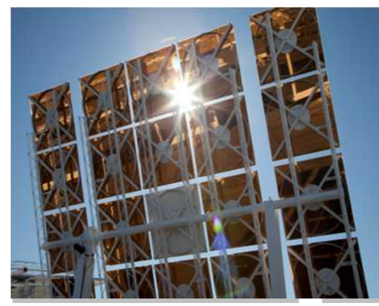
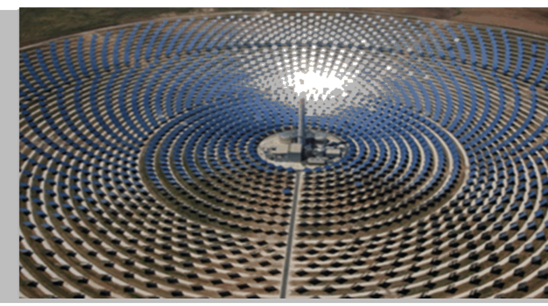
SAND2014-17536PE

Derivation of a Levelized Cost of Coating (LCOC) Metric for Evaluation of Solar Selective Absorber Materials

Exceptional service in the national interest





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Concentrating Solar Technologies

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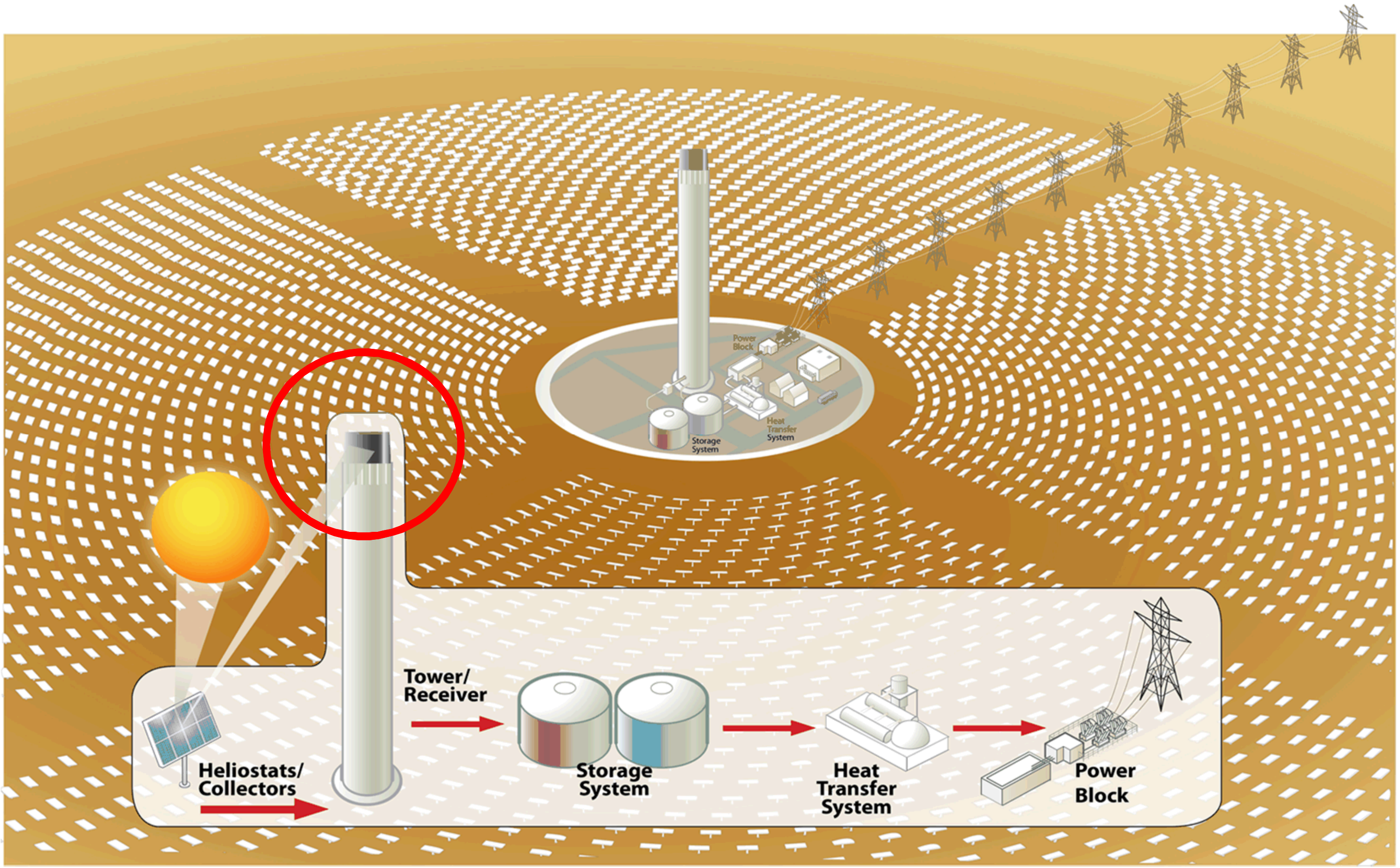
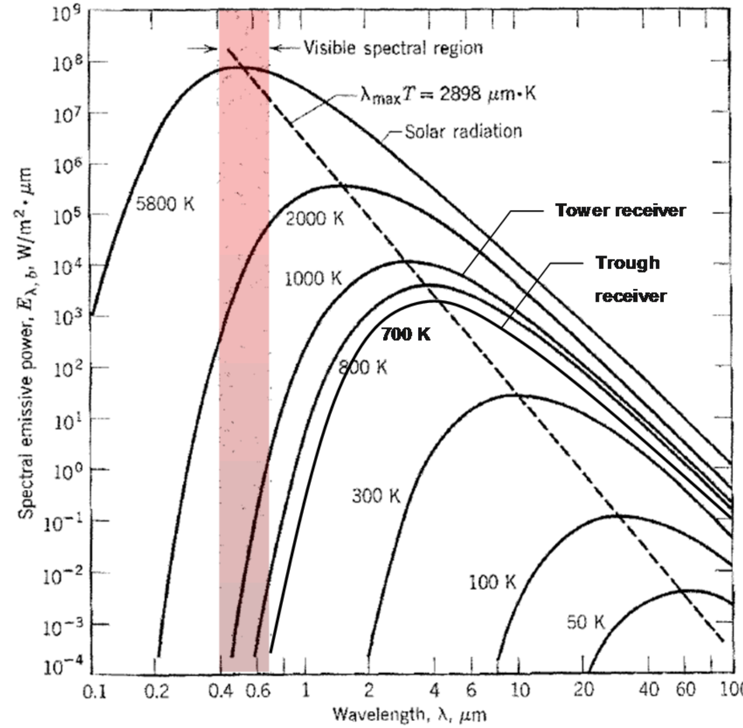
Overview



