RENEWABLE THERMAL COLLABORATIVE

Solar Thermal and C&I Decarbonization

Presented by the Renewable Thermal Collaborative

TODAY'S SPEAKERS

Blaine Collison
Renewable Thermal
Collaborative

Parthiv Kurup
Concentrating Solar Power (CSP)
Cost and Systems Analyst
National Renewable Energy
Laboratory

Vikas Tuteja
Chief Operating Officer
Heliogen

AGENDA

RTC Overview

NREL Presentation- Parthiv Kurup

Heliogen Presentation- Vikas Tuteja

THE RTC'S OBJECTIVES

1. Educate parties about the urgent need to address renewable options for thermal energy.

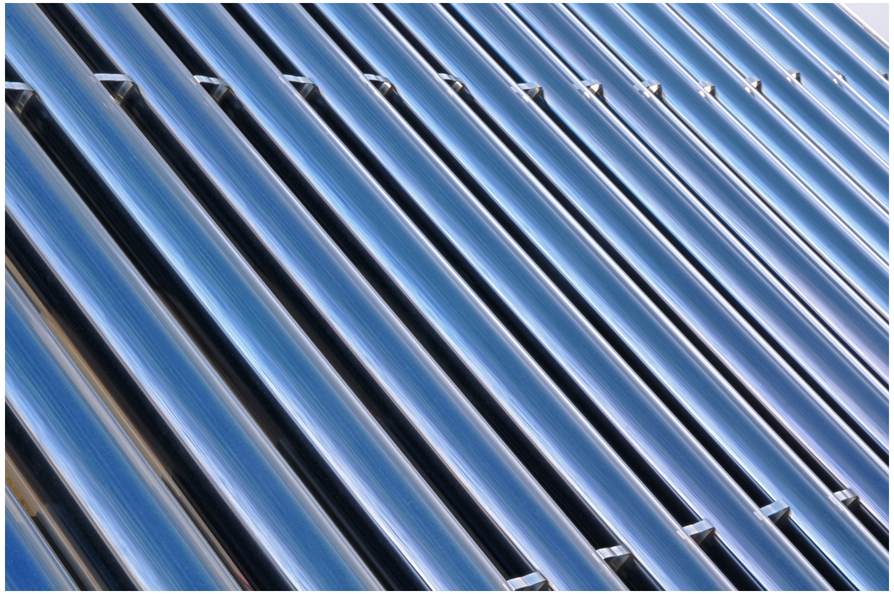
2. Identify market barriers to renewable thermal technologies.

3. Enable delivery of cost-competitive renewable thermal options.

4. Improve marketplace and financing for renewable thermal technology.

5. Develop long-term vision for scaling up renewable technologies in the U.S..

RTC PROJECT HIGHLIGHTS



1. Renewable Thermal Buyers' Statement
2. Renewable Natural Gas/ Power-to-Gas Technology Assessment Plan
3. Biomass Accounting Guidance
4. Renewable Thermal Policy
5. Solar Thermal Technology Assessment
6. Beneficial Electrification

UPCOMING EVENTS

Register today for the first annual Renewable Thermal Collaborative Virtual Summit, taking place on November 9 & 10, 2020.

Look out for new webinars and blogs every month!

Opportunities for Solar to Meet Industrial Process Heat Demands

Parthiv Kurup and Colin McMillan

24th Sept. 2020

Material includes unpublished preliminary data and analysis that is subject to change - not for distribution, quotation, or citation

Disclaimer

Material includes unpublished preliminary data and analysis that is subject to change

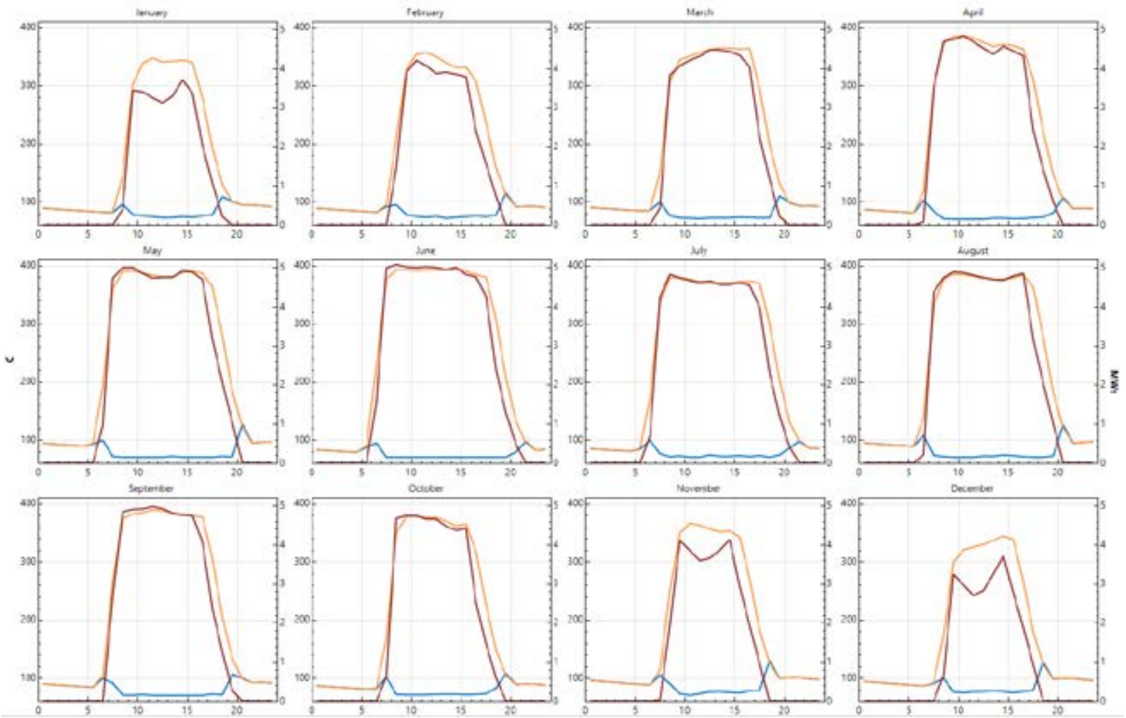
- Purpose of Presentation
  - To provide a general overview of solar for industrial process heat efforts
  - Not to convey findings or conclusions to take away or inform activities
- State of Content Presented
  - Data, results, conclusions, and interpretations presented have not been reviewed by technical experts outside NREL
  - Does not constitute a comprehensive treatment of the issues discussed or specific advice to inform decisions
- Request to Audience
  - Do not distribute, quote, or cite

Contents

NREL Solar Industrial Process Heat (IPH) Capabilities

Analysis for IPH needs at NREL

- Solar IPH technologies and renewable heat integration options for the end-user
- Industrial demand and hourly load estimations
- Geo-spatial tecno-economic analysis (TEA) which allows for the thermal yield generation potential to be determined
- Natural gas savings potential based on suited technologies and location



