Probabilistic Analysis To Quantify Optical Performance And Error Budgets For Next Generation Heliostats

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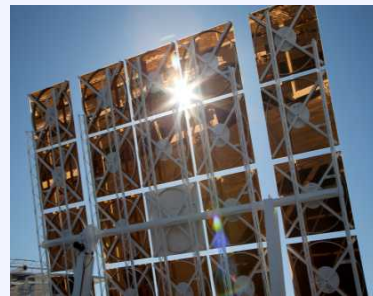
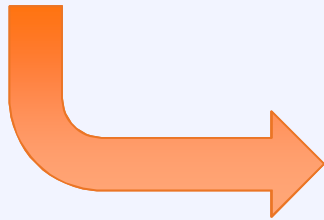**James Yuan**

SAND

Introduction

- What is the optical error budget for heliostats?
    - Plant levelized cost of energy (LCOE) is metric

Introduction

Design Basis Document Error Budget Values

Tracking Error Sources	Azimuth Error (mrad)	Elevation Error (mrad)
Encoder resolution/drive back-lash	0.6	0.4
Sun position prediction	0.15	0.15
Light refraction	0.05	0.05
Error corrected tracking	0.4	0.4
Total error (RSS, mrad)	0.74	0.59
Total error req. (RMS, mrad)*	0.75	0.75
Beam Quality Error Sources	Azimuth Error (mrad)	Elevation Error (mrad)
Slope Error	1	1
Mirror specularity	0.25	0.25
Mirror alignment error	0.25	0.25
Structural deflections from gravity	0.8	0.8
Focal change with temperature	0.5	0.5
Total error (RSS, mrad)	1.33	1.33
Total error req. (RMS, mrad)*	1.8	1.8

• Zavoico, A. B., 2001, "Solar Power Tower: Design Basis Document," No. SAND2001-2100, Sandia National Laboratories, Albuquerque, NM and Livermore, California.

Presentation Overview

- Objectives

- Approach

- Results

- Conclusion

Objectives

- Determine a feasible optical error budget for next generation heliostats.

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Probabilistic Modeling Approach

1. Optical Error Impacts: Determine which optical errors are most impactful on LCOE

   – Use DELSOL to analyze error sources

2. Bundled Error Source: Determine the acceptable magnitude of a "bundled" error source on heliostats to achieve LCOE goal

3. Budget: Break down the "bundled" error value into design error sources

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Optical Error Impacts

Heliostat Size Chosen (10-150 m^2)

