Concentrated Solar Thermal Integration into Spice Roasting Industry: An Energy Analysis of an Indian Masala Manufacturing Facility

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Introduction

- Tavish Fenbert: Mechanical Engineering student at Northeastern University in Boston, USA
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- Centre for Technology Alternatives for Rural Areas

Research Goals

- Analyze the thermal steps in the masala production process
- Determine power consumption of these processes
- Develop strategies for integrating solar thermal technology

Indian Masalas

- Masala = spice mixture
  - Coriander
  - Cumin
  - Black pepper
  - Cinnamon
  - Chili powder
  - Onion
  - Ginger
  - Garlic
  - Turmeric
  - Salt
  - And others…

- Used daily by families around the country
- 6.22M metric tons of spices consumed every year

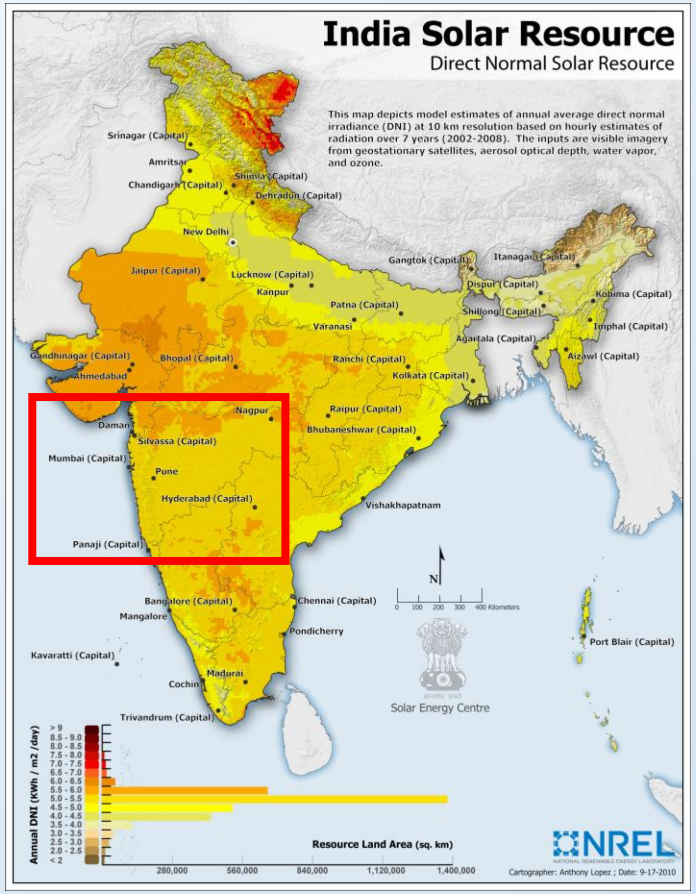
Purpose of Roasting Spices

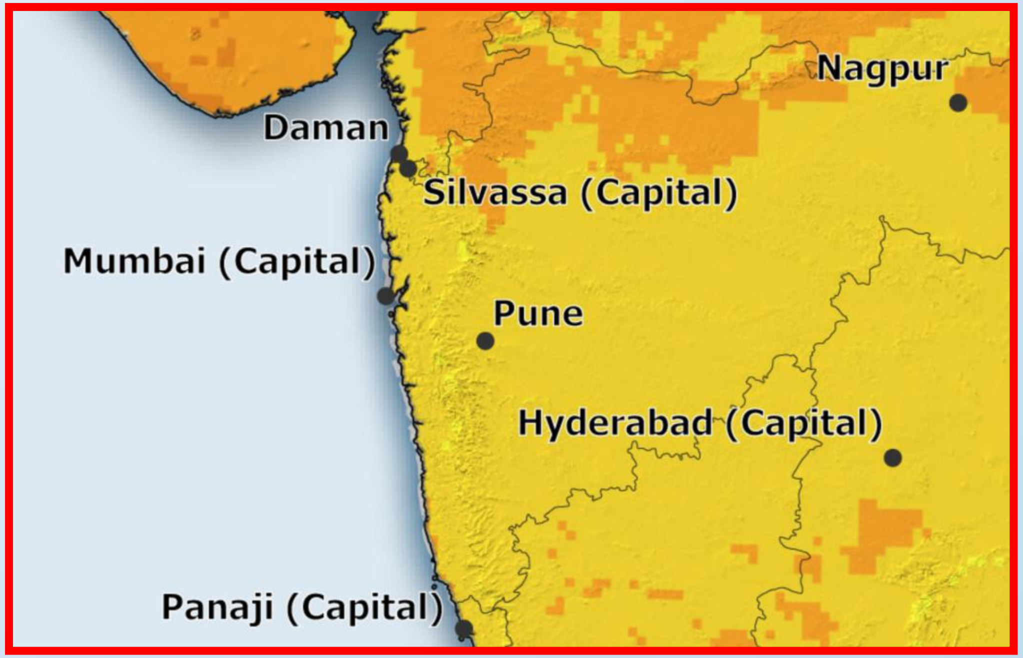
- Changes in:
  - Aroma
  - Texture
  - Appearance
  - Reduce moisture
- Labor-intensive process
- Skilled labor required

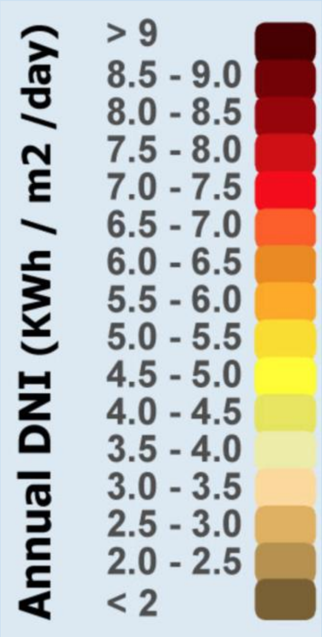
Indian Power Subsidies

- Main forms of heat for masala industry are LPG and electricity
- Indian Gov. subsidizes electricity and LPG in many parts of the country
- 21.55M tons of LPG consumed in India during 2016-2017
  - Over half was imported
- Solar thermal can:
  - Reduce greenhouse gas emissions
  - Reduce energy spending of Indian Gov.