Thermal yield generation for a Solar IPH site in Lancaster, CA

As of 21st Sept. 2020

Solar for Industrial Process Heat Project Summary

- The potential to use of solar technologies (solar thermal and PV) for meeting industrial process heat (IPH) in the United States is an understudied topic
- The motivating research questions are:
    1. What are the county-by-county **opportunities** to meet IPH demand with solar technologies?
    2. At what point may a solar technology reach economic **process parity** with an incumbent combustion IPH technology?
- Project team consists of researchers at NREL, Northwestern University, UC-Santa Barbara, and a private consultant

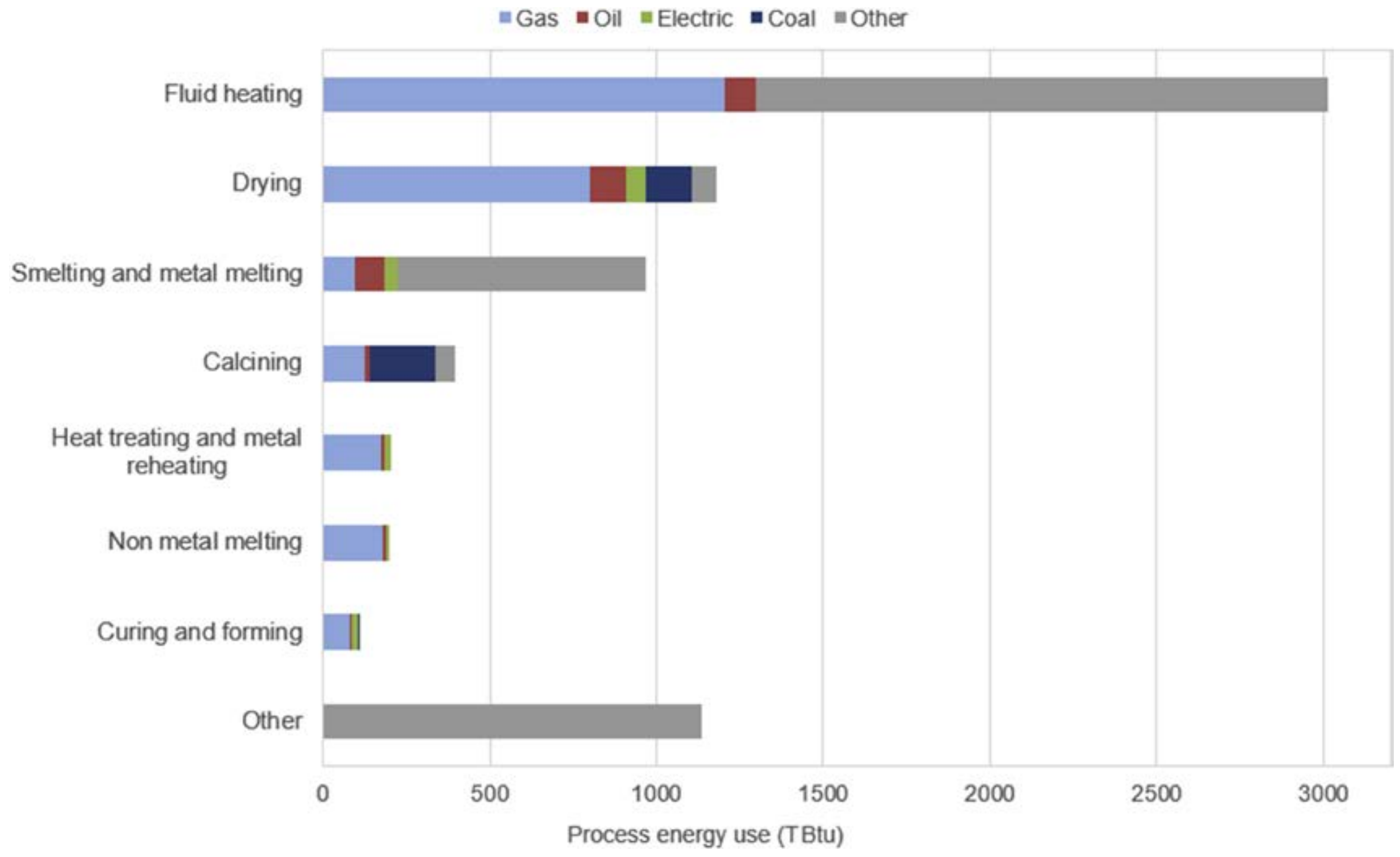
Literature Review Overview

- Solar technologies (solar thermal, PV)
- Process heating (steam/thermal, electric)
- Case studies and potential assessments
- Industrial efficiency measures
- Barriers (technical and economic)

- What is the current state of SIPH technologies, including technical and economic parameters?
- Which U.S. industries, unit processes, and climates represent the most viable SIPH markets?
- Why are SIPH technologies more relevant now than in the past for U.S. industry?
- What is the state of data and modeling for guiding SIPH adoption decisions at the plant level?
- What are critical knowledge gaps related to analysis of SIPH deployment potentials, and what future research tasks can address them to lead to more informed adoption decisions?

"Solar for industrial process heat: A review of technologies, analysis approaches, and potential applications in the United States" (Schoeneberger et al. 2020) https://doi.org/10.1016/j.energy.2020.118083

U.S. Process Heat Demand



- From our recent literature review (Schoeneberger et al. 2020):
  - Fluid heating is the largest user of Process Energy
  - Natural gas is the typical fuel of choice for most of industry

"Solar for industrial process heat: A review of technologies, analysis approaches, and potential applications in the United States" (Schoeneberger et al. 2020) https://doi.org/10.1016/j.energy.2020.118083

Technical Potential: Overview

Includes	Excludes
✓ County-average solar resource ✓ County total land availability ✓ IPH unit process detail, including temperature, heat media, and boiler type ✓ Hourly heat load and solar generation ✓ Uncertainty ranges of typical operating schedules ✓ Thermal storage (PTC, swh, PV+HP)	☒ Site-level analysis ☒ Economic considerations ☒ Battery storage ☒ Multiple varieties of a single solar technology type ☒ Emerging solar technologies

Technical Potential: Calculation Framework

IPH Demand

Opportunity

Solar Generation

Annual thermal energy demand	Process characteristics	Hourly process heat demand	Hourly process heat supply	Process characteristics	Solar heat from reV
County-level energy by fuel type, industry, industry size class, and end use	- Efficiency of end uses (boiler, CHP) - Process limitations: temperature, form of heat (steam, hot water, etc.)	- Thermal energy required by process - Representative hourly load shape	- Process heat supply, hourly	- Heat exchange (HTF from field to process) - Electrical efficiency of electro-technology	- MW_{th} from solar field - Mw_e from PV array