Power Block
Storage System
Heat Transfer System
Tower/ Receiver
Heliostats/ Collectors
Storage System
Heat Transfer System
Power Block

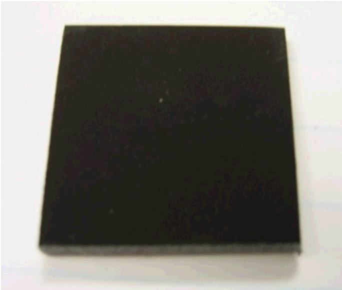
Selective Absorber Coatings

- Want high solar absorption (>0.95) in the visible and near-infrared
- Want low thermal emissivity (<0.4) in the infrared
- Need coatings that can withstand numerous high-temperature cycles in air



Solar Two receiver

Pyromark 2500 Paint



Pyromark 2500 on SS304 Coupon

Background and Need

Current figure of merit only accounts for performance

$$\eta_{sel} = \frac{\alpha_s Q - \varepsilon\sigma T^4}{Q}$$

Objectives

- Develop Levelized Cost of Coating (LCOC) metric to account for performance, cost, and durability of selective absorber coatings
- Determine acceptable combinations of selective absorber efficiency, degradation rate, reapplication interval, and costs for candidate materials relative to Pyromark 2500

LCOC definition

LCOC (Levelized Cost of Coating) = C / E

where

- *C* = total annualized coating costs
  = Initial coating cost/life of plant + recoating costs/recoating interval
  + cost of additional (or fewer) heliostats to yield baseline thermal energy production

