The Cost Effectiveness of Hybridized Solar and Fossil Power Plants Compared to Stand-Alone PV or CSP Plants

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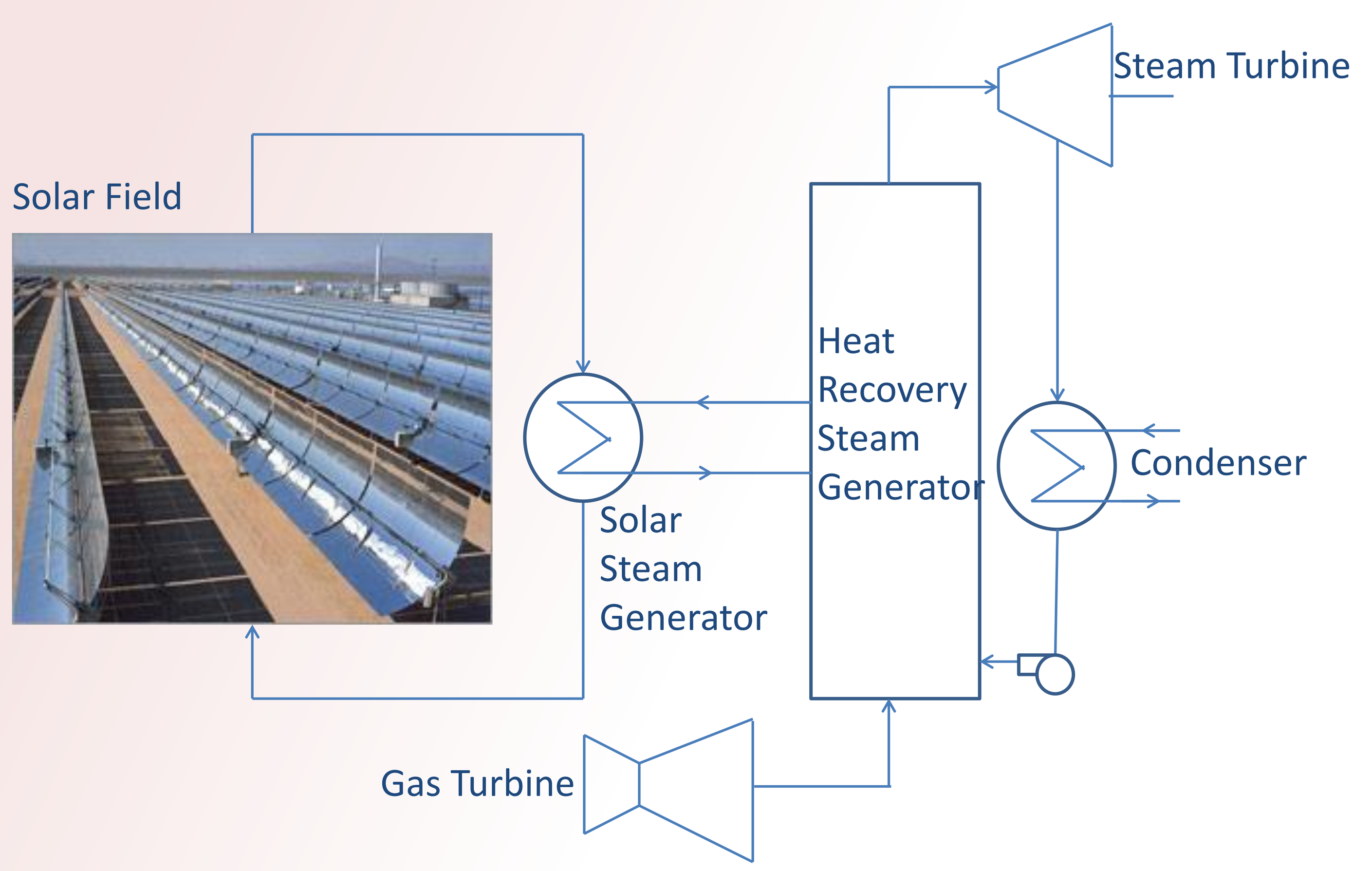
Integrated Solar Combined Cycle: Integrated Solar Combined Cycles (ISCC) are natural gas combined cycle (NGCC) power plants hybridized with solar thermal energy to boost the output of the heat recovery steam generator. The principal advantage to hybridization for solar power is the ability to directly off-set fossil fuel energy without having to pay for a power block or transmission lines dedicated to solar energy. The power block of a stand-alone CSP plant is appreciable, accounting for approximately 40% to 50% of the capital costs. Assuming that the capacity factor of stand-alone CSP plants are around 25%, sharing a power block with a fossil fuel power plant greatly increases its utilization. Additionally, since maintenance personnel are already on hand to monitor and maintain the power block, maintenance costs assigned to the solar portion are reduced.

