Modular Trough Power Plants

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Modular Trough Power Plants

Objective

- Study the feasibility of application of Organic Rankine Cycles to solar trough technology

- Carry out systems analysis and LEC calculations for a Modular Trough Power Plant (MTPP)

Modular Trough Power Plants

Concept Description

- MTPP combines field proven technologies of organic Rankine cycle (ORC) and the concentrating solar power (CSP) troughs
- ORC power units have been successfully used for resource temperatures up to 400 F
- CSP troughs have been deployed and used to provide heat resources up to 735 F
- Combination of these technologies may provide great opportunities for modular electrification

Modular Trough Power Plants

Unique Aspects and Advantages

- Links proven technologies such as ORC power cycle with trough solar technology
- Makes trough technology available to higher value distributed and remote power markets
- Allows lower operating temperatures (450 ^{o}F - 580 ^{o}F):
  - Lower-cost non-evacuated receiver tubes may be used
  - Efficient cost effective thermal storage
  - Smaller solar field
- Reduces water utilization (ORC air-cooled)
- Standalone and automated operation with minimal operator involvement

Modular Trough Power Plants

MTPP Analysis for 1 MWe Plant

- Three ORC power units were analyzed in this work:
  - Simple ORC
  - An ORC with recuperation
  - An ORC with recuperation and reheat

- Pentane was used as working fluid for the ORC and Caloria HT-43 was used for the solar field heat transfer fluid

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MTPP Analysis for 1 MWe Plant

- Assumptions:

  resource temp. = 580 F (304 C)
  sink temp. = 80 F (26.7 C)
  turbine eff. = 0.75
  pump eff. = 0.67
  generator eff. = 0.94
  recuperator effectiveness = 0.80
  heater pinch point = 17 F (9.4 C)
  air-cooler pinch = 13 F (7.2 C)

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MTPP Analysis for 1 MWe Plant

Table 1: ORCs Analyzed for 580 F (304 C) Resource Temperature

Cycle	Cold HTF ºF (C)	Gross Elec. kW	Parasitic Elec. kW	Net Effic %
Basic Rankine	181 (82.7)	1093	122.1	12.5
Recuperated	344 (173.3)	1093	124.0	20.1
Recup. & Reheat	415 (212.8)	1125	123.3	20.5