- *E* = Annual thermal energy absorbed (new) – Lost energy absorbed due to degradation – Lost energy absorbed due to recoating down time (annualized)

- These parameters depend not only on the selective absorber efficiency, η_{sel}, which impacts the thermal energy absorbed, but also on degradation rate, downtime, material costs, and reapplication costs

LCOC (explicitly defined)

Costs for initial coating and reapplication

Costs for additional (or fewer) heliostats to yield baseline thermal energy production

$$LCOC_i = \frac{C_i}{E_b} = \frac{A_r\left(\frac{IC_i}{n} + \frac{RC_i}{RI_i}\right) + \frac{\alpha\beta}{n}\left[\eta_{sel,b}\left(1 - \frac{DR_b RI_b}{2} - \frac{DT_b}{RI_b}\right) - \eta_{sel,i}\left(1 - \frac{DR_i RI_i}{2} - \frac{DT_i}{RI_i}\right)\right]}{\beta\eta_{sel,b}\left(1 - \frac{DR_b RI_b}{2} - \frac{DT_b}{RI_b}\right)}$$

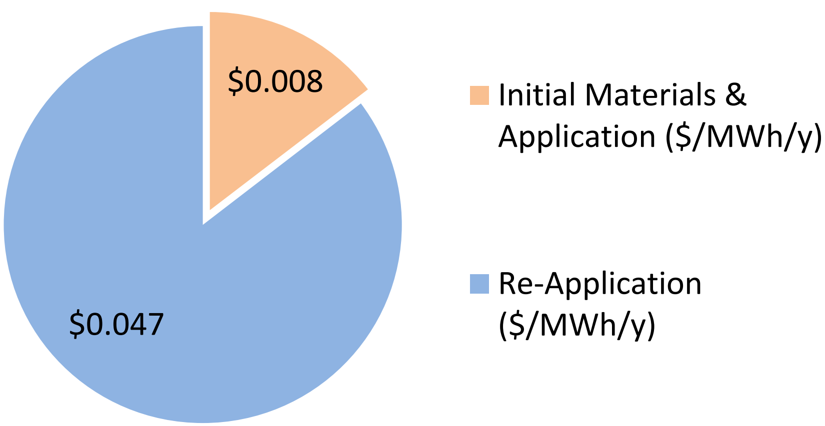
Baseline annual energy production

Pyromark 2500 Results

Determined the LCOC for Pyromark 2500 as a baseline

- Assumed 100 MW_e molten-salt power plant with a ~50% capacity factor
- η_{sel} = 0.89 (solar absorptance = 0.96, thermal emittance = 0.87)
- Assumed degradation rate of 0.5% per year
  - Degradation rates and costs for materials, application, and reapplication are based on available data from Solar One, Ho et al. (2012), and eSolar