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Slope Error Values Chosen (10,000 samples): Latin Hypercube Sampling (Beam Quality Errors 1-4 mrad, Tracking Errors 0.25-1.5 mrad)
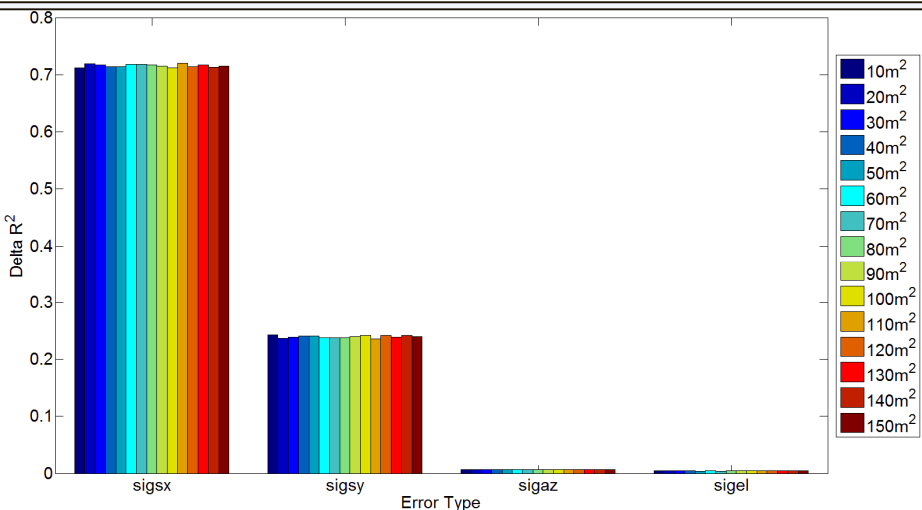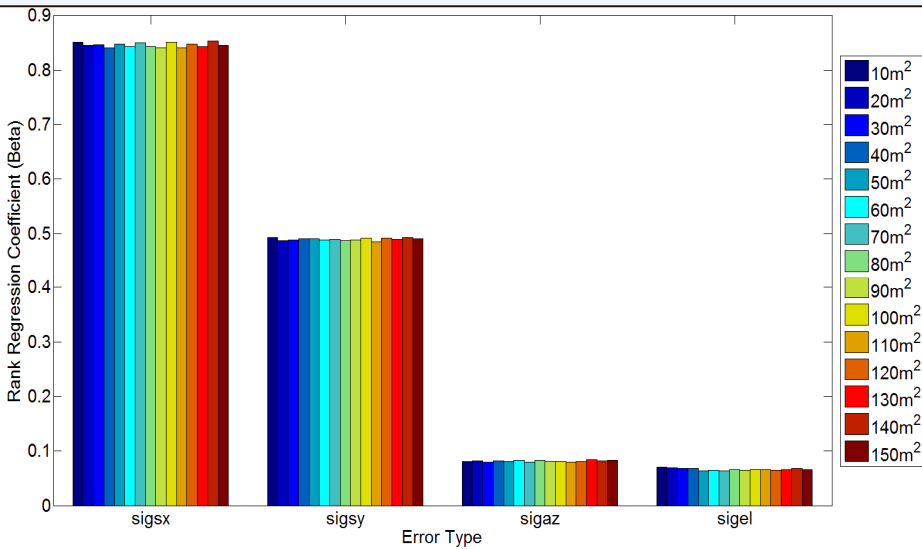
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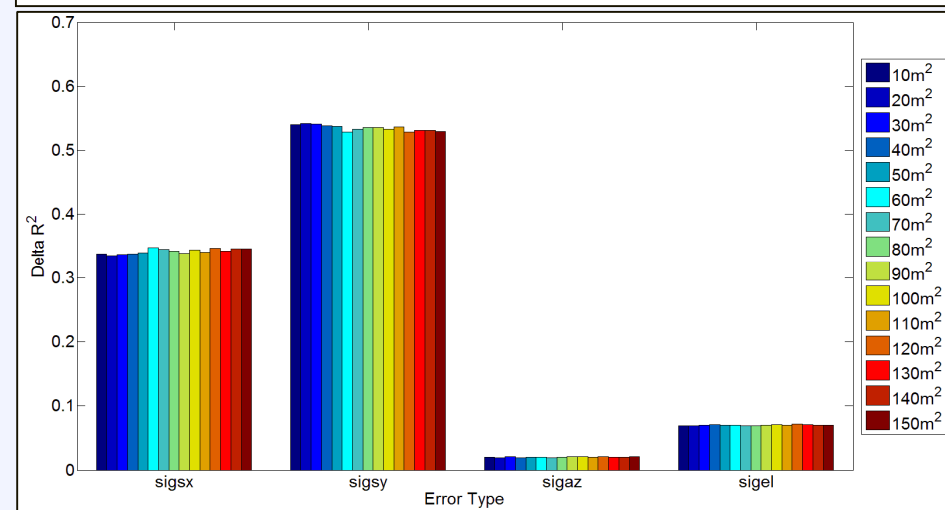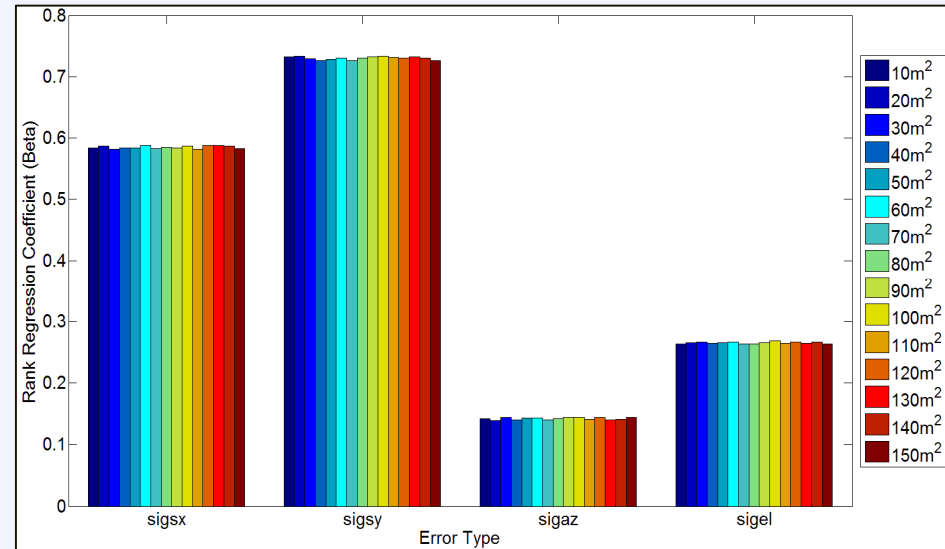DELSOL; 10,000 runs

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Statistical Analysis

- The tower height was 170 m and remains fixed throughout the analysis.

