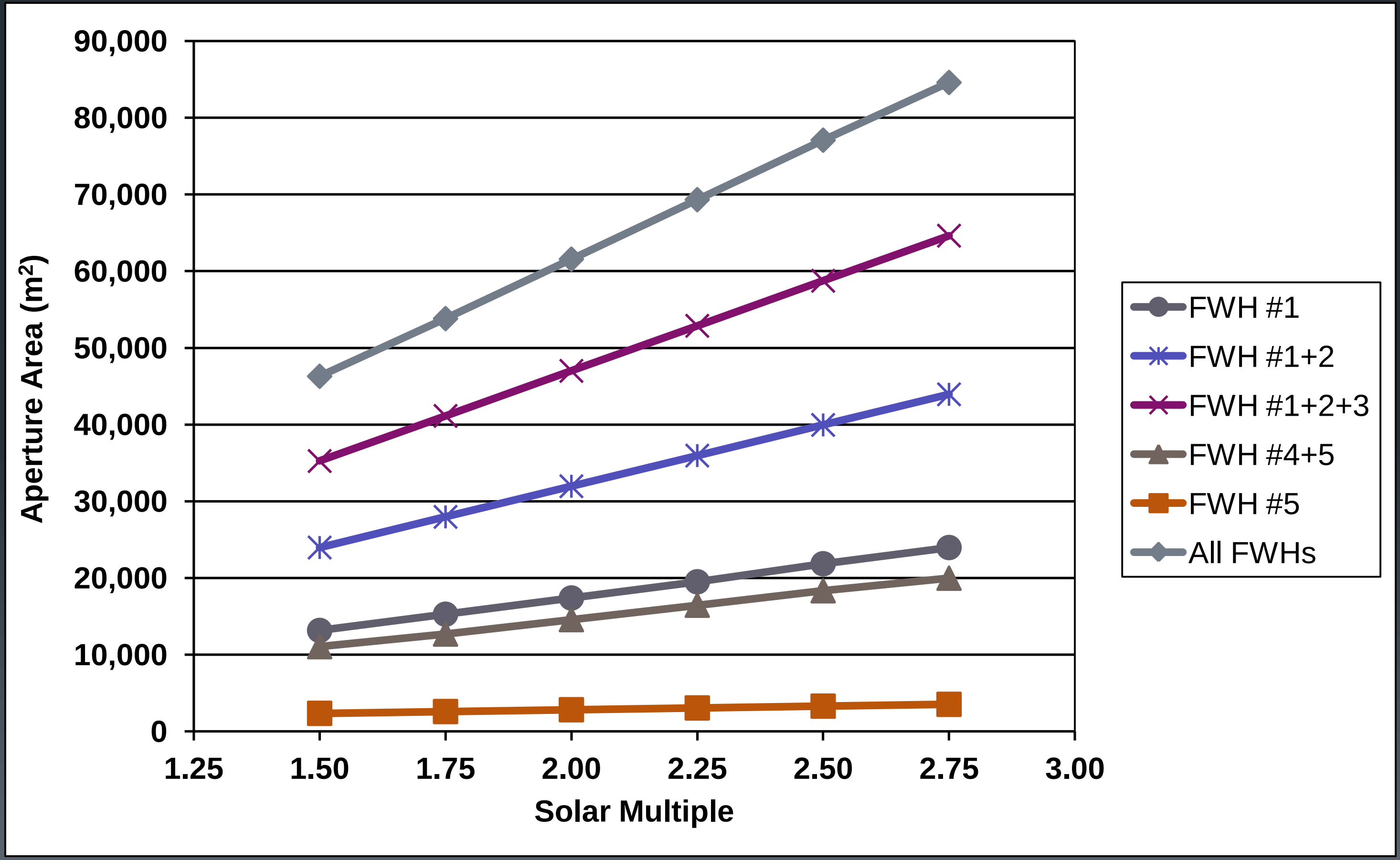
- **SM: the factor by which solar field amplified in relation to rated capacity required at design point.**
- **Active hours out of 8760 hours**
- **Out-of-service days out of 365 days**

Results of Simulation for FWH#1



Selection a CSP System

- In order to **increase active hours** and **operating days**; larger solar field required. Then **six simulations** for each replacement option were done in range of **(1.50 - 2.75, with 0.25 step) SM values**; in order to determine the optimal SM value.



Results Verification

- Two methods were used to check validity of calculated solar field aperture area:

1- Mathematical equation for estimation the aperture area proposed by Kalogirou.

By using Kalogirou's equation, aperture area was found to be about 12,084 m^2, which is less than obtained in SAM by 8%.

2- Technical comparison with existing commercial CSP plants:

By obtaining average "area-to-thermal power" ratio (m^2/MW_{th}) for plants like Shams 1, Andasol, SEGS, etc. and it was around 1,470 m^2/MW_{th}. So aperture area found to be about 12,657 m^2 which is less than obtained in SAM by 4%.