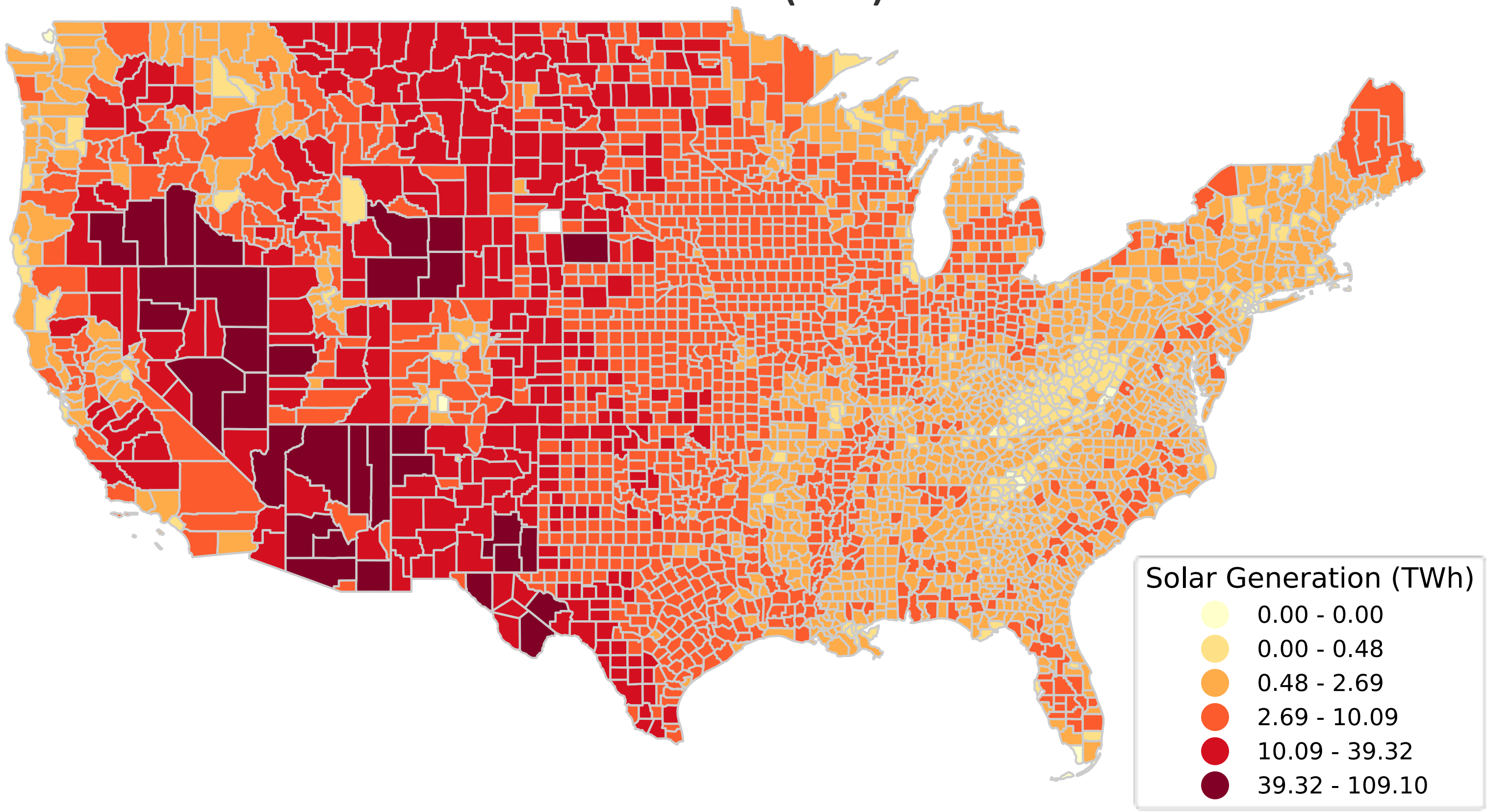
$$\textbf{Solar fraction (\%)} = \sum \frac{energy\ provided\ to\ process\ by\ solar\ tech_{county,hour}}{energy\ required\ for\ process\ heat_{county,hour}}$$

Technical Potential: Solar Technology Packages and Applications

IPH Technologies and Applications	Solar Technologies		
Conventional boilers, CHP; hot water and boiler feedwater preheating	Flat plate collector (w/ water storage)		(1)
Conventional boiler, CHP, direct process heat	Parabolic trough collector (w/wo 6-hr thermal energy storage)		(2)
	Linear Fresnel, direct steam generation		(3)
Conventional boilers; hot water	Ambient heat pump (HP) (w/ water storage)	(4)	PV
Conventional boiler; steam and hot water	Electric boiler	(5)	
Process heating (PH)	Resistance heater	(6)	
Conventional Boiler, CHP, PH (< 160° C)	Waste heat recovery HP	(7)	

Technical Potential: Annual Solar Generation

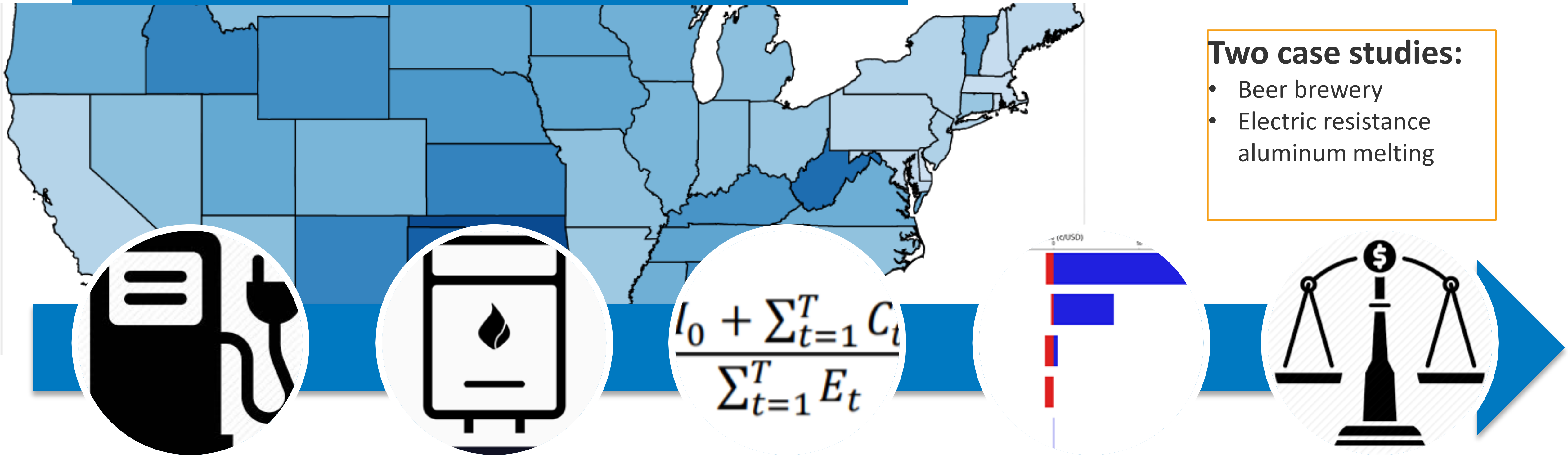
PV (DC)



