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Technical Feasibility of Integrating Concentrating Solar Thermal Energy in the Bayer Alumina Process

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3rd October 2019, The University of Adelaide

Partnership

An ARENA funded project:

Australian Government
Australian Renewable Energy Agency

ARENA

In Collaboration with:

Total project cost is ~ AUD 15M over 4.5 years (2017-2021)

>30 Academic staff, Postdocs, Engineers and PhD Students

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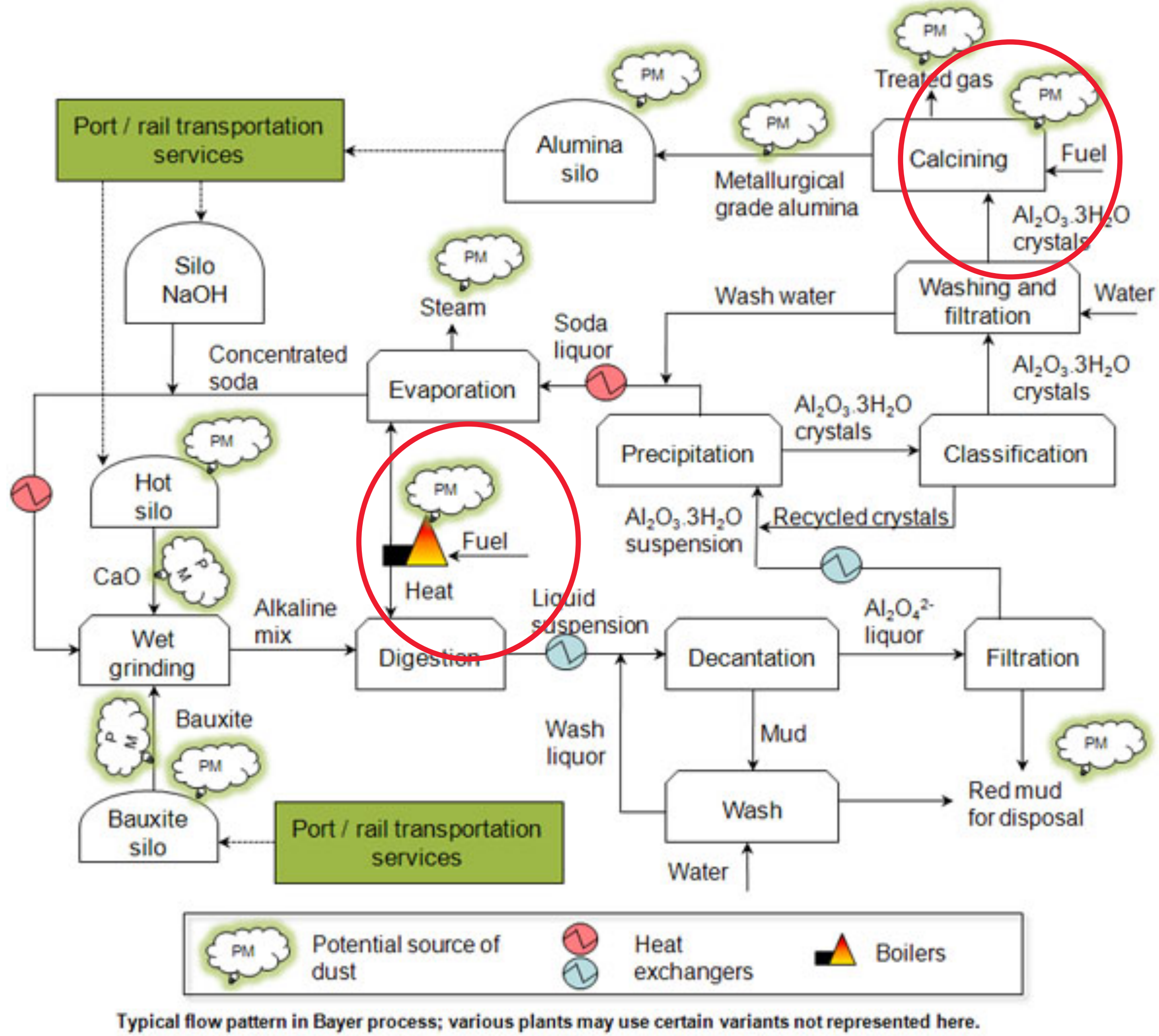
Introduction – The Bayer process