- Two receiver geometries (external cylindrical) were evaluated: 1) 14.87 m diameter by 18.62 m height and 2) 12 m diameter by 10 m height.

- Heliostats were comprised of 25 facets: 5 facets across the width and 5 facets across the height, on-axis canting, flat facets.

- The required total electric power of the plant was fixed at 100 MWe.

- The solar multiple is set to 2.0 which allowed for at least 8 hours of thermal storage.

- The maximum flux limit on the receiver was set to 1100 kW/m^2.

- The thermal to electric turbine efficiency was set to 55% matching the SunShot technical target.
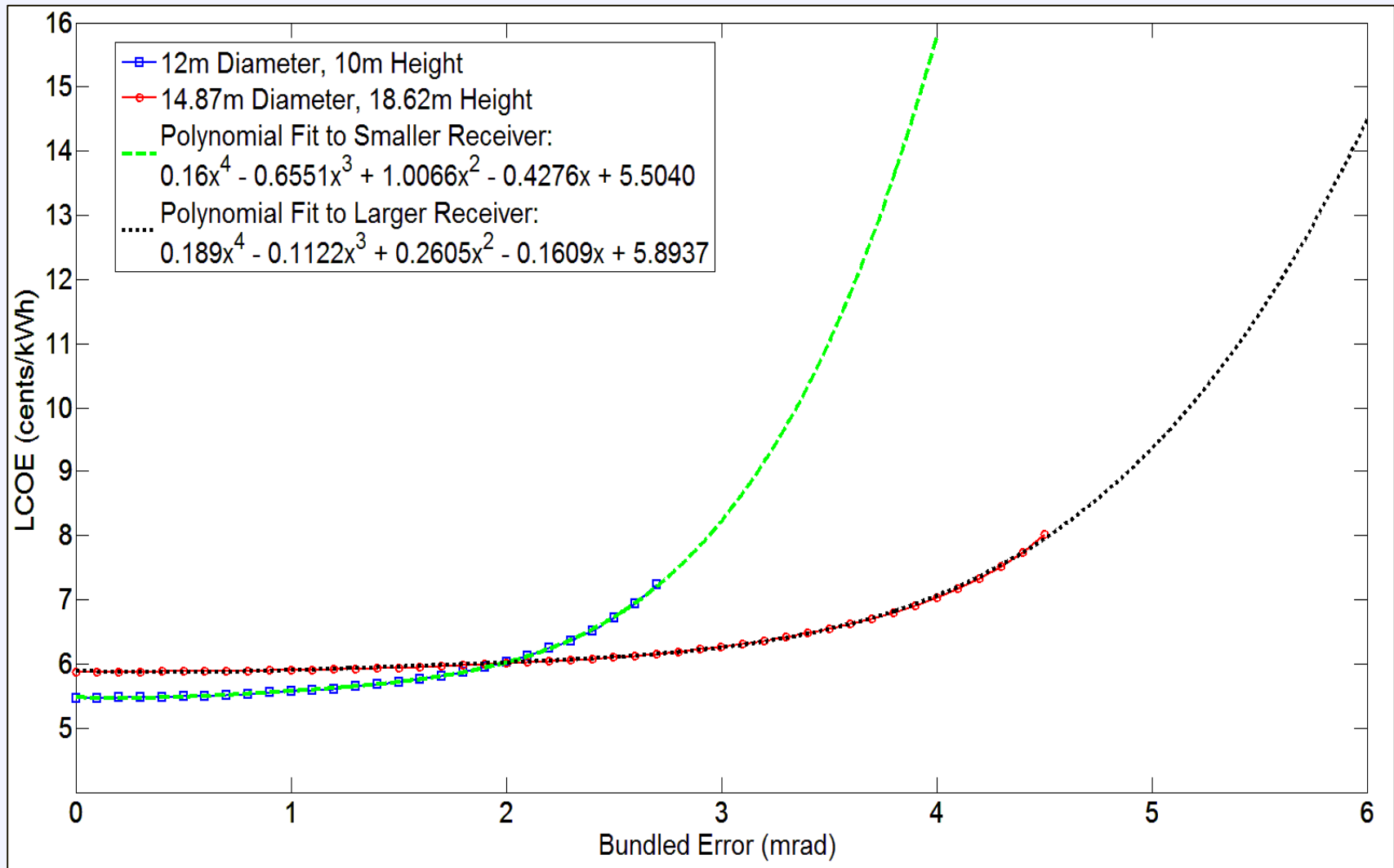
Optical Error Impacts