Diagram of an Integrated Solar Combined Cycle



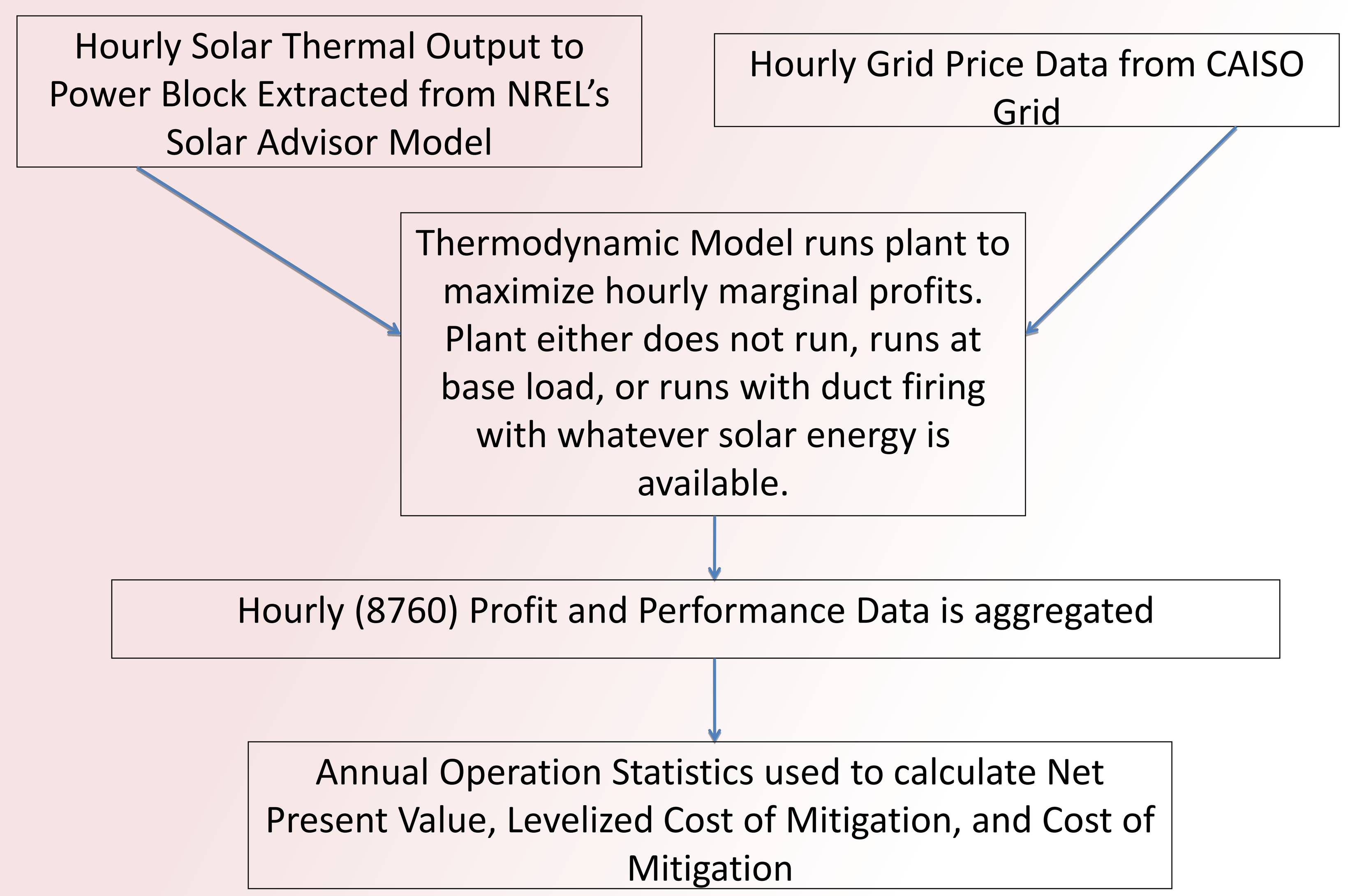
Solar thermal energy in integrated into the HRSG. Heat transfer fluid (HTF) is heated in the solar field by parabolic trough shaped mirrors. Hot HTF is then used to make steam in a heat exchanger before the steam returns to the HRSG. The added steam from the solar field is intended to off-set less efficient duct firing.