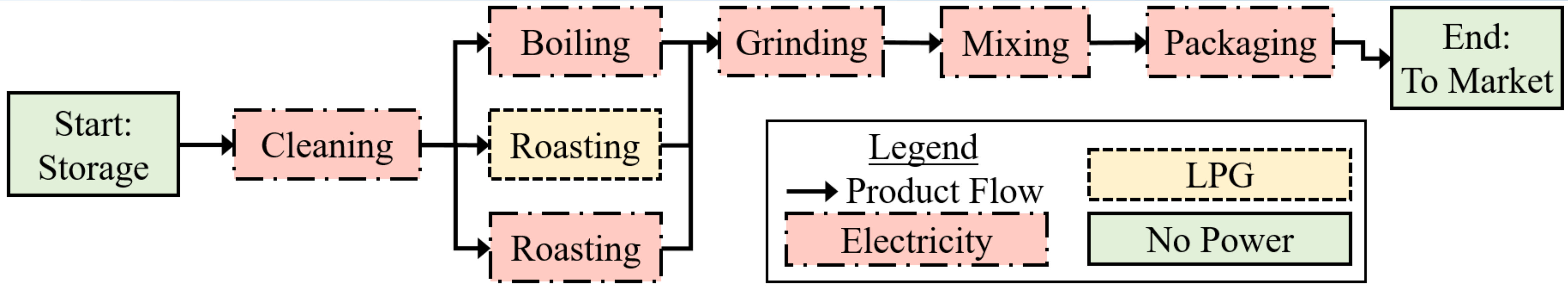
Indian Solar Availability



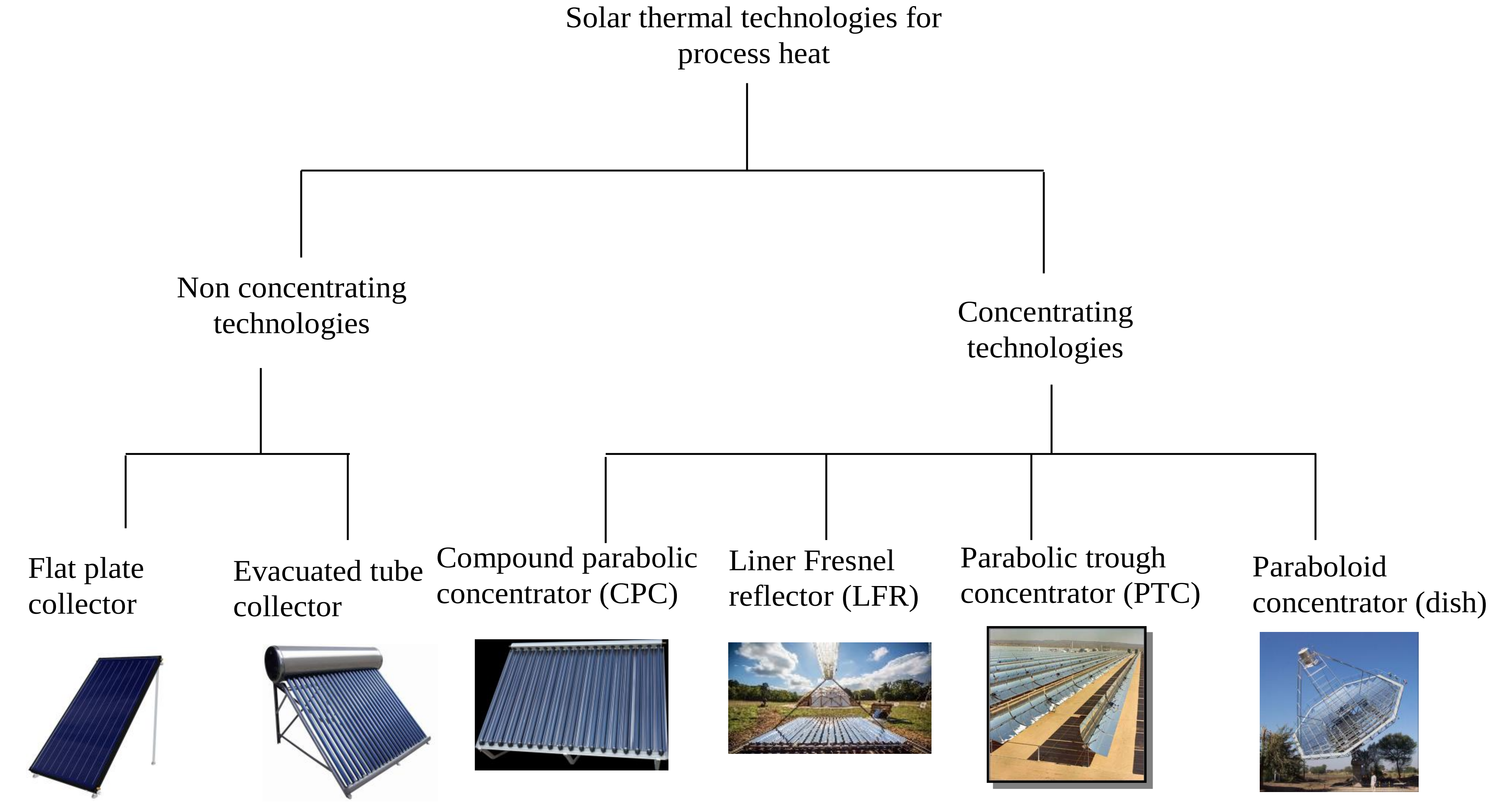




Masala Production Process

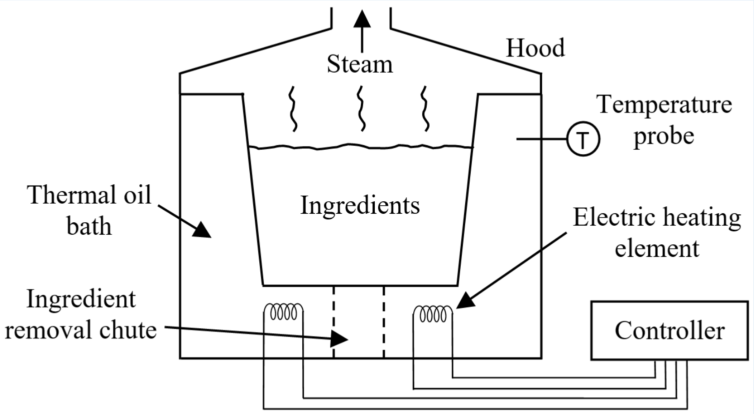