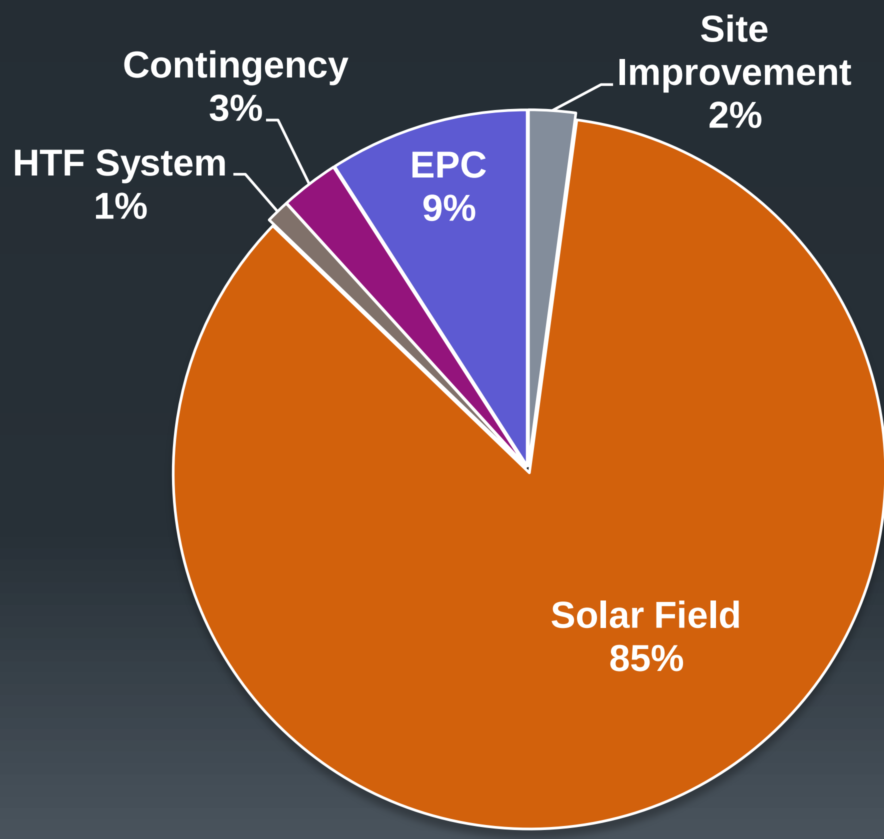
Cost of PTC System

- Based on World Bank Report, 2011 and "Cost Model" developed by NREL; **different cost factors were assumed** to estimate the cost of installed PTC system.
- Total capital cost for first case (FWH#1, SM=1.5) was calculated as below:

Parameter	Cost Factor	Cost of FWH#1, SM=1.5 (US$)
Direct Capital Cost		
Site Improvement (US$/m^2)	10.0	131,600.0
Solar Field (US$/m^2)	400.0	5,264,000.0
HTF System (US$/m^2)	5.0	65,800.0
Contingency (% of total direct cost)	3%	163,850.0
Indirect Capital Cost		
EPC (Engineering, procurement and construction) (% of total direct cost)	10%	562,530.0
Total Capital Cost (Direct & Indirect)		6,187,780.0
Annual Running Cost		
O&M (labor and material) (US$/kW-year)	12.0	68,880.0