Efficiency with Duct Firing and with Solar Energy

	Base Load		Duct Firing		Solar and Duct Firing	
	Efficiency	MW	Efficiency	MW	Efficiency	MW
CEC Application for Certification	55.2%	463	52.6%	563	58.8%	563
My Model	54.9%	463	52.9%	567	59.2%	564

Solar energy boosts the efficiency of the power plant. If duct firing is used to reach full capacity, efficiency of the power plant decreases. With solar energy, the efficiency of the power plant increases at full load.

Economic Model



Capacity Factor of the ISCC Power Plant / Capacity Factor of Solar Portion of ISCC Power Plant (Location: Phoenix)

		Average Wholesale Price of Electricity [$/MWh]					
		$ 35	$ 45	$ 55	$ 65	$ 75	$ 85
Price Of Gas [$/MCF]	2	88 / 22 %	89 / 22 %	90 / 22 %	90 / 22 %	91 / 22 %	91 / 22%
	4	71 / 21 %	83 / 21 %	86 / 22 %	88 / 22 %	89 / 22 %	89 / 22%
	6	27 / 10 %	55 / 18 %	74 / 21 %	82 / 21 %	85 / 22 %	87 / 22%
	8	8 / 2 %	23 / 9 %	44 / 15 %	63 / 20 %	76 / 21 %	82 / 21%
	10	4 / 1 %	9 / 3 %	21 / 8 %	38 / 14 %	55 / 18 %	68 / 20%
	12	4 / 1 %	5 / 1 %	9 / 3 %	20 / 8 %	34 / 12 %	47 / 16%

The capacity factor is defined as the number of MWh produce divided by the number of MWh that could have been produced if the plant ran at capacity for all 8760 hours of the year. The capacity factor for the solar portion of the power plant is close to the observed ~25% capacity factor for CSP generators. Since the solar side of the plant can run only while the power block is available, the capacity factor is slightly lower due to a forced outage rate of 5% on the fossil side of the ISCC plant.

Cost Assumptions

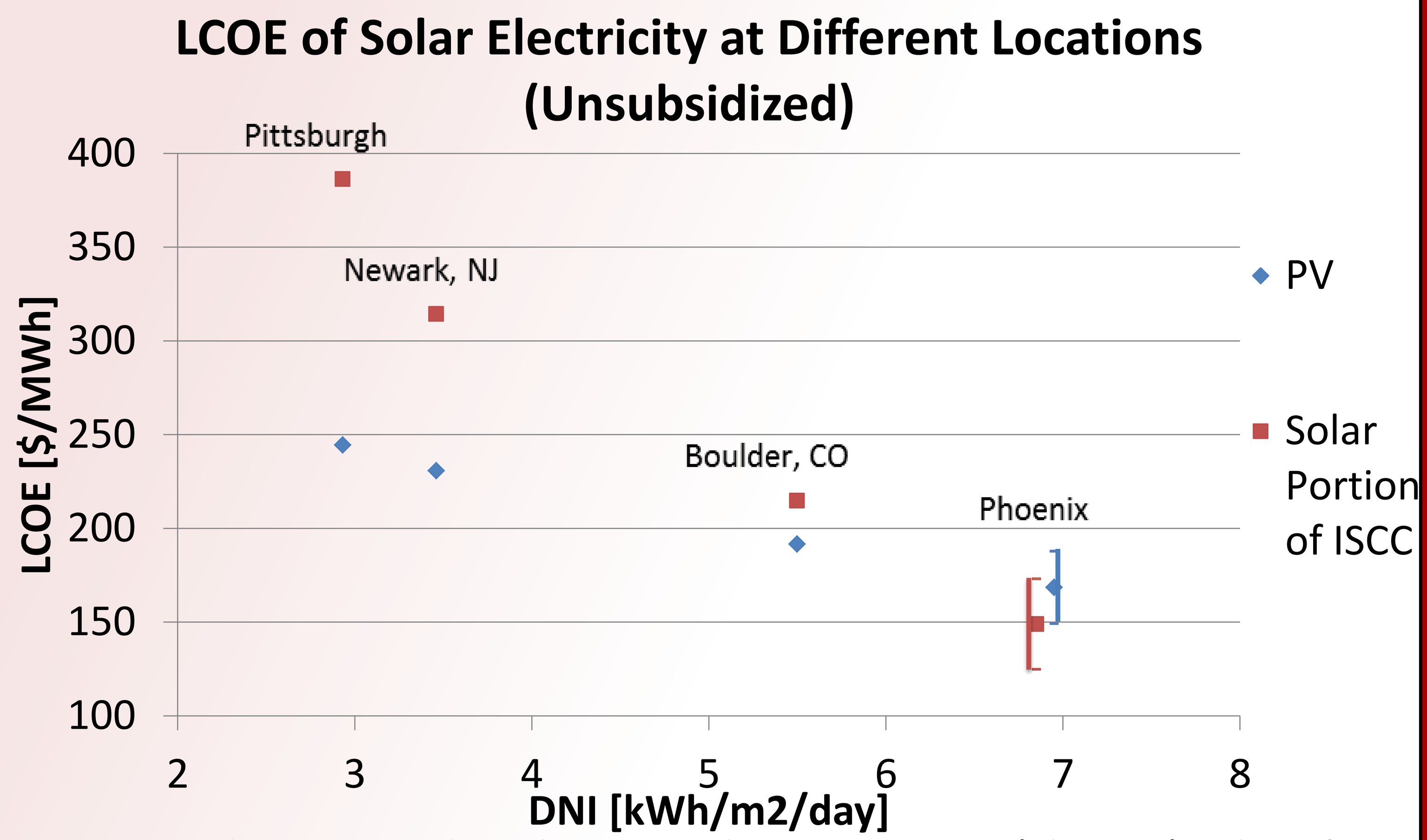
	NGCC	Solar Thermal (Trough, No Storage)	Solar PV	Solar Part of ISCC
Capital Costs $/kW	1000 ± 100	5800 ± 500	4400 ± 500	3900 ± 600
Fixed Maintenance Costs $/kW-year	5.8 ± 1	65 ± 15	25 ± 10	30 ± 10
Lifetime of Plant (Years)	25	25	20	25