D=14.87 m, H=18.62 m

D=12 m, H=10 m

Bundled Error Source

Legend:
- 12m Diameter, 10m Height
- 14.87m Diameter, 18.62m Height
- Polynomial Fit to Smaller Receiver:
  $0.16x^4 - 0.6551x^3 + 1.0066x^2 - 0.4276x + 5.5040$
- Polynomial Fit to Larger Receiver:
  $0.189x^4 - 0.1122x^3 + 0.2605x^2 - 0.1609x + 5.8937$

Y-axis: LCOE (cents/kWh)
X-axis: Bundled Error (mrad)

Optical Error Budget

Error	Initial Value (mrad)	Adjusted Error Value (mrad)
Slope error	1	1.26
Tracking	0.75	0.945
Canting (alignment)	0.25	0.315
Structural deflections	0.8	1.008
Temperature dependent slope error	0.5	0.63
RSS bundled error	1.59	2.00

Optical Error Budget: 14.9 m by 18.6 m Receiver
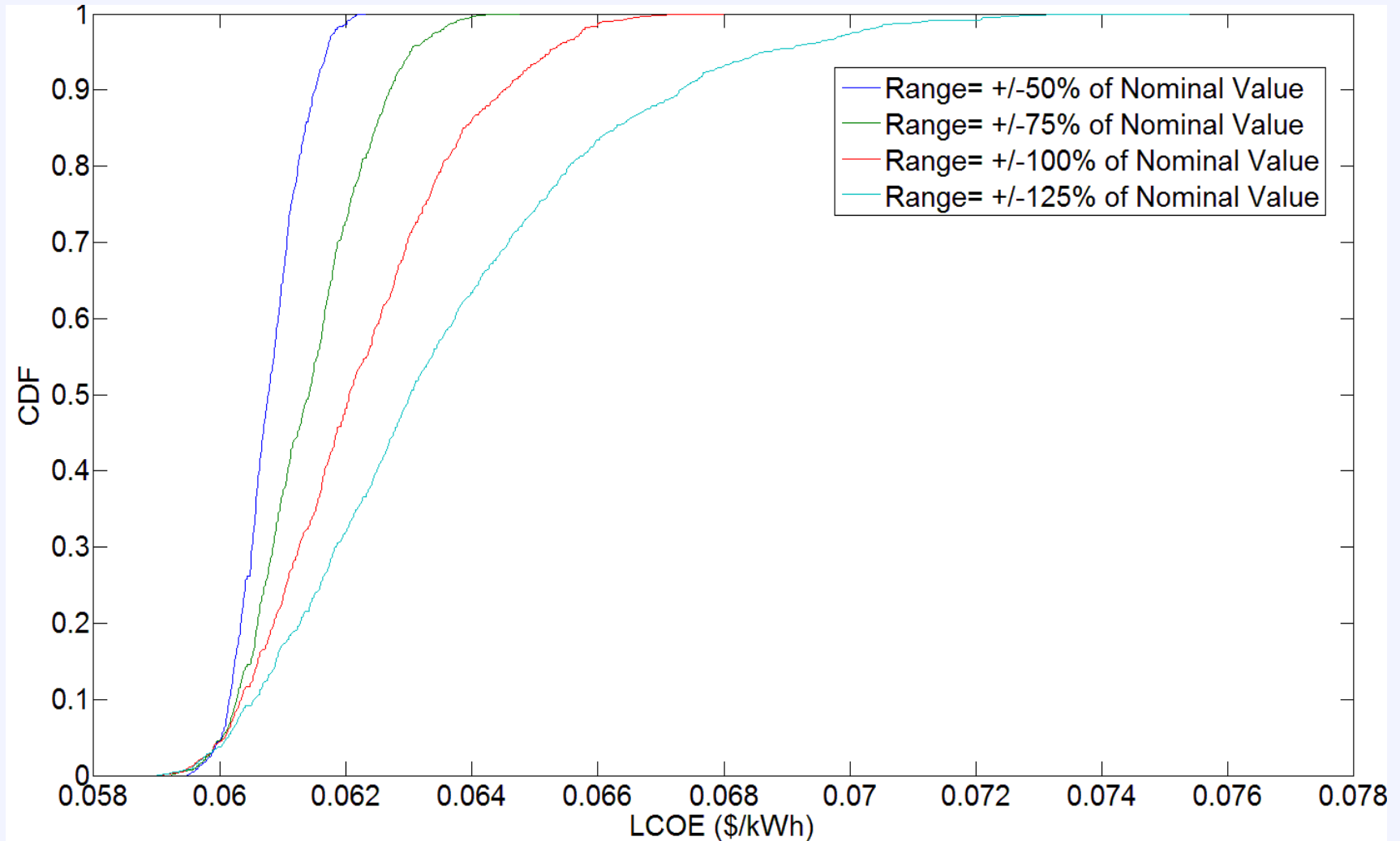
Optical Error Budget: 12 m by 10 m Receiver
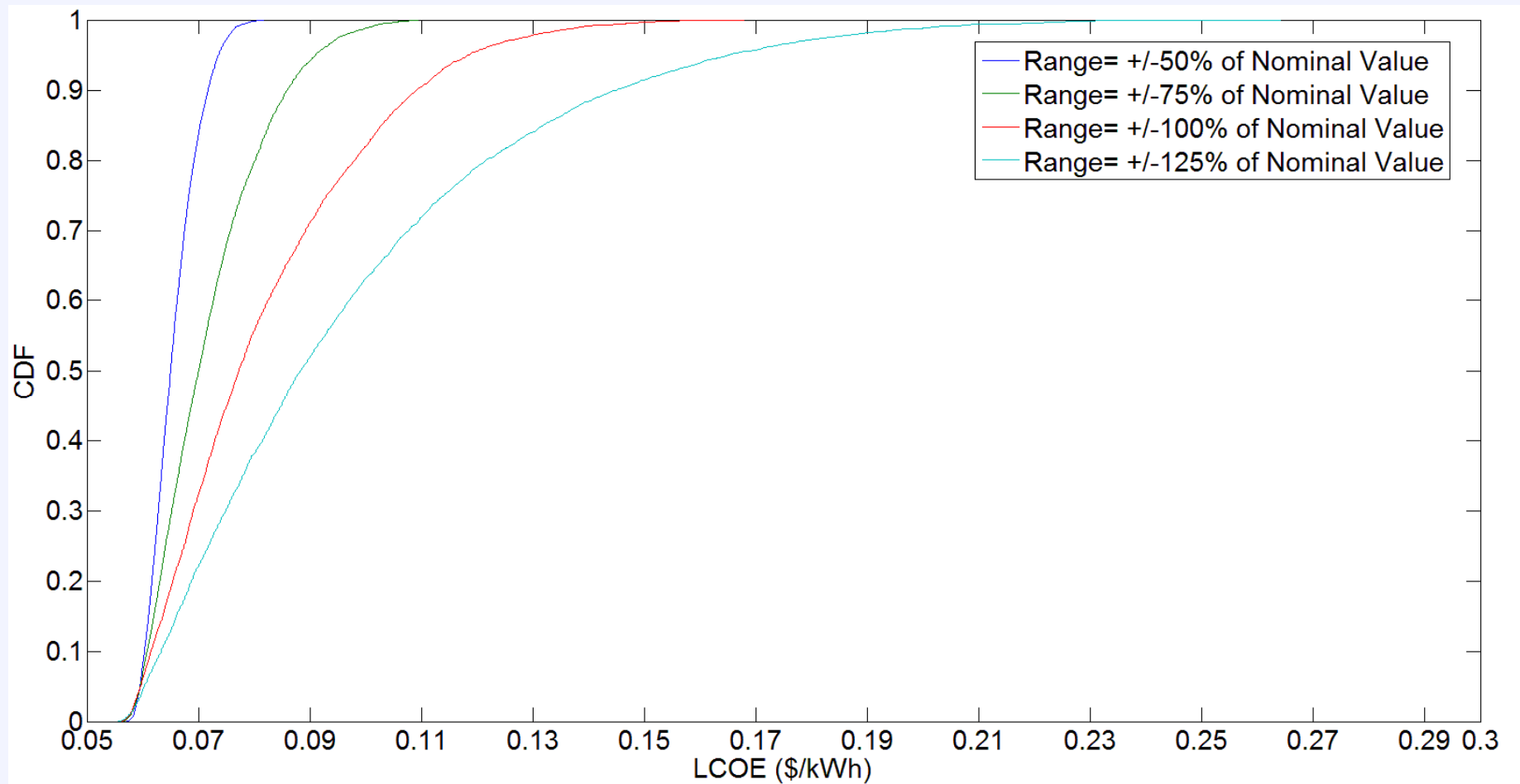
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Conclusions

- Beam quality errors have a significant impact on plant LCOE

- Size of receiver is a critical design feature

- A larger range of error magnitudes can be used depending on receiver design