- Annual solar generation is a function of solar resource, solar technology, and available land area
- Distribution of generation similar by solar technology; differences in magnitude
- Direct heating technologies (e.g. PTC, LF-dsg) have high yield potential in northern latitudes

Preliminary Results—Do Not Distribute, Quote or Cite

Process Parity: Calculation Framework



Two case studies:

- Beer brewery
- Electric resistance aluminum melting

Main Inputs

- Fuel
- Location
- Load Profile
- Investment Type
- Technologies

Models

- Capital Costs
- O&M Costs
- Fuel Costs
- Electricity Costs
- Land Costs

LCOH

- Incentives
- Tax Rates
- Depreciation
- Decommission
- Inflation

Process Parity

- PP Iteration
- Payback Period
- Sensitivity Tests

Outputs

- Cash Flow Diagram
- Sensitivity Analyses
- Payback Period/IRR
- LCOH Maps
- Parity Solution Space

Thank you

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www.nrel.gov

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office and Office of Strategic Programs. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL Transforming ENERGY

Heliogen

Replacing Fuels with Sunlight

Vikas Tuteja

Chief Operating Officer

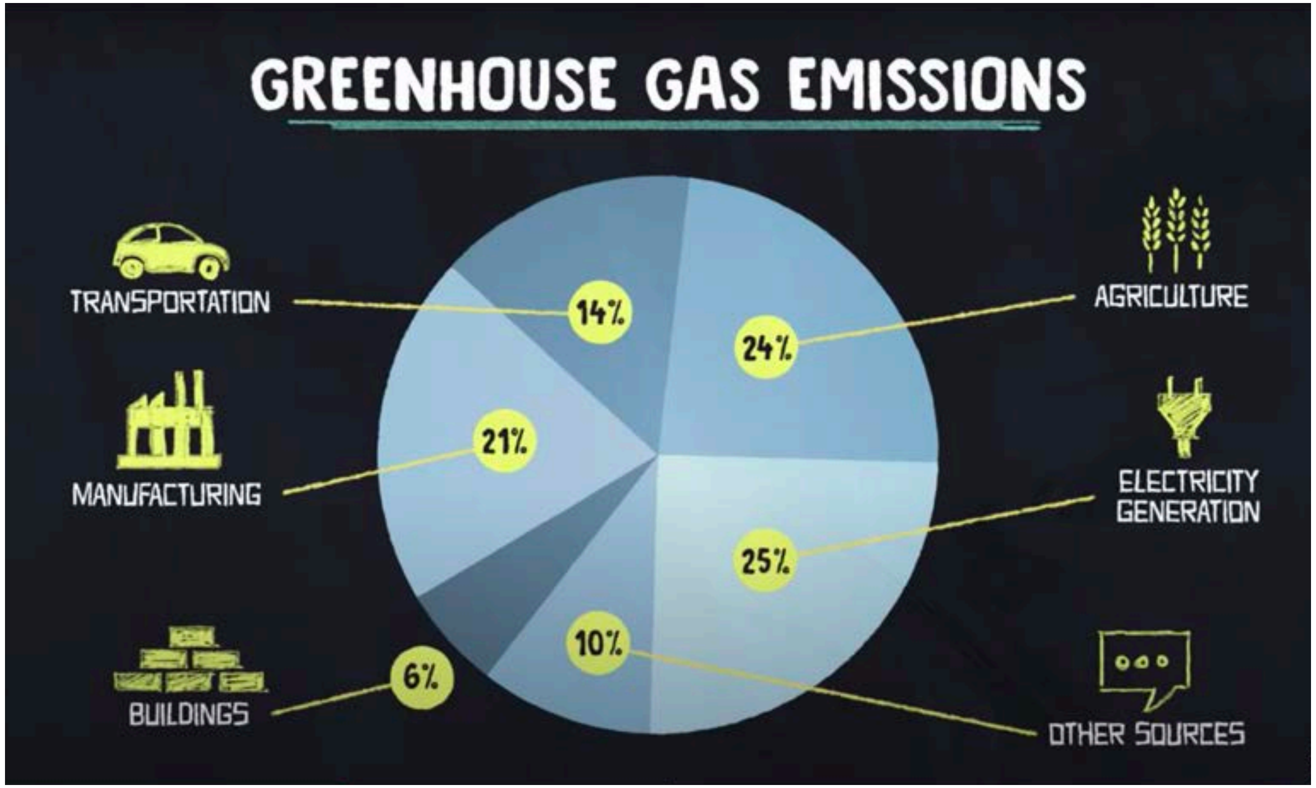
September 24, 2020

Cost-effectively replacing fossil fuels solves the world's CO_2 problem.

Heliogen develops the technology to do just that.

Solving The World's CO_2 Problem

- Making electricity is responsible for only 25% of greenhouse gas emissions each year
- Production of electricity is being addressed by low-cost PV and wind
- Heliogen is focused on addressing the majority of the other 75% through solar heat and fuels



Source: Gates Notes, 2018

The Heliogen Solution

HelioHeat™

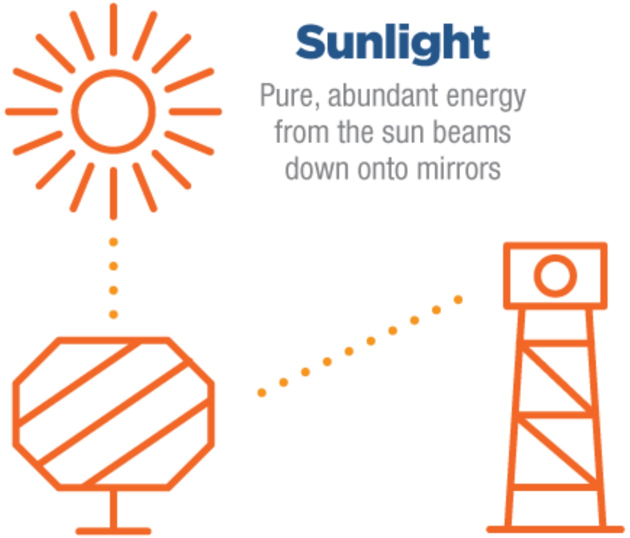
- Carbon-free, ultra-high temperature heat from the sun made on site
- Reduce fuel costs and greenhouse gas emissions
- Make strides in reaching corporate sustainability goals
- Customers have the choice of either purchasing a Heliogen system or buying energy under a Heat Purchase Agreement (HPA)

Heliogen's facility in Lancaster, California

Tower

Mirror array

How it Works



Sunlight

Pure, abundant energy from the sun beams down onto mirrors

HelioMax™

An array of computer-controlled mirrors (heliostats) collects and concentrates sunlight

Tower and Receiver

Captured sunlight equivalent to 1,200+ suns is converted to ultra-high temperature heat

