Policy Tradeoffs with Solar Thermal Energy Storage

Problem: With the United States electricity industry responsible for approximately 40% of national greenhouse gas emissions [1], renewable portfolio standards (RPS) and federal incentives have created a recent momentum for the development of large solar energy projects. Parabolic trough (PT) concentrated solar power (CSP) has dominated the utility-scale solar electricity market since the 1980s, with a current U.S. capacity of 419 megawatts (MW) and nearly 6 gigawatts (GW) under development [2]. One key advantage of CSP over other solar technologies is its ability to store energy for later use. As the PT market continues to grow, industry leaders are divided over the question of whether thermal energy storage (TES) should be included in new installations. Proponents claim that TES improves power plant economics by extending operational hours into peak demand periods, and opponents argue it represents a significant increase in the already high capital cost of a PT plant, further reducing the likelihood of obtaining project financing. However, this is not solely an industry question; the public also has a stake in how future renewable energy development proceed. Therefore, it is crucial that policy-makers understand whether TES for CSP should be an integral part of future renewable energy policy from an economic and environmental standpoint.

Approach: In order to understand whether renewable energy policy should include provisions to encourage TES, the economic and environmental effects associated with using CSP with TES must be assessed and compared. This study assesses the effect of TES on CSP plant economics through an engineering-economic model that simulates the hourly and annual operation of a PT plant with and without storage. This model calculates the total plant capital cost, operation and maintenance (O&M) costs, levelized cost of electricity (LCOE), and expected annual revenue and profit and the results are compared for a CSP plant with TES and a CSP plant with an equivalent amount of natural gas backup capacity. The effect of incentives and electricity pricing is also examined. The environmental analysis uses life cycle assessment to calculate the effect of TES on the life cycle greenhouse gas emissions, water and land use of the power plant. A multi-attribute decision model ties the two analysis together to provide a framework for policy-makers to evaluate the decision in the context of particular preferences.

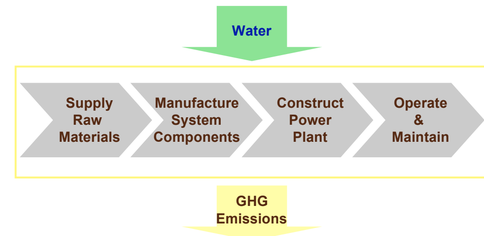
References:

1. "Annual Energy Review 2009," U.S. Energy Information Administration, Office of Energy Markets and End Use 0384, 2010.
2. B. Prior, "Concentrating Solar Power 2011: Technology, Costs and Markets," ed: Greentech Media Webinar, 2011.

2 Economic Model

- $C_{cap} = c \cdot (C_{solar\ field} + C_{TES} + C_{heater} + C_{power\ block}) + C_{indirect}$
  - c = contingency = 1.1
  - $C_{indirect}$ = engineer, procure, construct, misc, sales tax
- $C_{cap\text{-}subsidized} = C_{cap} \cdot (1\text{-}ITC)$
  - ITC = 30% investment tax credit
  - Applied as the current cash grant option under ARRA
- $C_{loan} = [k \div (1-(1+k)^{-j})] \cdot C_{cap} \cdot F_{debt}$
  - k = loan rate = 7%
  - j = 20 yrs
  - F_{debt}= 60%
- $NPV_{loan} = \Sigma\ [C_{loan} \div (1+i)^{year}]$
- Levelized Annual Capital Cost (LAC):
  - $LAC = [i \div (1-(1+i)^{-n})] \cdot [NPV_{loan} + C_{cap} \cdot F_{equity}]$
    - i = cost of capital = 12%
    - n = 30 yrs
- $C_{OM} = C_{labor}+C_{service\text{-}contracts}+C_{utilities}+C_{misc}$
  - $C_{utilities}$:
    - C_{NG} = \$6/MMBtu
    - C_{H2O} = \$450/acreft
    - C_{AUX} = \$135/MWh
- $LCOE = (LAC + C_{OM}) \div E_{sold}$
- $P = \Sigma\ (E_{sold\text{-}hourly} \cdot (p - LCOE))$
  - p = hourly real-time price from CAISO
- $P_{PPA} = \Sigma\ (E_{sold\text{-}hourly} \cdot (p_{PPA} - LCOE))$
  - p_{PPA} = guaranteed price of electricity through power purchase agreement (\$200/MWh)