Cost of PTC System

- **Share of direct and indirect parameters in total capital cost for FWH#1:**



Fuel Savings

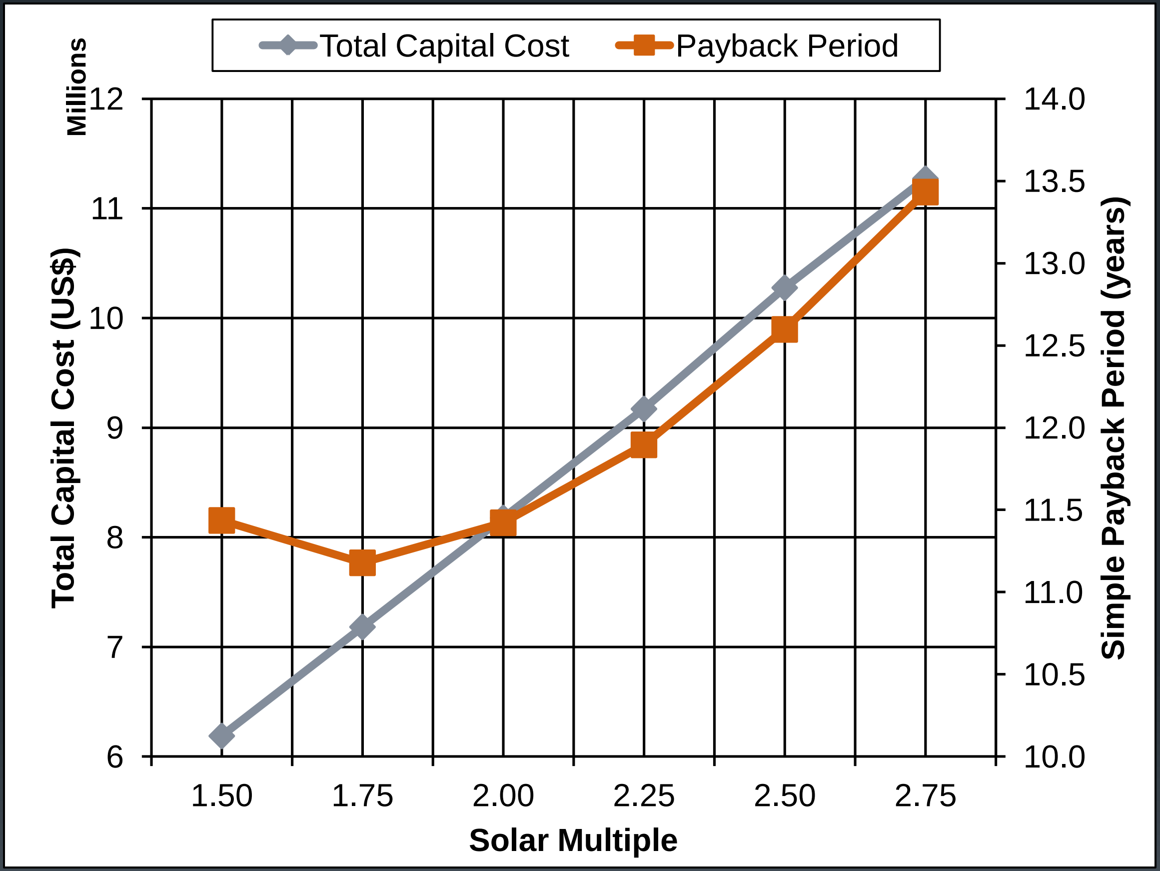
- **Fuel savings for FWH#1 with different SM values were as below table:**

SM	Solar Field Aperture (m^2)	Total Capital Cost (M.US$)	US$/$kW_{th}$ Ratio	Actual Active Hours (hour)	Thermal Energy Saved (kcal×10^9/yr.)	Fuel Saving (US$/yr.)	Simple Payback Period (year)
1.50	13,160	6.188	1,077	2,002	11.237	541,046	11.44
1.75	15,275	7.182	1,251	2,377	13.344	642,476	11.18
2.00	17,390	8.177	1,424	2,649	14.868	715,834	11.42
2.25	19,505	9.171	1,597	2,853	16.012	770,918	11.90
2.50	21,855	10.276	1,789	3,018	16.941	815,674	12.60
2.75	23,970	11.271	1,962	3,105	17.425	838,979	13.43

- **Based on this, cost for all FWHs replacement options with different SM values were done. After that, SPBP was carried out for all options.**