Solar Concentrators Overview

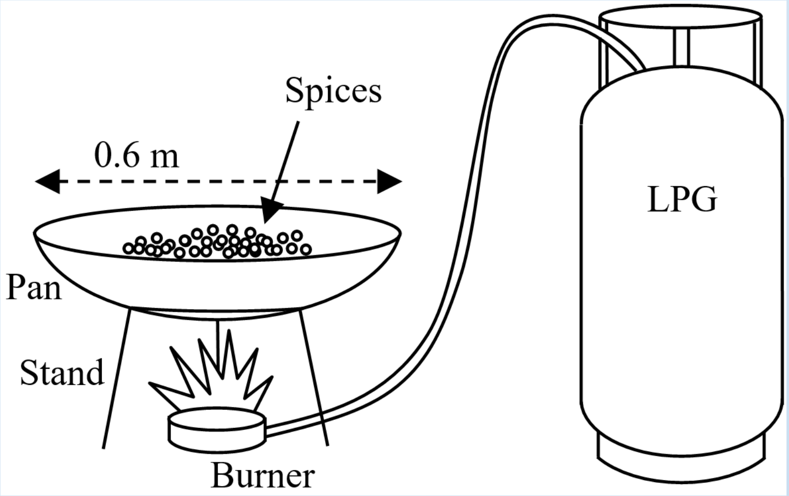


Method: Thermal processes

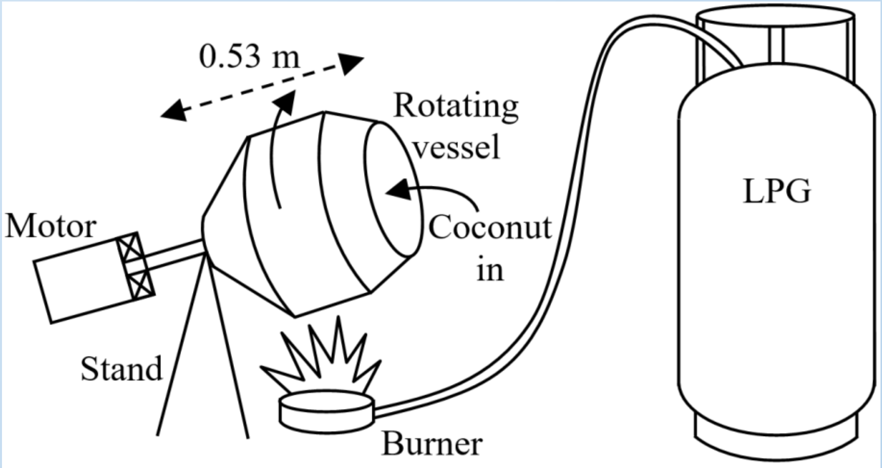
Boiling/Roasting in thermal oil vessel (elec.)