- Annualized LCOC for Pyromark 2500 is \$0.055/MWh_{th}



LCOC breakdown for Pyromark 2500

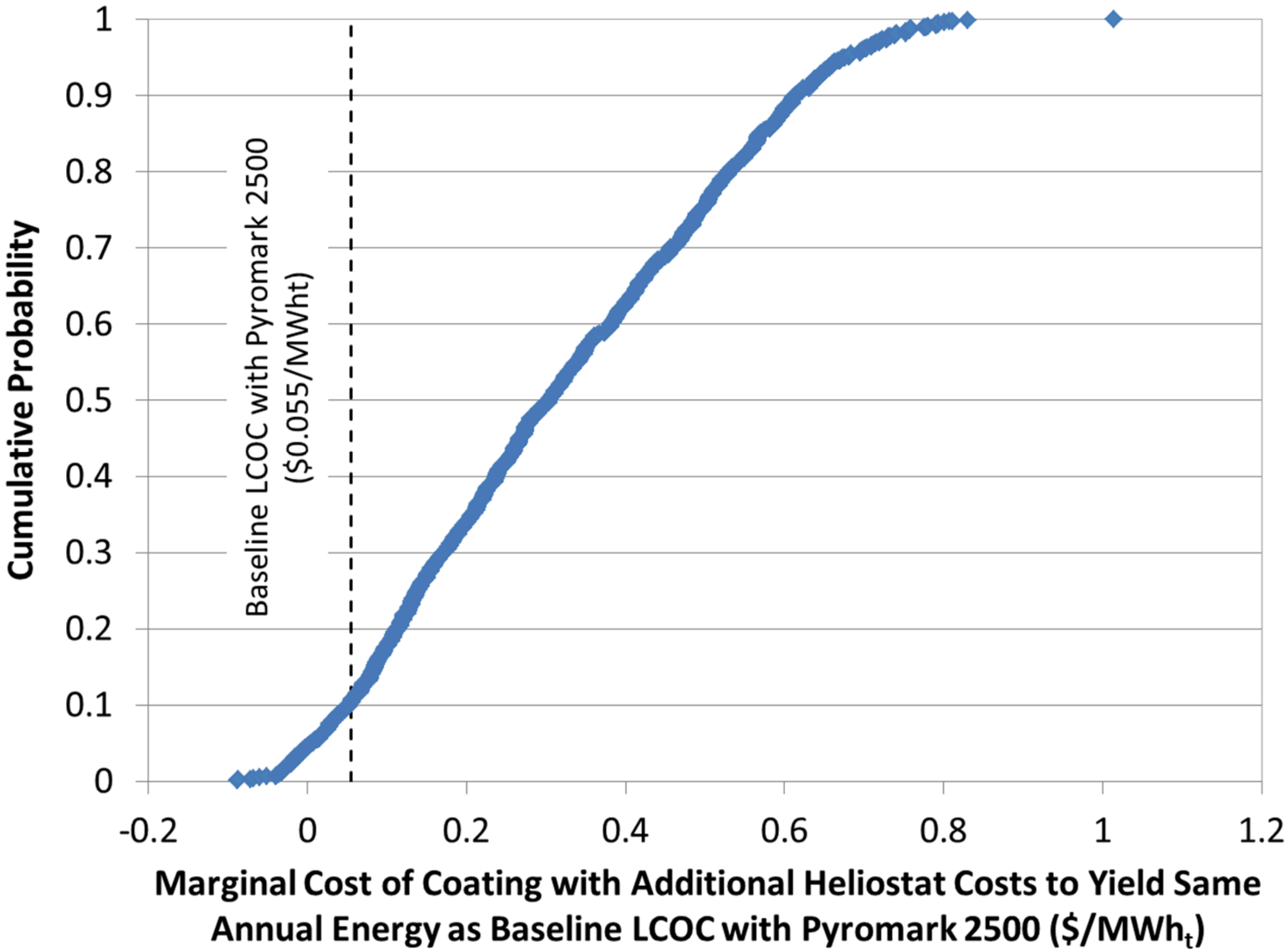
Probabilistic Analysis

Performed probabilistic analysis to evaluate LCOC for candidate selective absorber materials

Input Parameter	Nominal	Min	Max
Initial Absorptance	0.96	0.75	0.97
Initial Emittance	0.87	0.4	0.9
Coating material cost ($/m^2)	$5.41	$5.00	$50.00
Initial coating application cost ($/m^2)	$287	$143	$430
Plant life (years)	30	30	30
Re-application interval (years)	5	1	15
Reapplication cost ($/m^2)	$286	$142.85	$428.56
Downtime during reapplication (days)	12	6	18
Degradation rate (%/year)	0.50%	0.25%	0.75%

- Nominal value based on Pyromark 2500
- Uncertainty distributions based on data from candidate materials and professional judgment