HelioHeat™

Carbon-free, ultra-high temperature heat (up to 1,500ºC) is generated and available for industrial processes

Applications

- Cement
- Steel
- Mining
- Petrochemicals
- Waste treatment

HelioFuel™

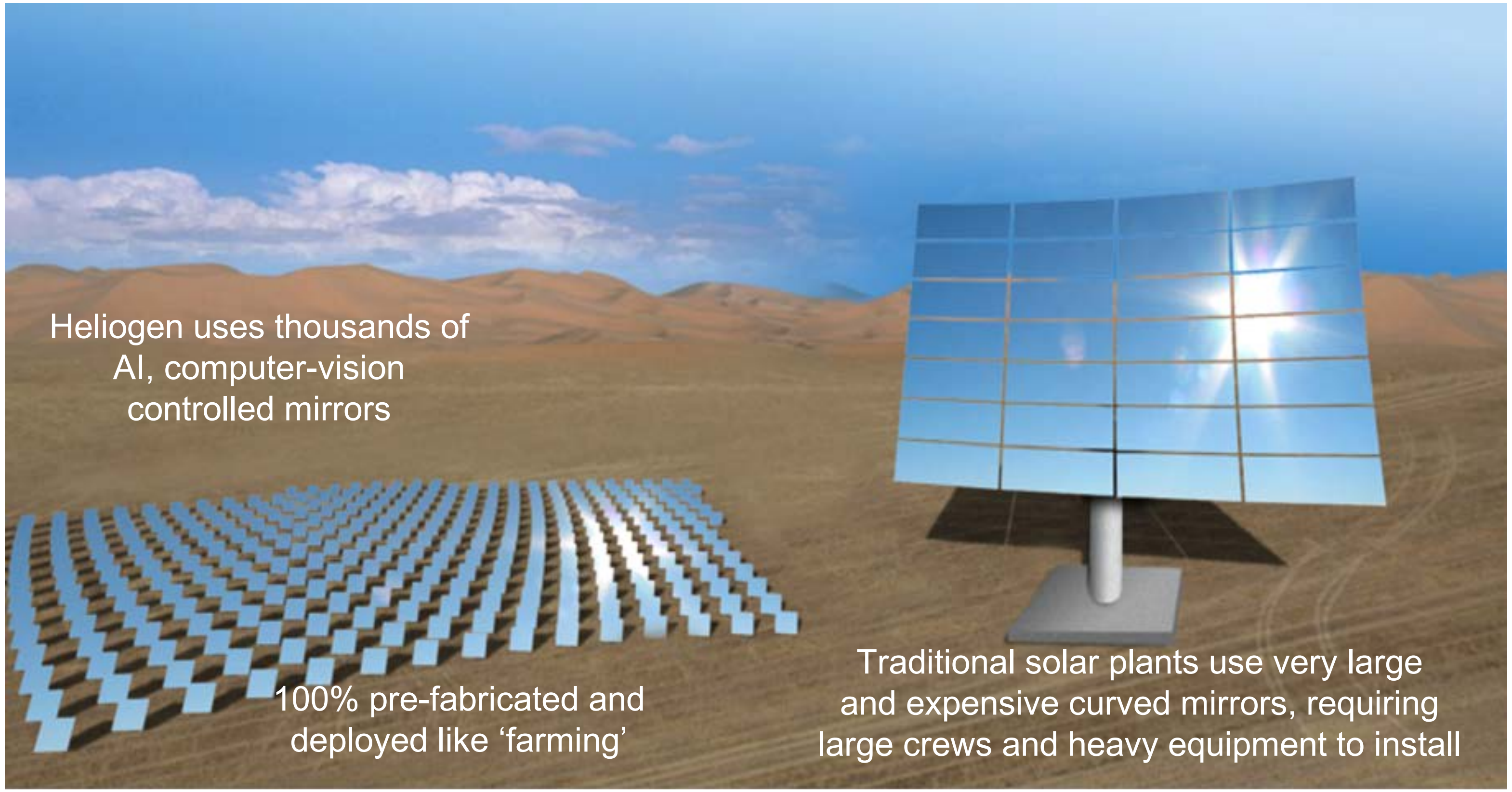
100% green fuels like hydrogen are created and available to a wide array of industries

Applications

- Transportation
- Heavy equipment
- Household heating

Leveraging Breakthrough Technology

- Moore's Law / Software / Artificial Intelligence
- Computer-controlled mirror array acts as a multi-acre magnifying glass for sunlight concentration
- Smaller Parts / Reduced Installation Costs
- No Calibration Required



Our Technology is

Sustainable
Uses sunlight – an infinitely renewable resource – to power industry

Scientifically Proven
Designed by scientists and engineers from Caltech, MIT, and other premier institutions

Cost-Effective
Competitive economics over fossil fuels without CO_2

Scalable
Can be scaled from sizes as low as 5 MW to 100s of MW

Applications unlocked with HelioHeat

Steam: 150 – 450°C
Food processing, drying, desalination, mining, enhanced geothermal

Metals Processing: 600 – 1200°C
Aluminum, low-carbon steel with low greenhouse gas emissions