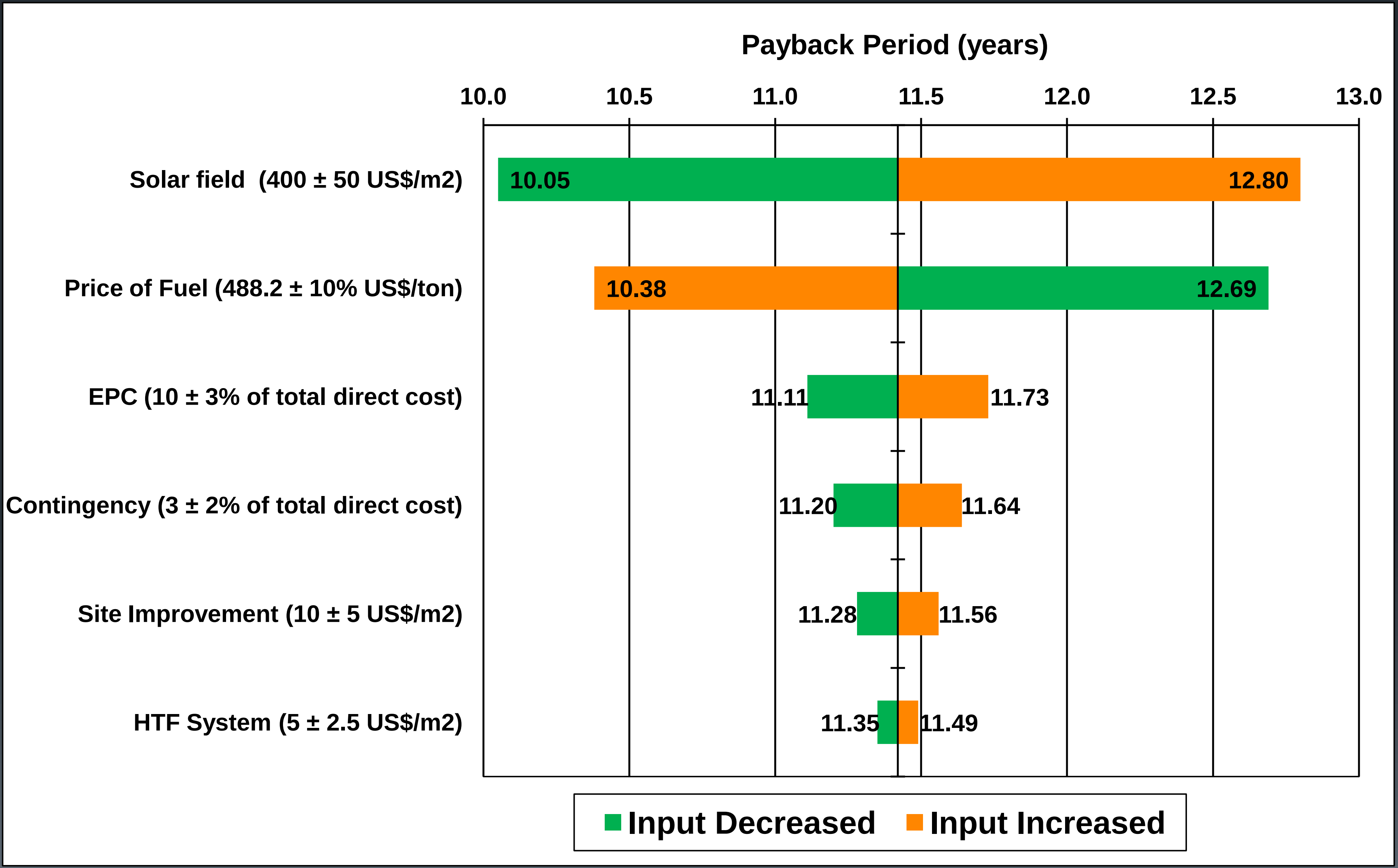
Optimizing PTC System:

- Relation between **SM values, total capital cost** and **SPBP** for FWH#1:



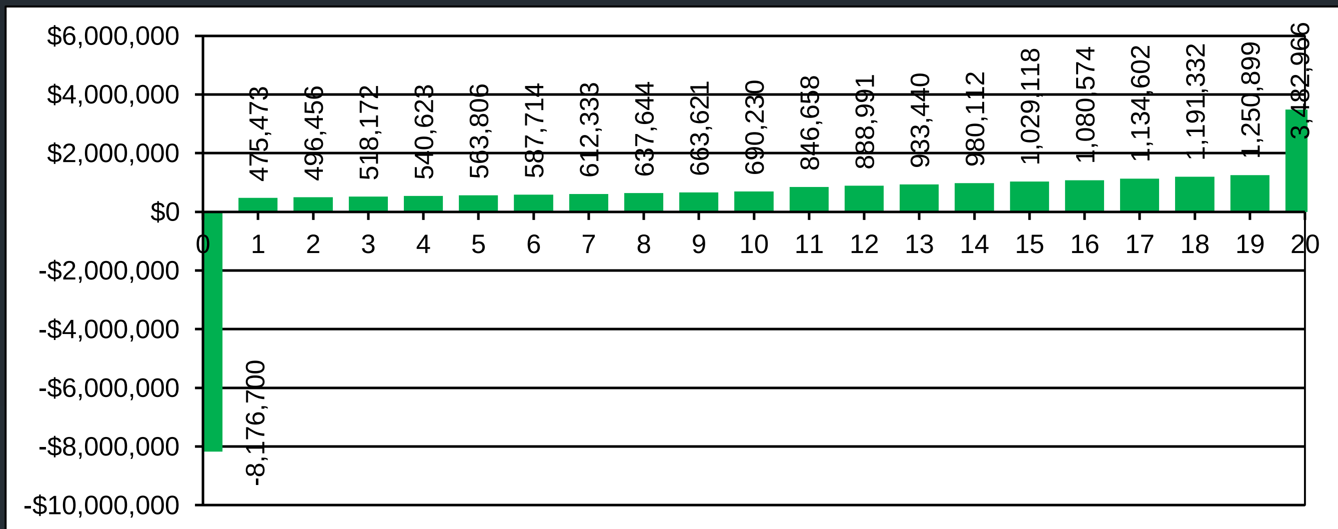
- Optimal SM value for this case at **SM=2.00**, and optimal values for other replacement options ranges between **1.75 - 2.00 SM values**.