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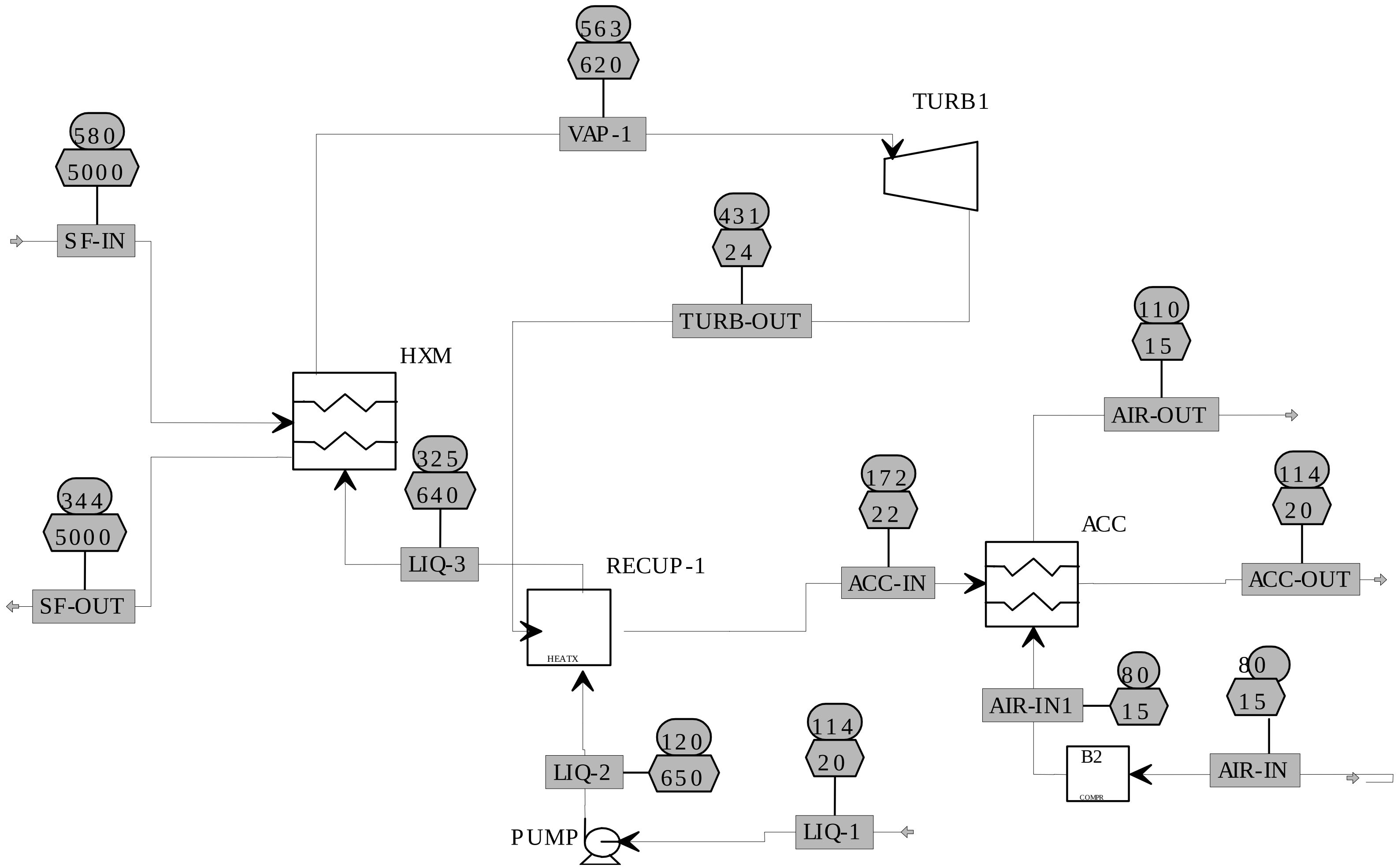
MTPP with Recuperation



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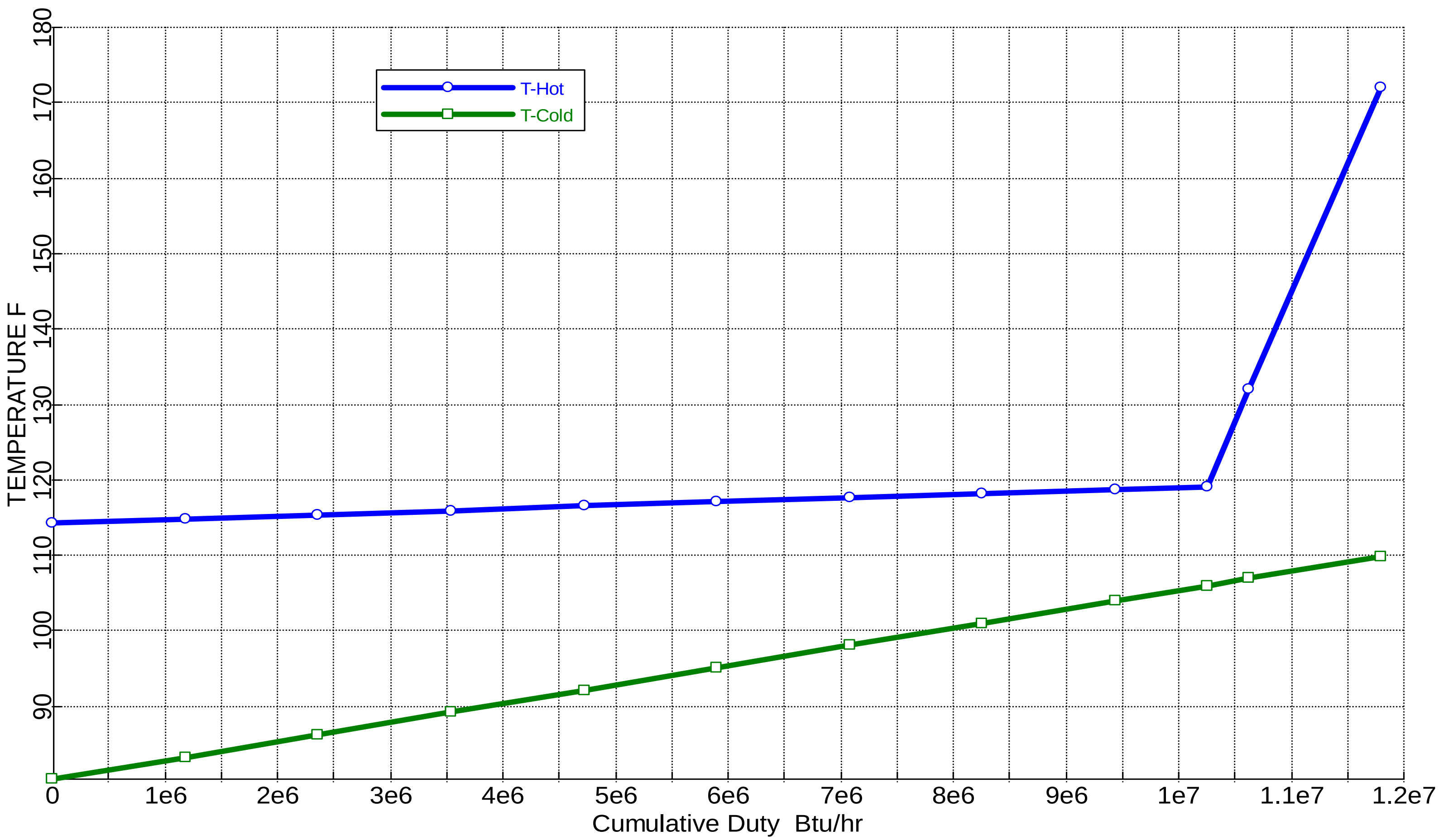
Cooling curve for the recuperated cycle