The cost estimate for PV is based on the cost per AC watt. Cost estimates for PV are frequently quoted in $/Watt$_{DC}$. To arrive at the cost per watt AC, we multiply the DC cost estimates by 1.15 for the AC to DC capacity difference. Therefore, the mid-value for capital costs for PV we garnered from studies was $3.8/W$_{DC}$.

Levelized Cost of Electricity of Solar Portion of ISCC Power Plant (Location: Phoenix)

		Average Price of Electricity [$/MWh]					
		$ 35	$ 45	$ 55	$ 65	$ 75	$ 85
Price Of Gas [$/MCF]	2	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**
	4	**$160**	**$150**	**$150**	**$150**	**$150**	**$150**
	6	$330	$180	**$160**	**$150**	**$150**	**$150**
	8	$1,500	$370	$220	$170	**$160**	**$150**
	10	$2,800	$1,300	$400	$240	$180	**$160**
	12	$3,300	$2,400	$1,100	$430	$270	$200

LCOE for PV from model is $170 / MWh, for CSP from model is $190 / MWh. Bold signifies ISCC solar portion LCOE is lower than PV or CSP



CSP power plants can only utilize direct beam radiation (aka DNI). Therefore, the solar portion of ISCC power plants would likely only be more competitive than PV power plants if located in areas with strong DNI—Southwest U.S.

Cost of Mitigation for Solar Portion of ISCC Plant in Phoenix, AZ (If coal is off set / If NGCC if off set) [$/tonne CO_2 avoided]

		Average Wholesale Price of Electricity [$/MWh]					
		$ 35	$ 45	$ 55	$ 65	$ 75	$ 85
Price Of Gas [$/MCF]	2	**$110 / 310**	**$110 / 310**	**$110 / 310**	**$110 / 310**	**$100 / 310**	**$100 / 310**
	4	**$120 / 340**	**$110 / 320**	**$110 / 320**	**$110 / 310**	**$110 / 310**	**$110 / 310**
	6	$310 / 810	**$140 / 400**	**$110 / 330**	**$110 / 320**	**$110 / 320**	**$110 / 310**
	8	$1,700 +	$360 / 940	$180 / 500	**$130 / 360**	**$110 / 330**	**$110 / 320**
	10	$3,200 +	$1,400 +	$400 / 1000	$210 / 570	**$140 / 400**	**$120 / 340**
	12	$3,800 +	$2,800 +	$1,200 +	$430 / 1,100	$240 / 640	$160 / 460

Bold font signifies a lower COM for the solar portion of the ISCC plant compared to PV and CSP. The COM for PV and CSP if coal was offset $140 and $160/tonne of CO_2. The COM for PV and CSP if natural gas was offset is $410 and $440/tonne of CO_2.

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