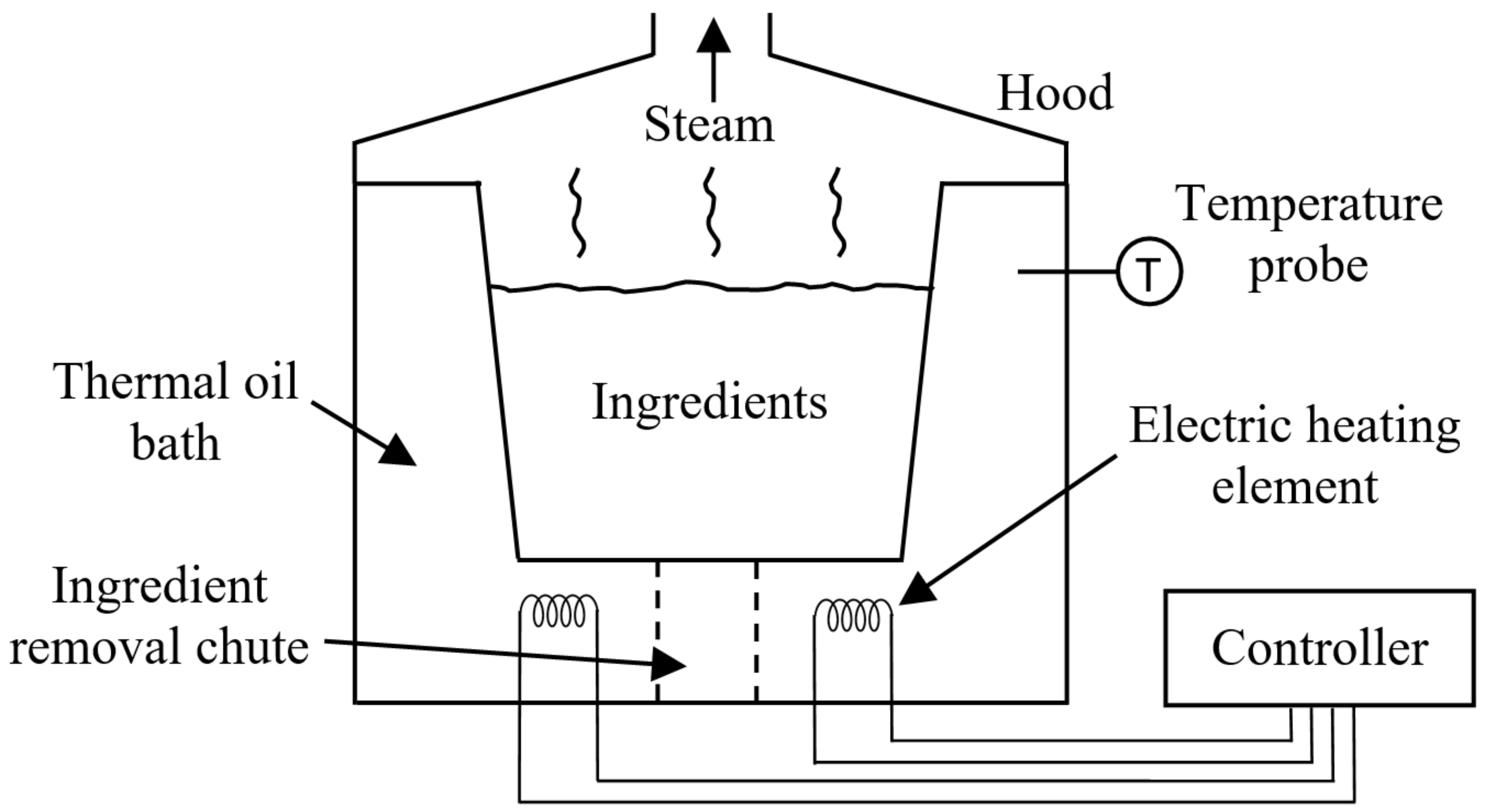
Roasting in pan (LPG)



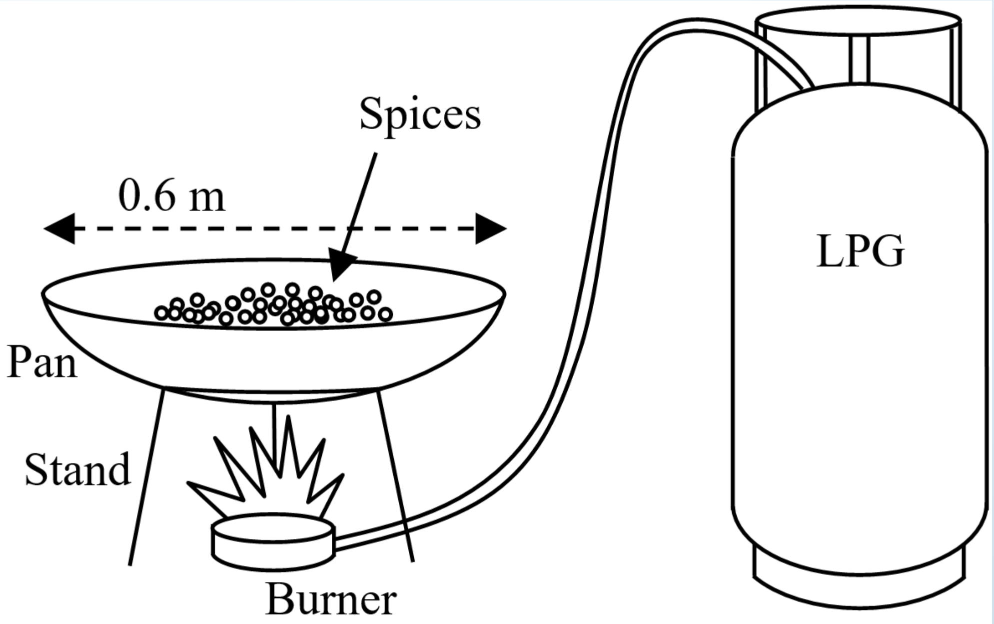
Roasting in rotating vessel (LPG)