3 Environmental Model (LCA)



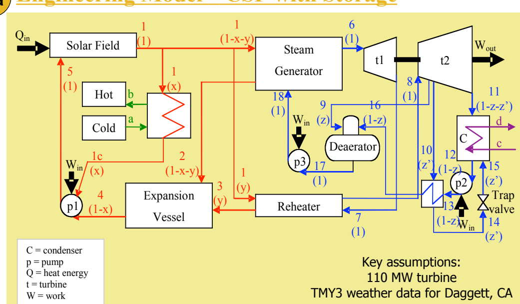
4 Multi-Attribute Decision Model

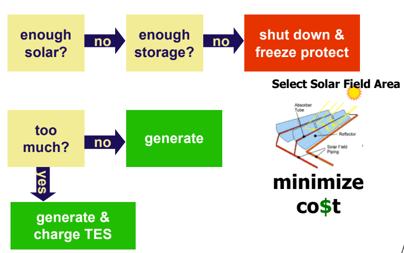
Utility (U) Function: $U = aE + bC + cG + dW + eL$

Attributes	Weights (preference)
E = annual electricity generation	a = 0.2
C = Levelized cost of electricity (unsubsidized)	b = 0.2
G = Life cycle greenhouse gas emissions	c = 0.2
W = O&M water use	d = 0.2
L = Total land use	e = 0.2

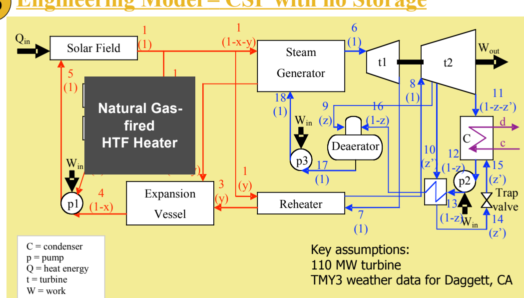
$$0 < \text{Attribute score} = \frac{\text{nominal - optimal}}{\text{high - low}} < 1$$

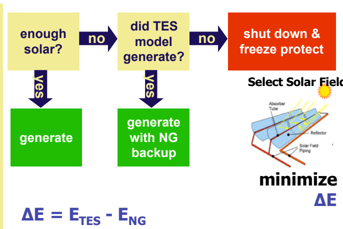
1a Engineering Model – CSP with Storage



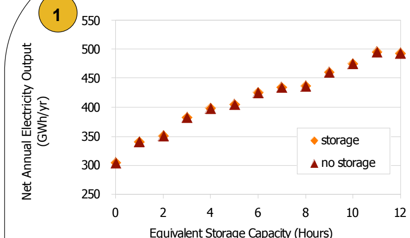


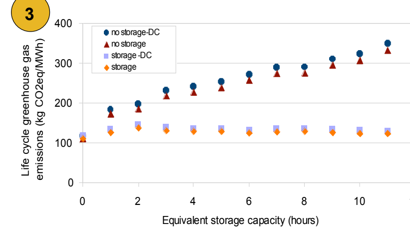
1b Engineering Model – CSP with no Storage

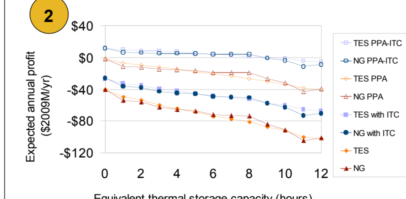


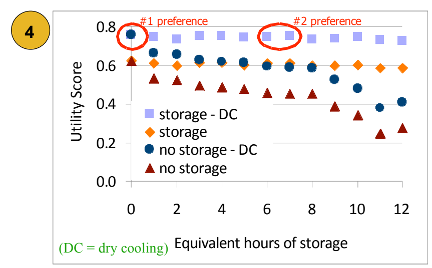


Illustrative Results









Preliminary Conclusions: 0 hr TES/NG is optimal for most attributes (GHG emissions, water, land, cost, profit). If reliability is important and economic and environmental preferences are equal, it may be beneficial to develop policies that encourage 6-7 hours of storage instead of NG and dry cooling. The combination of the federal ITC and a PPA is required for CSP to be profitable with or without TES. A CO_2 price ≥\$150/tonne CO_{2eq} is required for CSP to be competitive with coal-fired electricity generation. *Still to do: conduct sensitivity analysis and quantify uncertainty.*