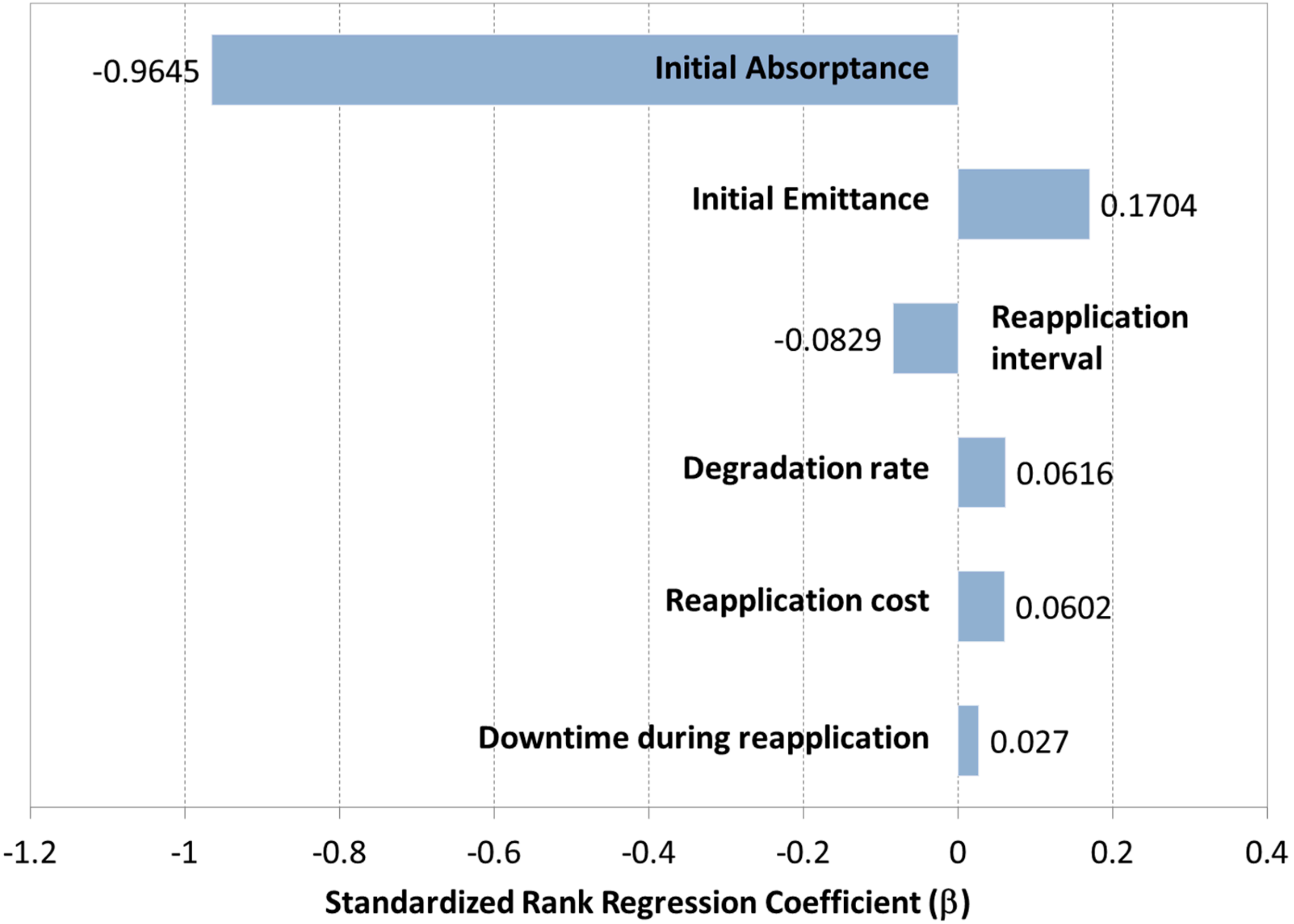
Probabilistic Results



Pyromark is very good, but LCOC can still be improved

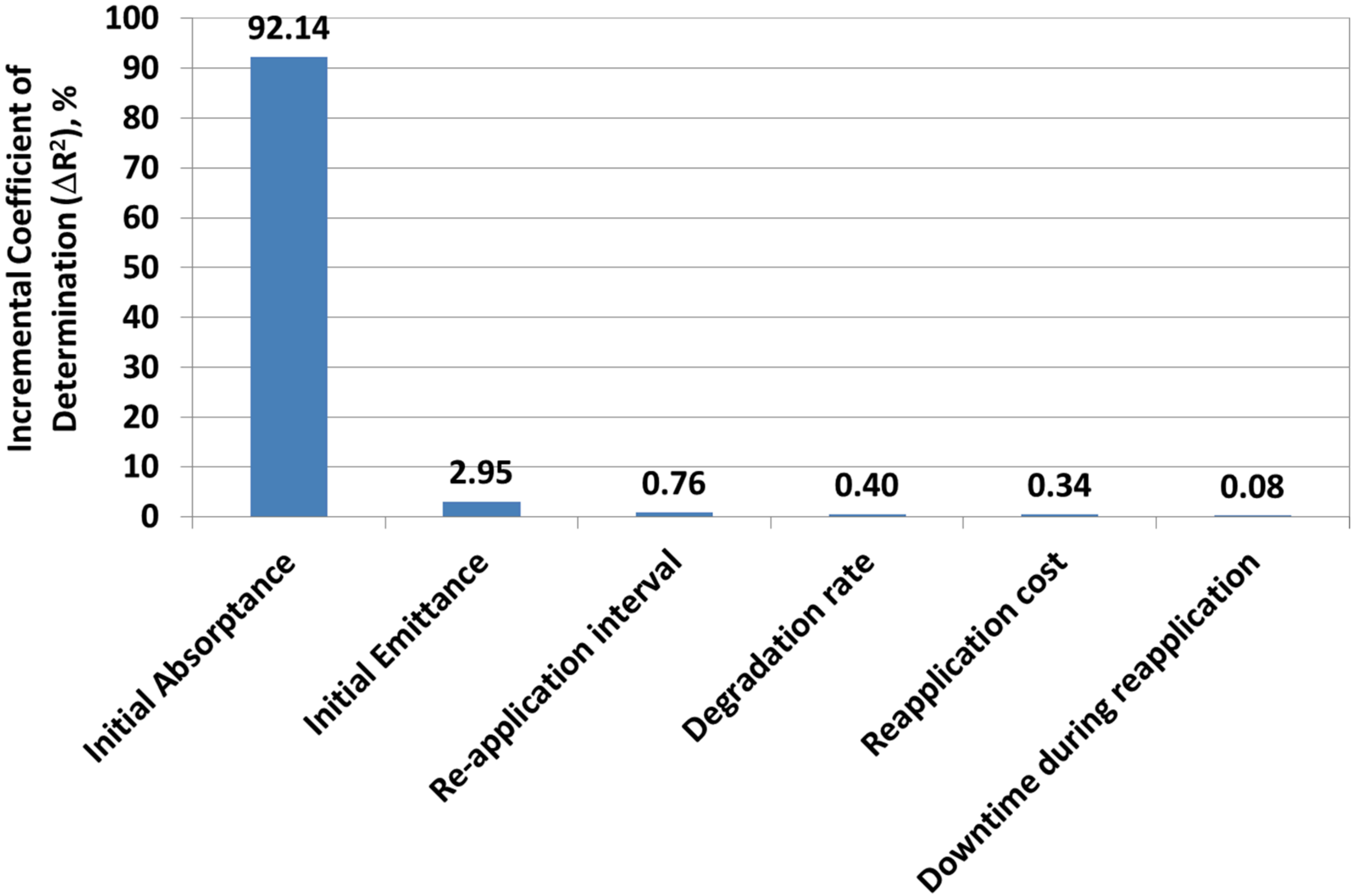
Probabilistic Results

Standardized rank regression coefficient



Probabilistic Results

Incremental coefficient of determination

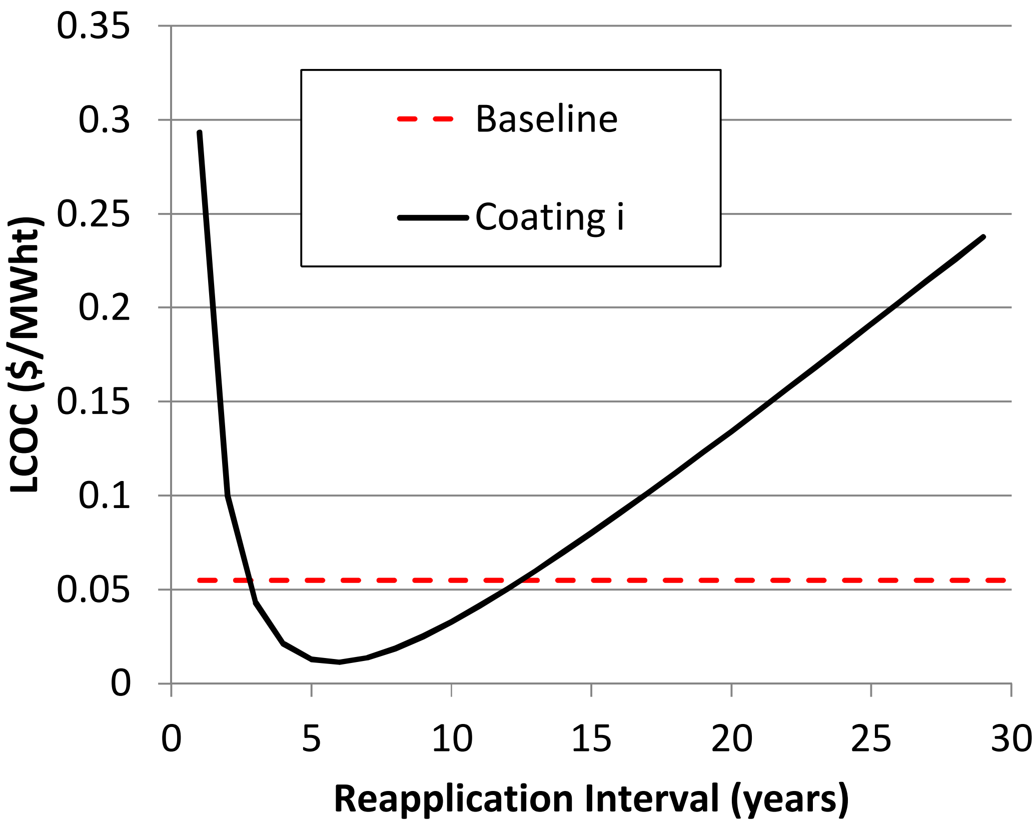


Measured/Estimated Variables for LCOC Calculation

- Costs
  - Initial coating cost ($\$/m^2$)
  - Reapplication cost ($\$/m^2$)
- Performance parameters
  - Selective absorber efficiency
    - From measured solar absorptance, thermal emittance, irradiance, and surface temperature
  - Degradation rate (% per year)
    - Estimated from measured reflectance measurements during high-temperature exposure tests
  - Downtime during reapplication (yrs)