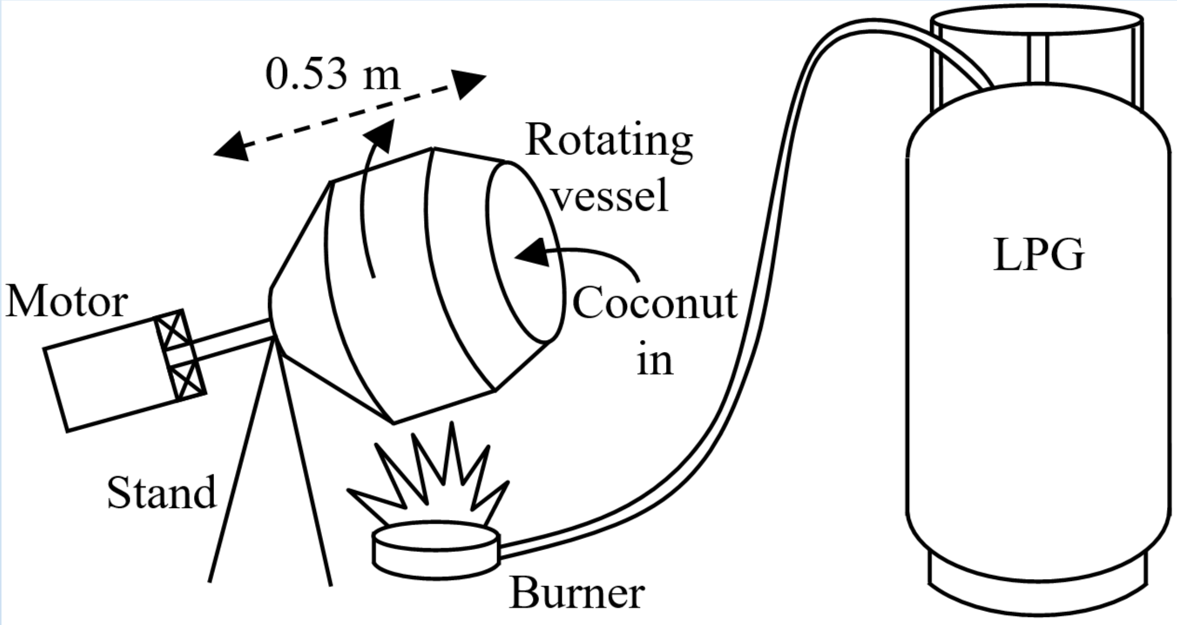


Method: Boiling/Roasting in electric thermal oil vessel



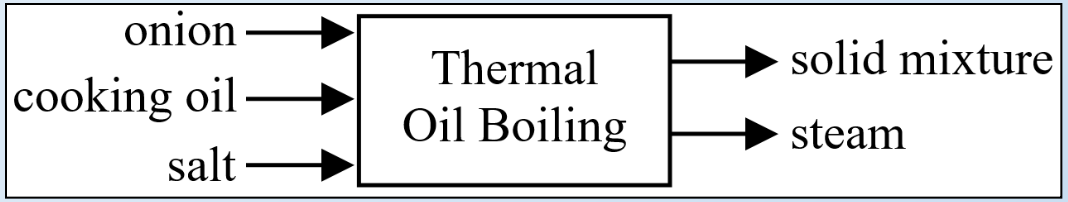
Method: LPG roasting



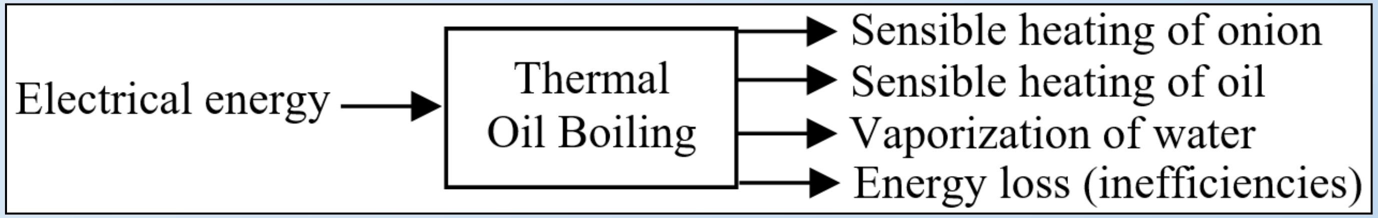


Energy Analysis Framework

Mass Balance: $m_{in} = m_{out}$



Energy Balance: $E_{in} = E_{out}$

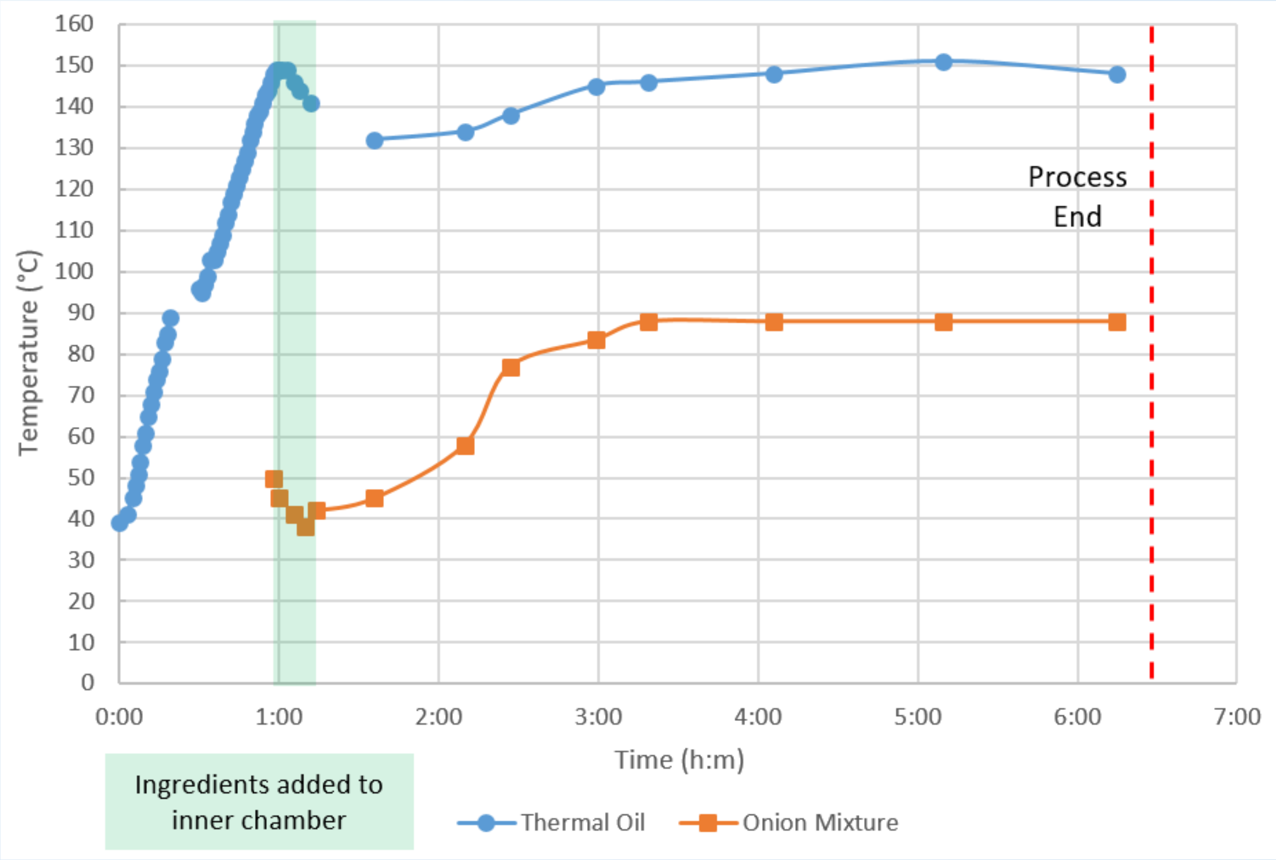


$$Q_{elec} = m_{onion} {}^{*} c_{onion} {}^{*} \Delta T_{onion} + m_{oil} {}^{*} c_{oil} {}^{*} \Delta