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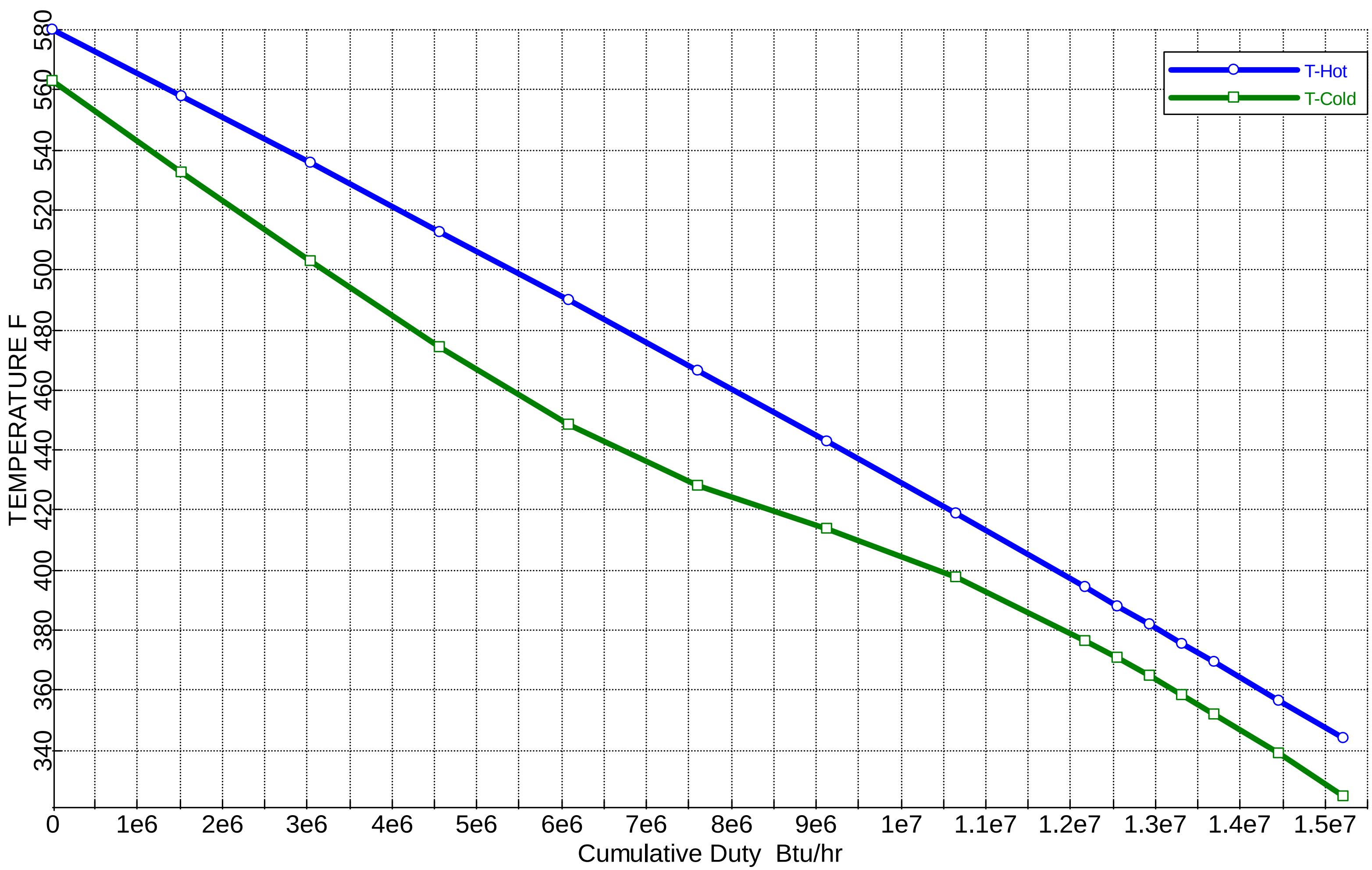
Boiling curve for the recuperated cycle