    - Estimated based on required time for reapplication processes

Optimum Reapplication Interval

- Reapplication interval can be optimized to yield lowest LCOC



Parameter	Pyromark 2500	Coating i
Initial coating cost ($/m^2)	287	400
Reapplication cost ($/m^2)	286	400
Degradation rate (fraction of energy loss per year)	0.005	0.005
Downtime during reapp (days)	12	6
Solar absorptance	0.96	0.94
Thermal emittance	0.87	0.5
Selective absorber efficiency	0.89	0.90
Reapplication interval (years)	5	variable

Conclusions

- Solar absorptance is most important at temperatures up to 700 C
  - Thermal emittance, reapplication interval, degradation rate, reapplication cost, and downtime during reapplication also important
- Potential improvements over Pyromark 2500
  - Reduced thermal emittance (<0.85)
  - Reduced degradation rate, especially at higher temperatures
- Can use LCOC model to determine optimal reapplication interval

Backup Slides

Probabilistic LCOC Comparisons

	Initial Absorptance	Initial Emittance	Re-application Interval (years)	Degradation rate (%/year)	Re-application cost ($/m^2)	Downtime during re-application (days)	LCOC ($/MWht)
Pyromark 2500 Baseline LCOC	0.96	0.87	5	0.50%**	285.7	12.0	$0.055
Lowest LCOC*	0.97	0.42	12	0.34%	175.3	11.3	-$0.09
Highest LCOC*	0.75	0.89	1	0.59%	321.4	9.1	$1.01

*Considers costs associated with additional (or fewer) heliostats required to yield same annual energy production as Pyromark 2500 baseline

(additional costs associated with changes in receiver size are not considered)

**Significantly greater degradation rates at temperatures ~750 C and higher