T_{oil} + m_{steam} {}^{*} \Delta H_{vap} + Q_{loss}$$

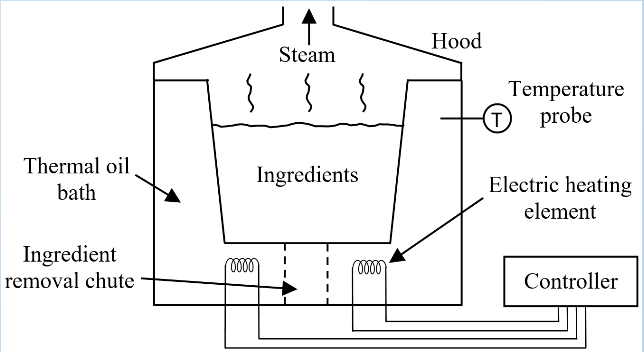
Efficiency: $\eta_{LPG} = \frac{E_{required}}{E_{consumed}}$

Energy Analysis: Boiling in electric thermal oil vessel

Temperature vs. Time for Onion Boiling

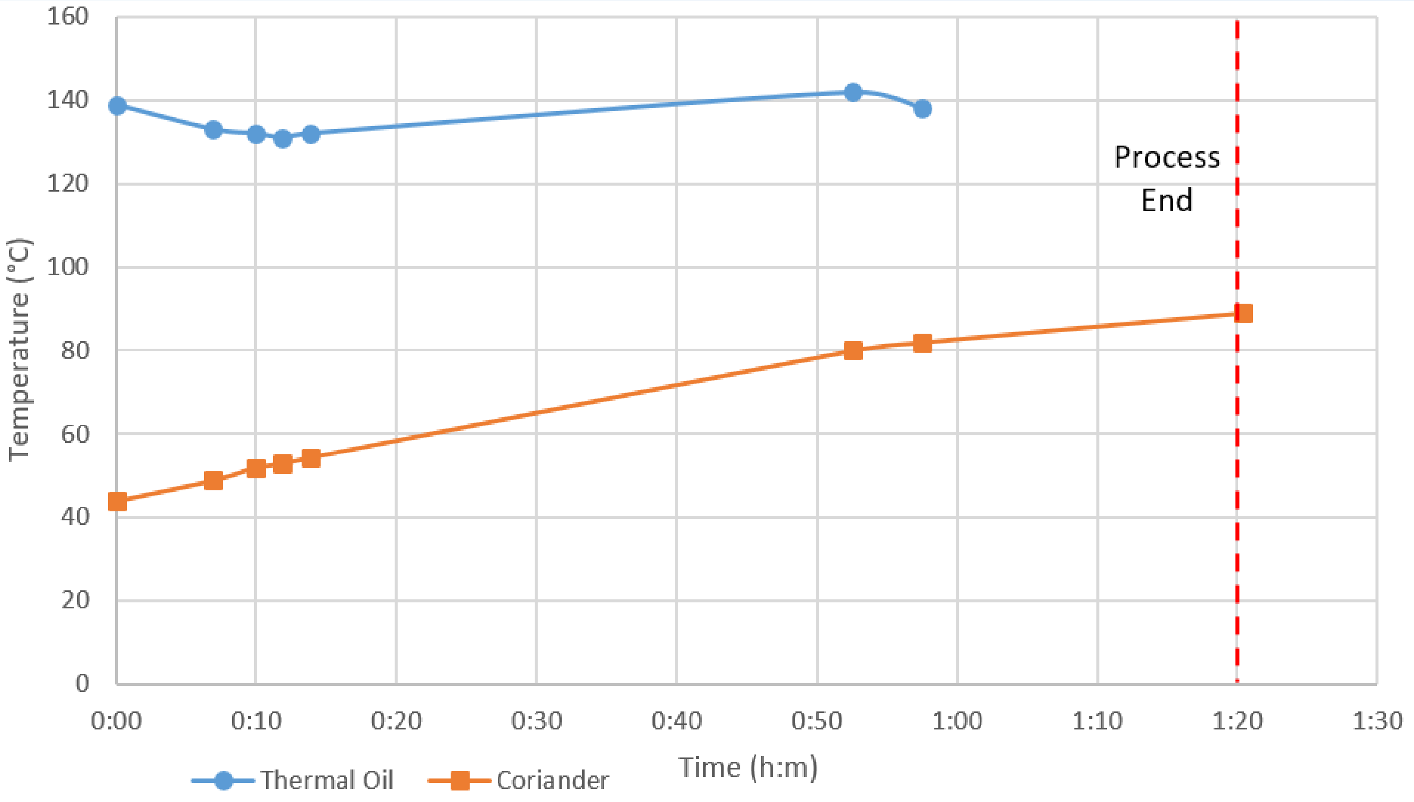


Particular	Unit	Thermal Oil Boiling
Batch mass	kg	700
Batch time	min	390
Vessel temperature	°C	130 to 150
Power required	kW	34.9