Calcining: 900 – 1100°C
Cement, lime, magnesium, phosphorus and other minerals

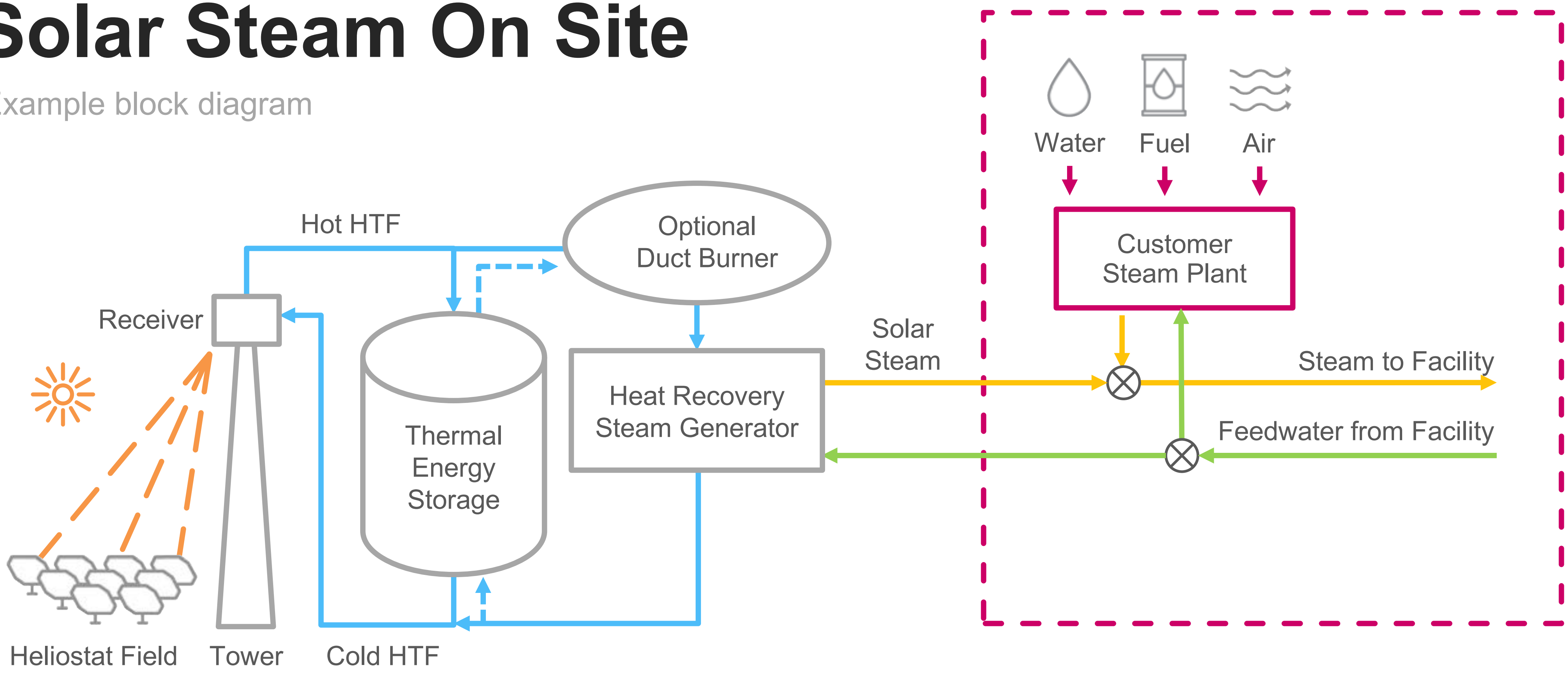
Gasification: 900 – 1100°C
Power generation and process heating

Solar Methane Reforming: 900 – 1100°C
Syngas, hydrogen

Thermo-Chemical Water Splitting: 1500°C
Direct green hydrogen production with low or no greenhouse gas emissions