Sensitivity Analysis

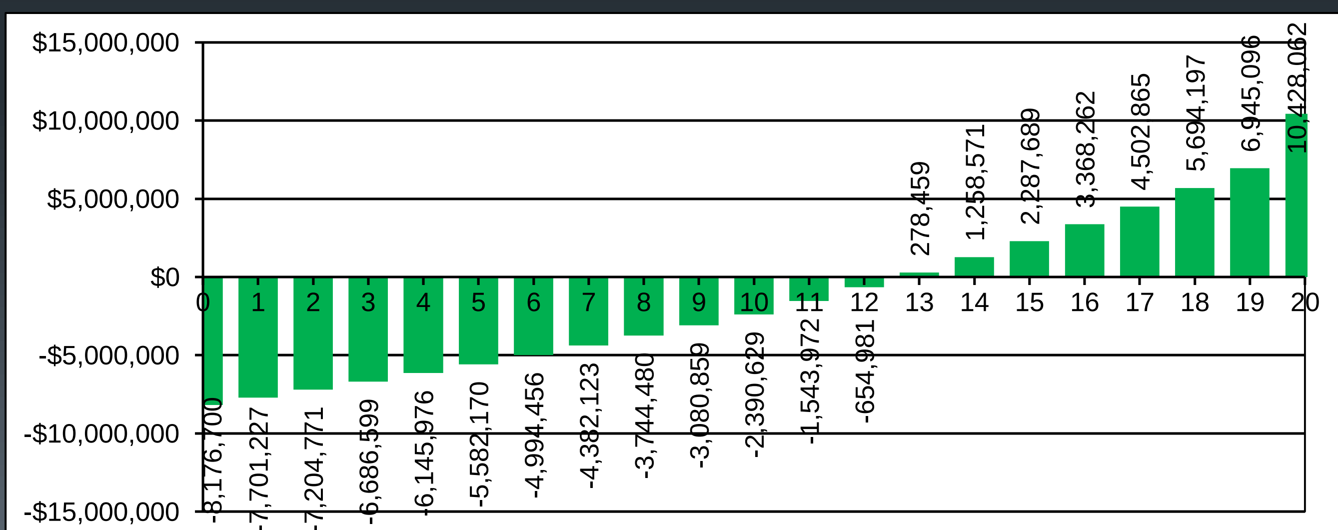


Economic Analysis:

- **Presented by cash flow diagram and Net Present Value (NPV).**
- **Financial parameters (ex: inflation, discount rates, etc.) were assumed.**