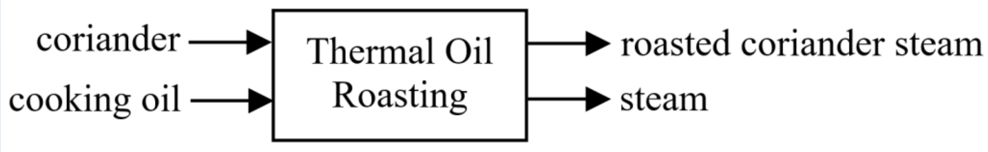


Energy Analysis: Roasting in electric thermal oil vessel

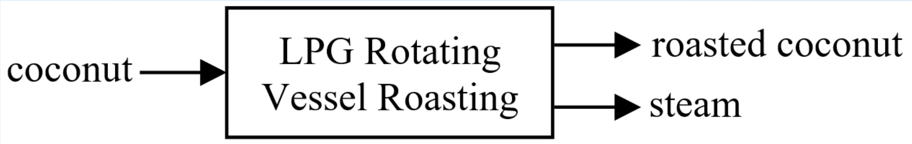
Temperature vs. Time for Coriander Roasting



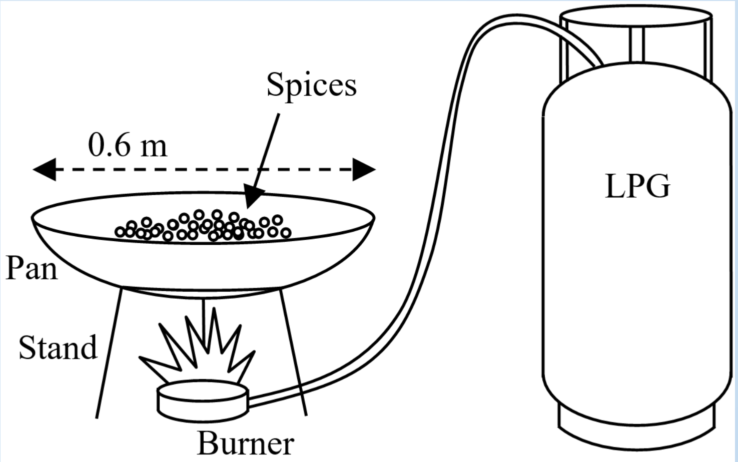
Particular	Unit	Thermal Oil Roasting
Batch mass	kg	100
Batch time	min	80
Vessel temperature	°C	130 to 140
Power required	kW	4.8

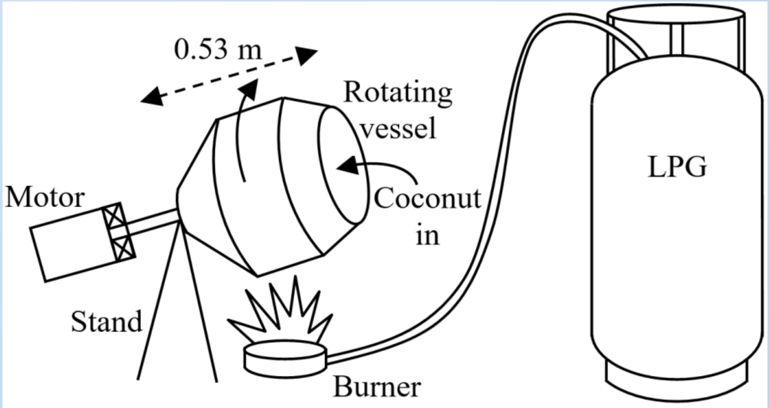


Energy Use: LPG roasting



Particular	Unit	Pan	Rotating Vessel
Batch mass	kg	35	5
Batch time	min	28	7.4
LPG consumption rate	kg_{LPG}/hr	1.07	2.71
Power consumed	kW	13.7	34.7
Power required	kW	5.31	7.24
LPG heating efficiency, η_{LPG}	%	38.8	20.9