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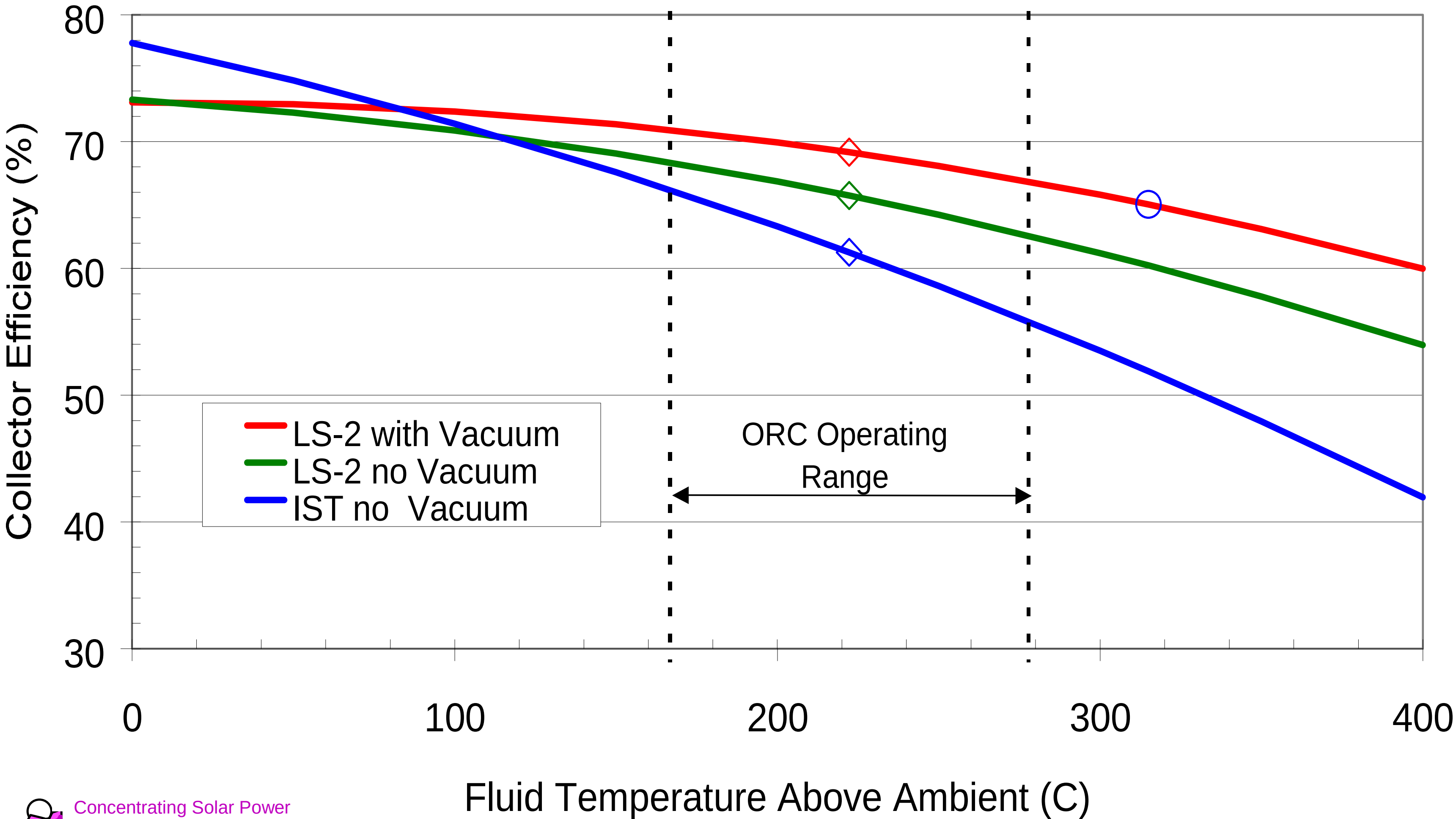
Options for Improving Cycle Efficiency