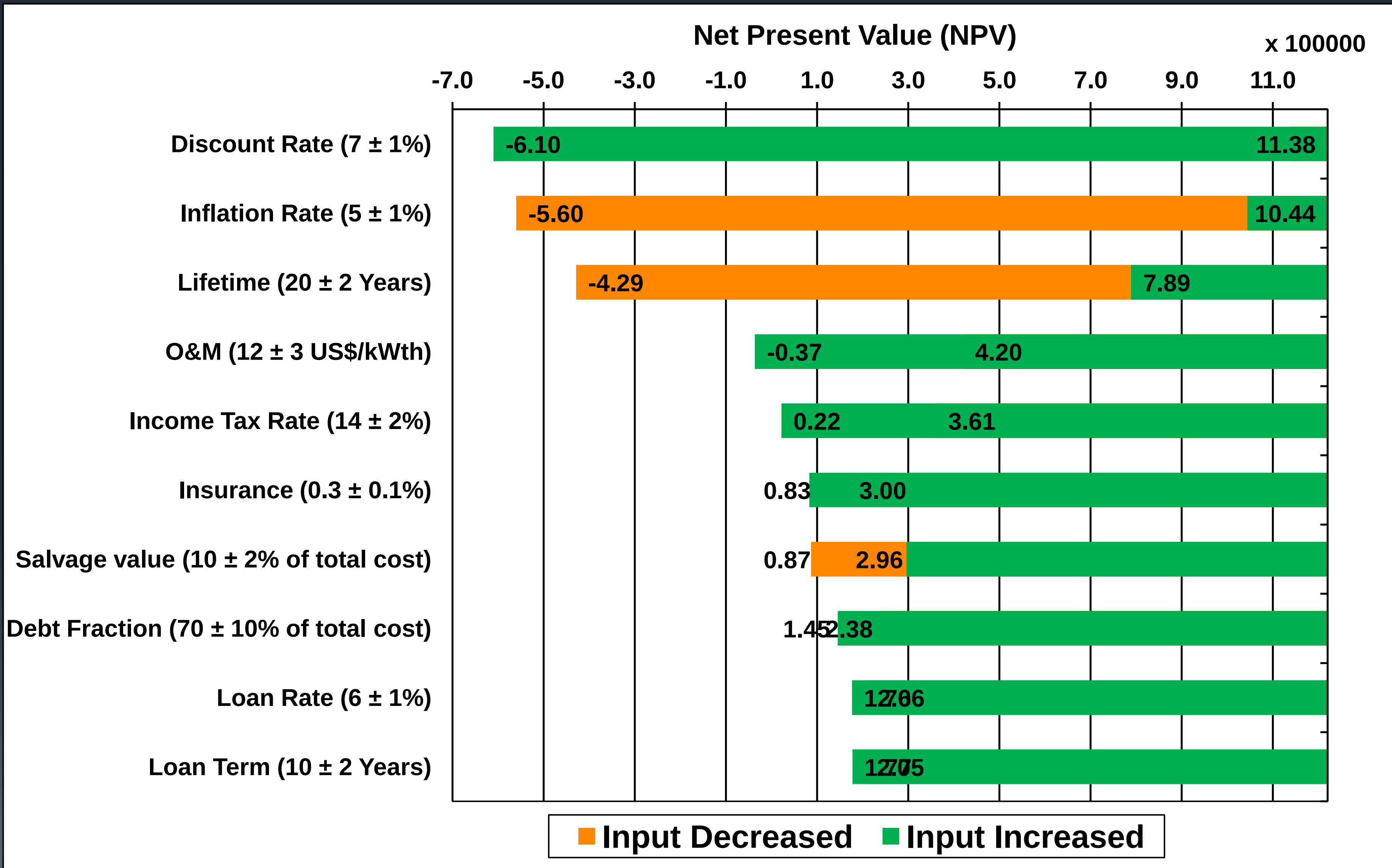


NPV of +191,503 US$

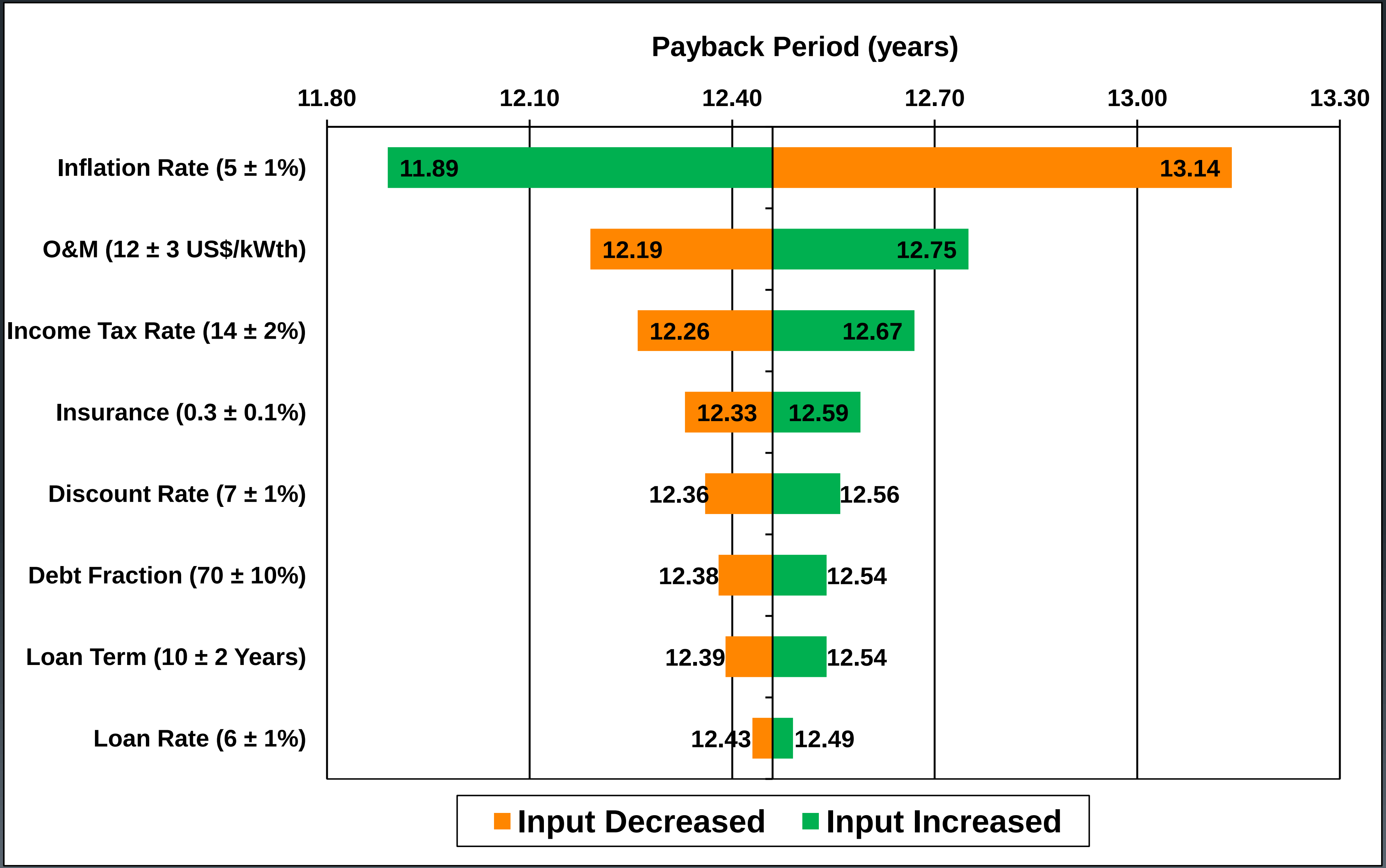


PBP of 12 years and 6 months

Sensitivity Analysis for NPV

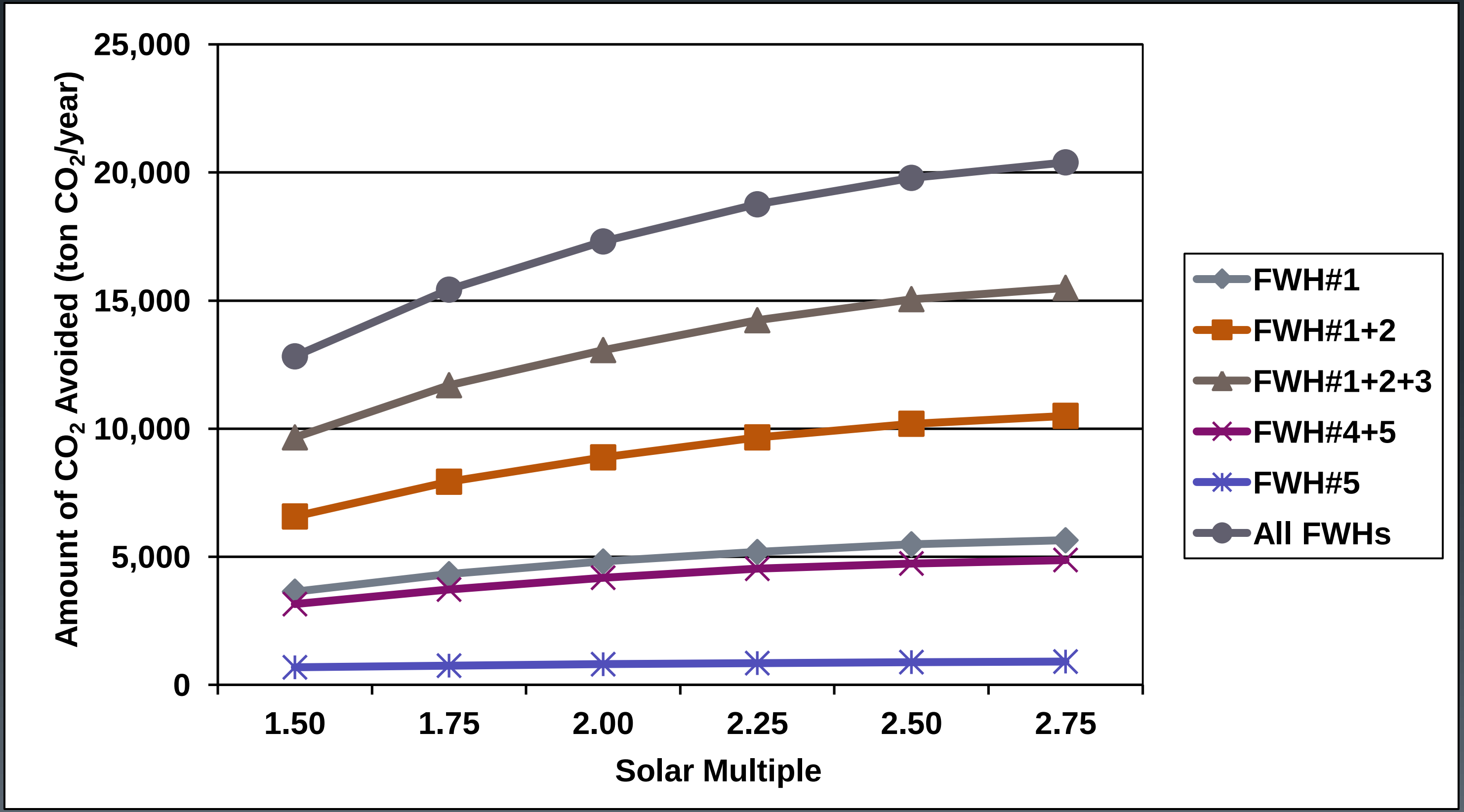


Sensitivity Analysis for PBP



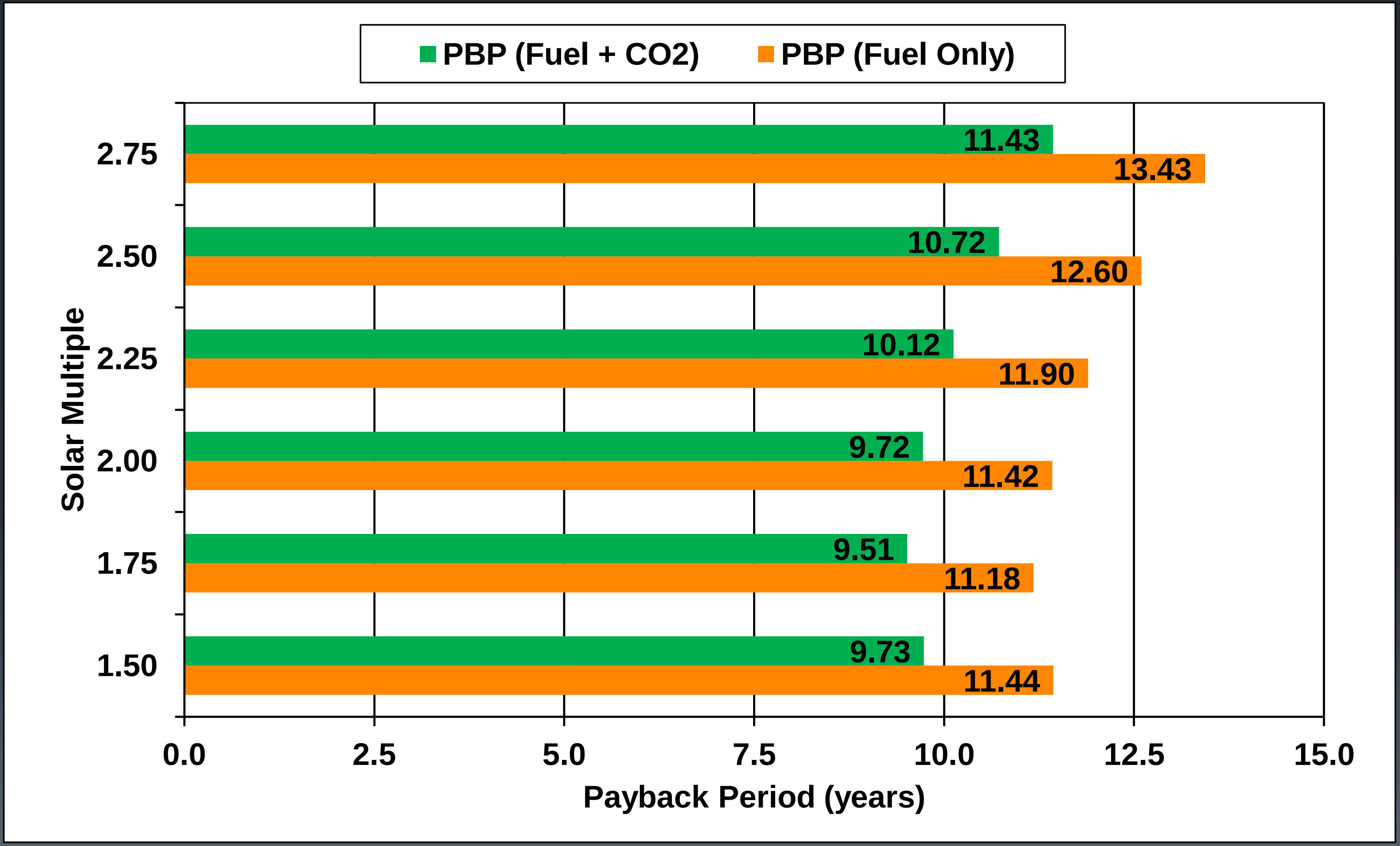
Environmental Consideration

- GHG emissions, (specifically CO_2 emissions) were considered.
- In addition to protecting the environment, other potential of reduction the investment cost was considered.
- 77.4 ton of CO_2 could be avoided per each 1 Tera joule of energy saved (77.4 ton CO_2/TJ). And each ton avoided will save 26 US$.



Environmental Consideration

- CO_2 saving contributes in **reducing SPBPs by about 15%** with respect to SPBP before considering CO_2 emissions.



Main Findings

Technical

Increasing the **efficiency** of existing Rankine cycle up to **2.47%** (from 33.63% to 36.10%);
due to increasing turbine's output work by up to 7.5% to the base case (33.92 to 36.41 MW)

Economic

- Optimum solar field SM range between 1.75 - 2.00
- Fuel savings up to 6,200 ton of HFO (3 Million US$) per year
- Payback periods around 11 years

Environmental

- Up to 17,500 ton of CO_2 avoided per year
- With additional savings of 450,000 US$ per year
- Payback period around 9 years

Future Work

- Based on findings of the study in hand, future work is recommended as below:

1	Using Linear Fresnel Reflectors (LFR) instead of PTC
2	Introducing thermal energy storage systems
3	Applying same study on other HTPP units (i.e. 66 MW Unit) and other power plants in Jordan
4	Integration with combined-cycle power plants (IPP1 & IPP2)
5	Studying solar field configuration and orientation for selected CSP technology
6	Studying how to connect selected CSP system with FWHs or the application/component that integrates directly with CSP system

Thank You!