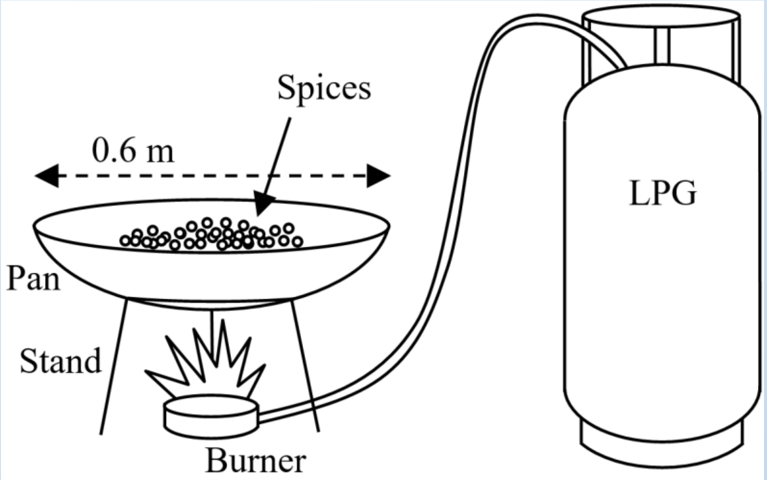


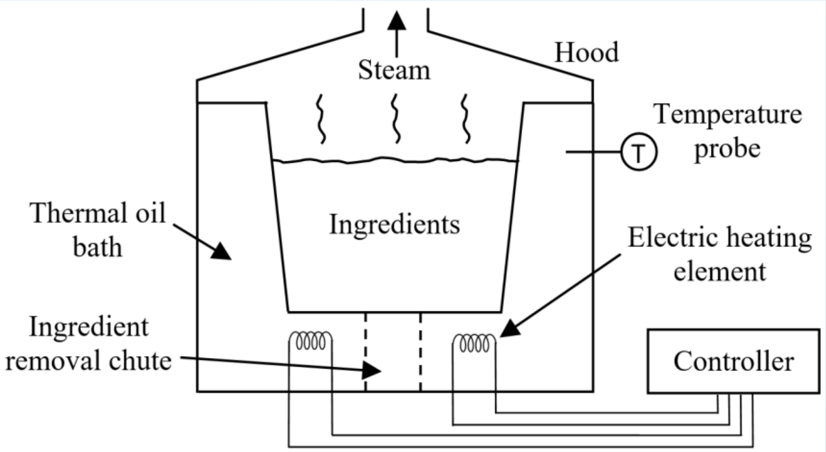
Solar Thermal Integration: Factors for consideration

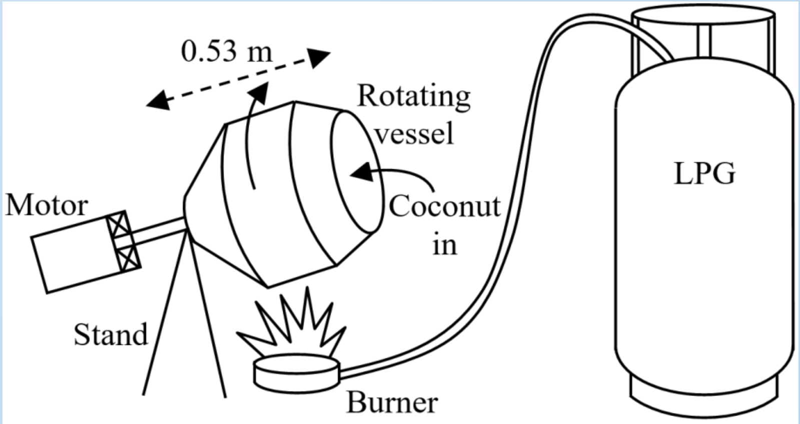
- **Temperature/power requirements**
  - Time of day
- Solar space availability
- Backup power
- Plant layout
- Energy storage
- Cost

Solar Thermal Integration: Temp and power requirements

Process	Solar Technology Suggestions	Area Required (m^2)
Thermal oil boiling	PTC	117
Thermal oil roasting	PTC	16
LPG roasting in pan	Scheffler	~50
LPG roasting in rotating vessel	Scheffler	~50





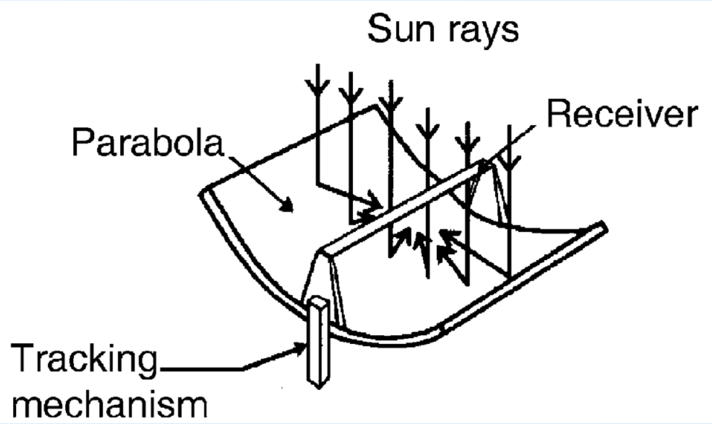


Solar Thermal Integration: Potential Implementation Strategy

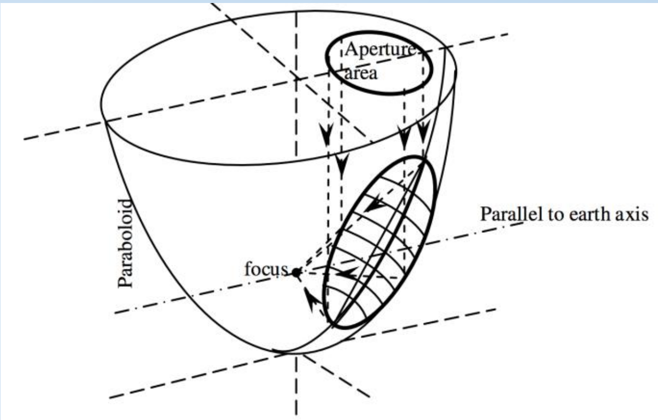
- Integrate a system of PTCs to heat the thermal oil for electric boiling/roasting processes
- Install Scheffler dishes to replace LPG for the pan and rotating vessel processes

- Some plant layout rearranging required
- PTCs are likely more practical than Scheffler

Parabolic Trough Concentrator (PTC)



Scheffler Dish



Conclusions

- Masala production industry is candidate for solar thermal integration
- Temperature range of processes is 140°C to 320°C

- Next steps:
  - Continue to gather data on energy use in masala production industry
  - Detailed economic analysis of solar thermal integration

Thank You!

Questions?