- The efficiency of the recuperated cycle can be improved from 20.1% to 23.0% by:
  - lowering the condenser pressure to 17.5 psia (0.121 MPa)
  - reducing the pinch points in all heat exchangers to 5 F (2.8 C)
- The installed cost for ORC is about $1700/kW
  - air-cooled condenser is 20% of the total capital cost
  - turbine is about 45% of the capital cost
- Our goal is to develop packaged systems with an installed cost of $1000/kW

Parabolic Trough Collector Efficiency

Sandia Collector Test Results (Dudley 1994)



Concentrating Solar Power
Sun♦Lab
Sandia National Laboratories, Albuquerque, NM
National Renewable Energy Laboratory, Golden CO

Trough ORC Case Study
Design Assumptions

- Location: Barstow, California
  - Annual Direct Normal Radiation 2800 kWh_t/m2
- ORC Plant Design (Barber Nichols)
  - 1 MWe (net electric generation)
  - Recuperated Organic Rankine Cycle
  - Air Cooling - 80 F (27C) design point
  - 22.5% thermal to net electric efficiency

Trough ORC Case Study

Design Assumptions (Cont.)

- Solar Field Design Assumptions
  - Luz LS-2 Type Collector
  - Collector field temperature 380-580F (193-304C)
  - Optical Efficiency: 77%
  - Collector Cleanliness 90%
  - Solar Field Availability 99%
  - Non-evacuated receiver with cermet selective coating
  - Field Size: 20,000 m2 (Solar Multiple of 2.4)
- Thermal Storage
  - Heat transfer fluid: Caloria HT-43
  - 2-Tank Thermal storage system
  - 9 hours of thermal storage (47 MWh_t)

Trough ORC Case Study
Plant Performance

Annual Solar Field Efficiency	44%
Annual Heat Losses from Storage	2.2%
Dumped Energy (storage full)	1.3%
Annual Solar to Electric Efficiency:	8.4%
Annual Net Electric Output	4632 MWh
Capacity Factor @ 1 MWe:	53%

Trough ORC Case Study
Economic Analysis

- Plant Cost $7044/kWe
  - ORC Power Plant: $1700/kWe
  - Parabolic Trough Collector Field: $200/m2
  - Thermal Storage: $12.5/kWht
  - 10% Engr. Design, Construction Mgt., Contingency
- O&M cost
  - Solar Field, 1.0¢/kWh
  - Power Plant Maintenance/Operation, 1.5¢/kWh
- Economic Assumptions
  - Lifetime, 20 years
  - Discount Rate, 10%
  - Annual Insurance, 0.5% of Capital Cost
- Levelized Energy Cost, 21¢/kWh

Conclusions

- Modular trough/ORC power plants feasible
  - ORC and trough solar technology proven
  - Integration issues need to be addressed
  - O&M costs are a key issue
- Near-term costs ~ 20¢/kWh (Second Plant)
  - 10^{th} plant ~ 15 ¢/kWh
  - Financial incentives would further reduce cost.