HelioHeat™ for 24/7 Solar Steam On Site

Example block diagram

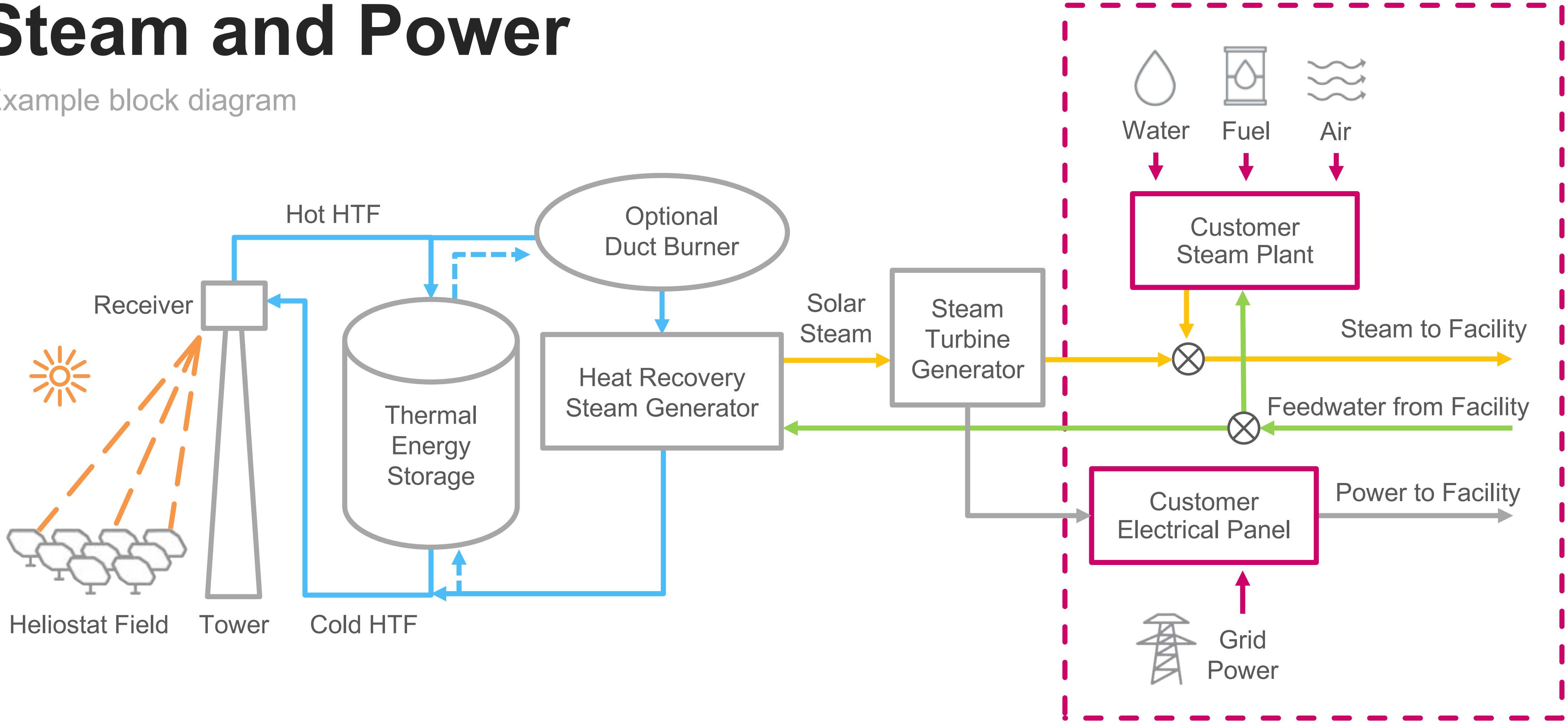


REPLACING FUELS WITH SUNLIGHT

Heliogen

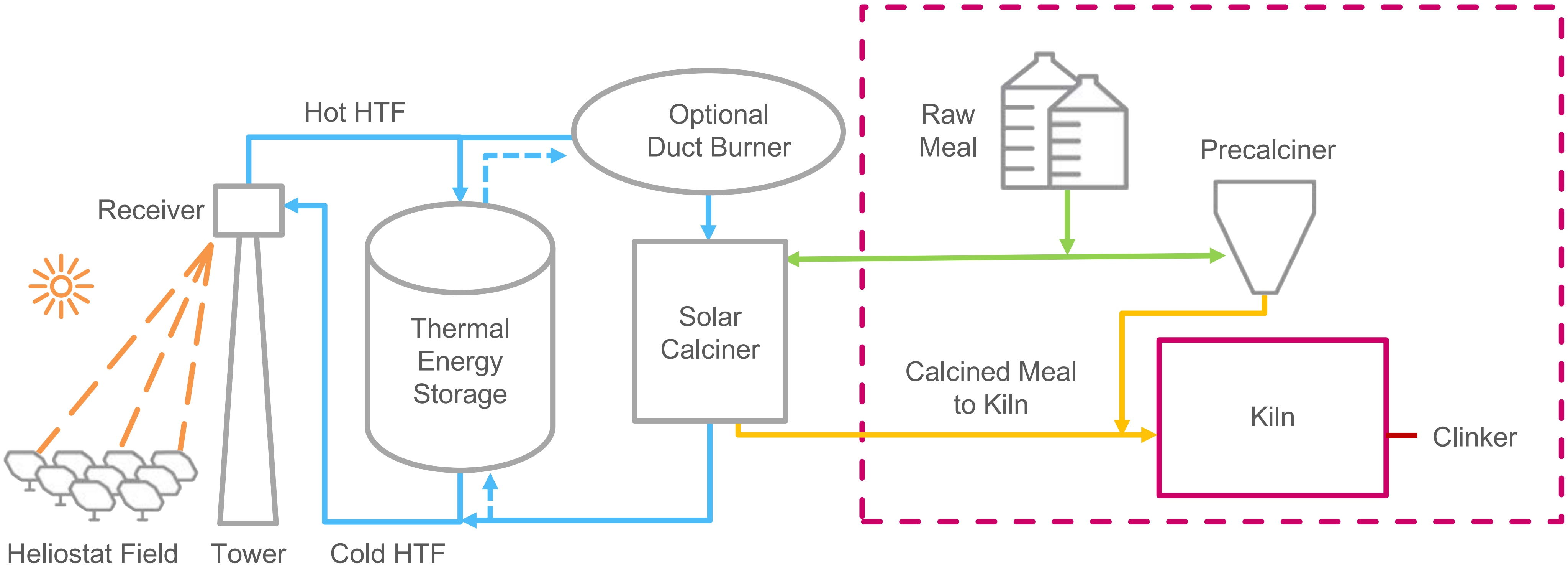
HelioHeat™ for 24/7 Solar Steam and Power

Example block diagram



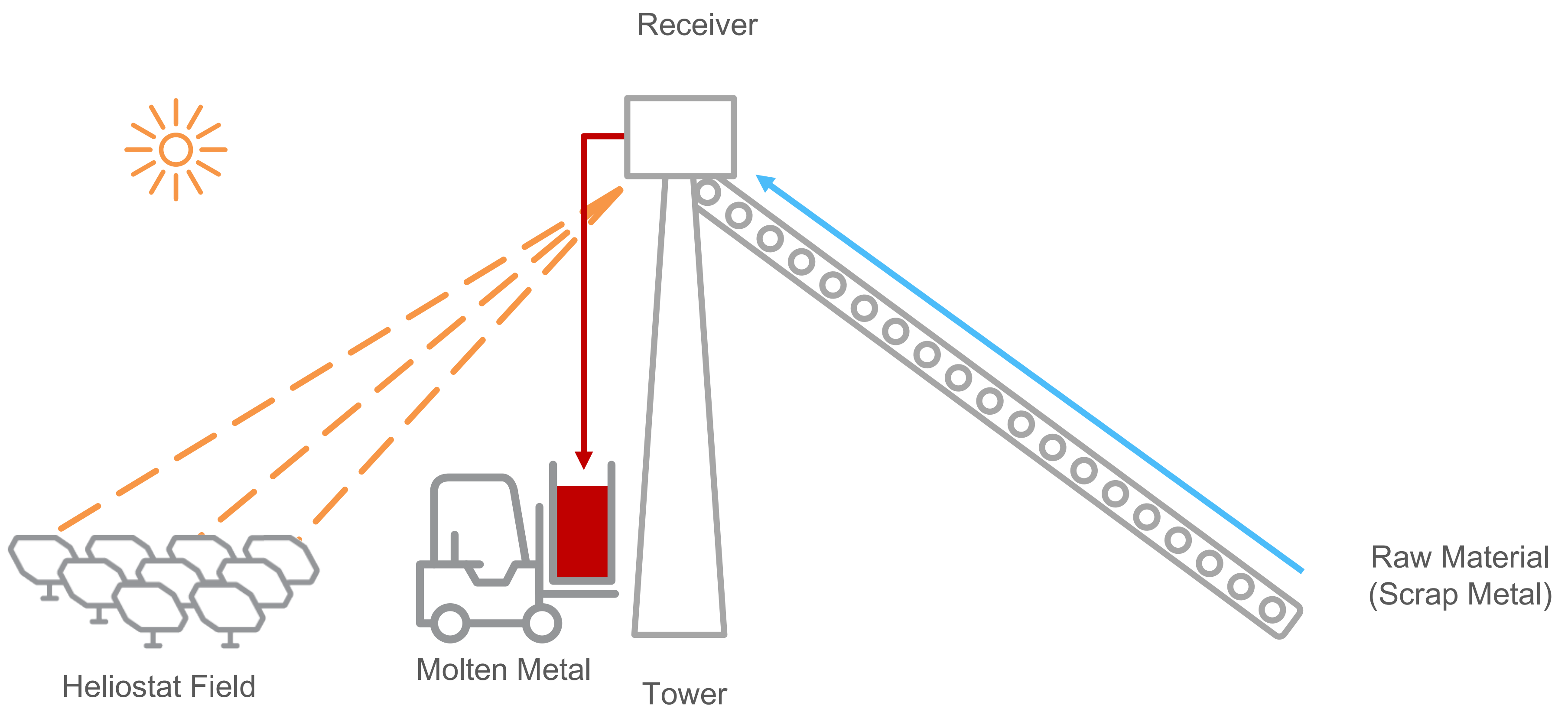
HelioHeat™ for Calcining

Example block diagram



HelioHeat™ for Direct Melting

Example block diagram

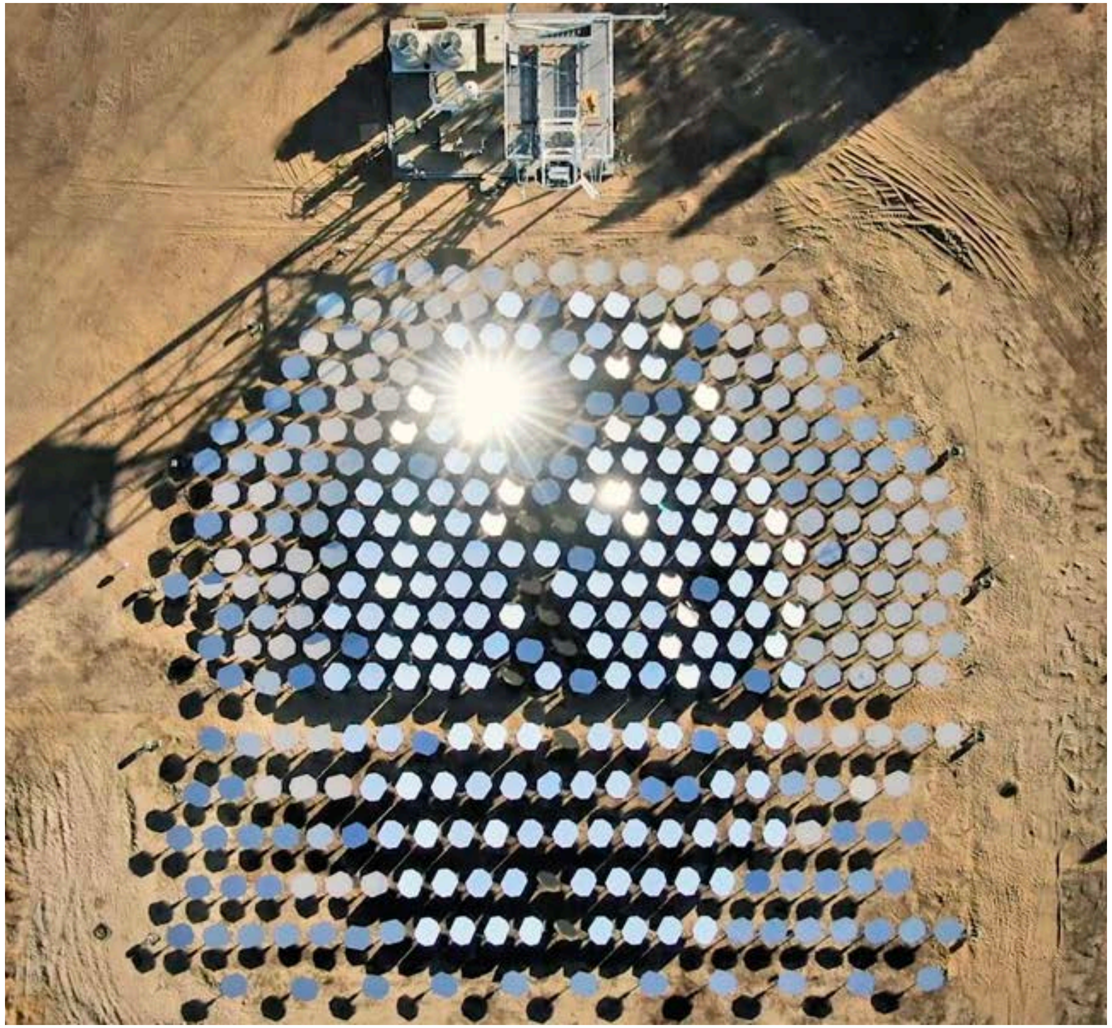


In Conclusion

Heliogen's concentrated solar technology is the only commercially available solution today that can cost-effectively provide the 24/7 heat needed for high-temperature industrial processes.

We are backed by supportive and aggressive investors, and have built a pipeline of customers eager to replace their use of fossil fuels.

We are eager to work with you to address this enormous market.



Heliogen's demonstration facility in Lancaster, California

Thank You

Vikas Tuteja

Chief Operating Officer

vikas@Heliogen.com

Q&A and Next Steps

Questions? Submit them through the Q&A box below.

Sign up for our newsletter at renewablethermal.org

To learn more about the RTC and how to become a member, contact Blaine Collison at blaine@dgardiner.com

Follow us on Twitter and LinkedIn @Rethermal

Appendix

Heliogen, Inc.

Replacing Fuels with Sunlight

hello@heliogen.com

Our Team

Bill Gross
CEO & Founder

Heliogen is the brainchild of Bill Gross, founder of renowned technology incubator, Idealab. Bill has founded many innovative companies including several in solar energy such as eSolar, RayTracker, Thermata, and EI Solutions.

Vikas Tuteja
COO

Vikas is an operations, finance and strategy professional with over 25 years of experience as an engineer, management consultant, investor and operator for companies in a wide variety of industries.

Steve Schell
CTO

Steve is a mechanical engineer by training and an entrepreneur at heart, with over 15 years of experience in R&D and commercialization of new technologies spanning solar energy, robotics, and 3D printing.

Fatimah Bello
VP, Business Development

Fatimah is a technology and strategic business development leader with 20 years of global experience in growth projects development, process engineering, and operations management across chemicals, cleantech, and downstream oil and gas industries.

Dolf Joekes
VP, Sales

Dolf has been commercializing cleantech for 17 years across 4 continents, bridging the startup and corporate worlds in hydrogen fuel cells, biomass and EV smart grid charging.

Our Backers

Swaroop 'Kittu' Kolluri
NeoTribe

Patrick Soon-Shiong
Nant Capital

Steve Case
Revolution's Rise of the Rest Fund

Bill Gates
Gates Foundation

REPLACING FUELS WITH SUNLIGHT

Heliogen

MarketWatch

The Economic Times

npr

global cement

CNN BUSINESS

Vox

greentechmedia

WIRED

MIT Technology Review

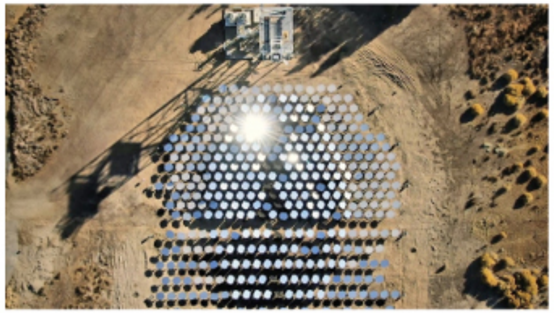
QUARTZ

TC

FAST COMPANY

This Bill Gates-backed solar tech could help finally decarbonize heavy industry

Using mirrors to concentrate solar power isn't new, but now the tech can push temperatures high enough to be used for manufacturing things such as steel and cement.



[Photo: courtesy Heliogen]

Climate Change / Clean Energy

How heat from the sun could help clean up steel and cement

Serial entrepreneur Bill Gross has launched a new solar thermal venture, designed to cut climate emissions from industrial heat.

tonyrobbins Follow

976 posts 4.9m followers 262 following

THE TIMES OF INDIA TECHNOLOGY

BBC

GeekWire

SolarPACES
Solar Power & Chemical Energy Systems

Forbes

UTILITY DIVE

REPLACING FUELS WITH SUNLIGHT

Heliogen

Backup

Technical Potential: Solar Technologies

- Seven solar-IPH combinations with five solar technologies

  (1) Solar water heater (flat plate collector [FPC]), with water storage

  (2) CSP oil trough, **with and without** 6-hrs thermal storage

  (3) CSP with direct steam Linear Fresnel, without storage

  (4 – 7) PV (AC & DC) for connection with resistance heating, electric boilers, and heat pumps (ambient and WHR)

- Technology parameters defined with NREL's System Advisor Model (SAM); NREL's Renewable Energy Potential (reV) Model used to estimate generation by county
  - Defined as ~1 MW systems; scaled by sizing to winter peak and summer peak, system footprint, and available land area
  - Developed new land area exclusions to better represent requirements of IPH systems