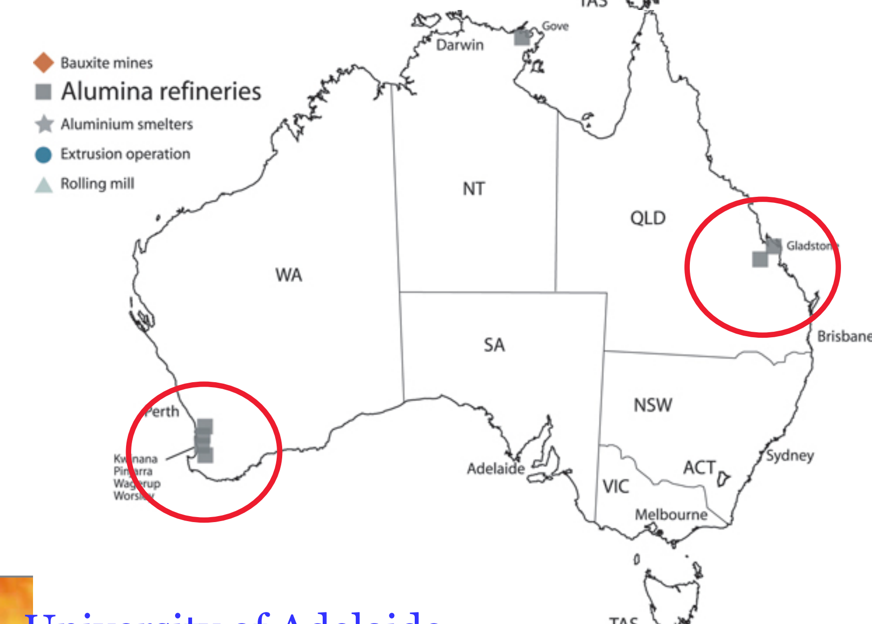
- Australia is the second largest producer of alumina, generating **AUD 10 billion** in 2018 [1];
- The energy consumption of the Bayer process is **~10 GJ/tonne** of alumina;
- The total natural gas consumption in the Alumina refineries is approximately **4%** of the natural gas produced in Australia

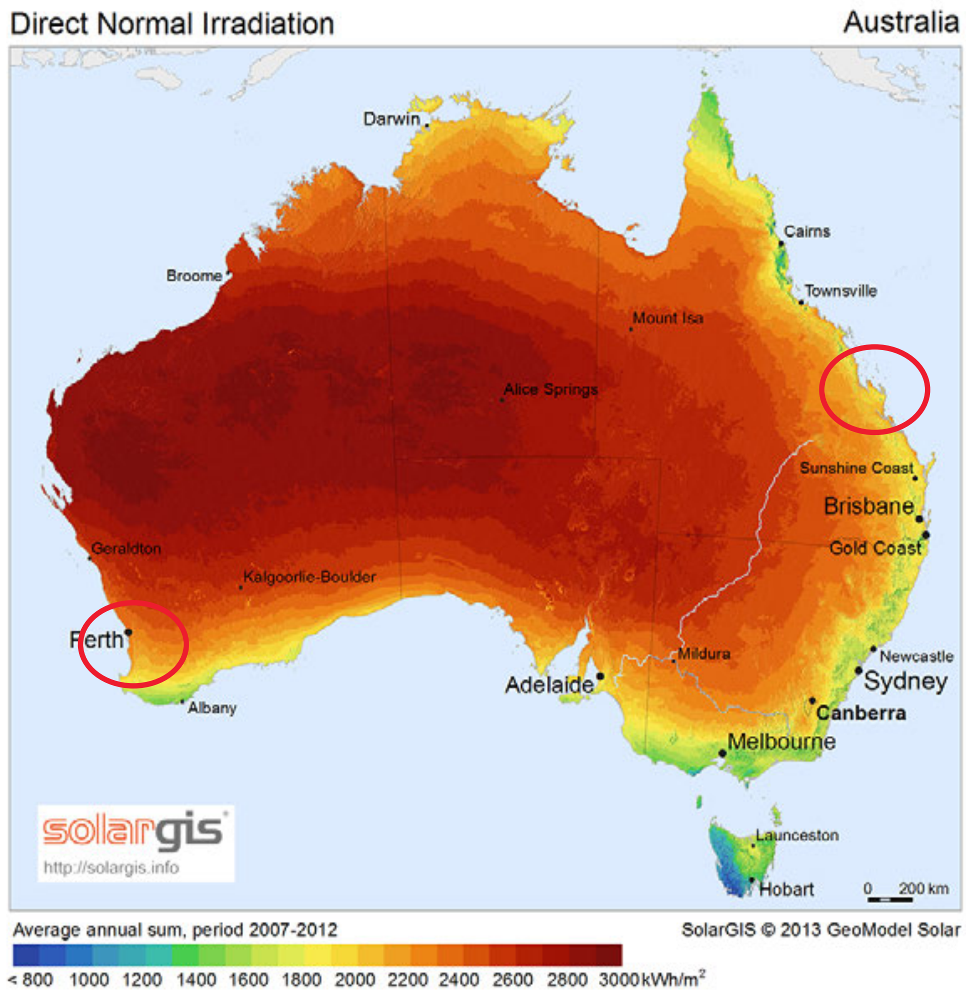


Typical flow pattern in Bayer process; various plants may use certain variants not represented here.

http://www2.ec.gc.ca

Introduction – Alumina refineries in Australia

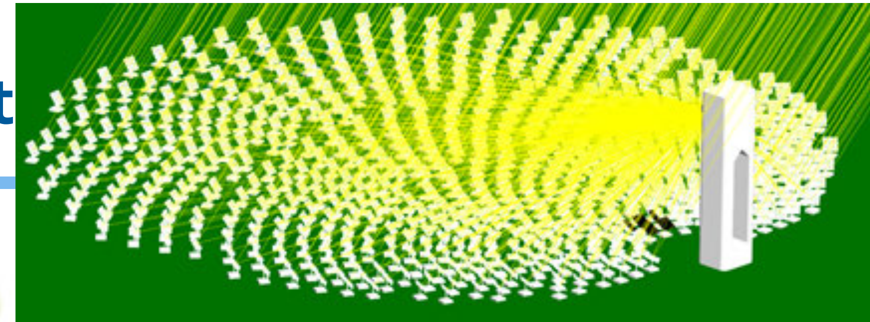




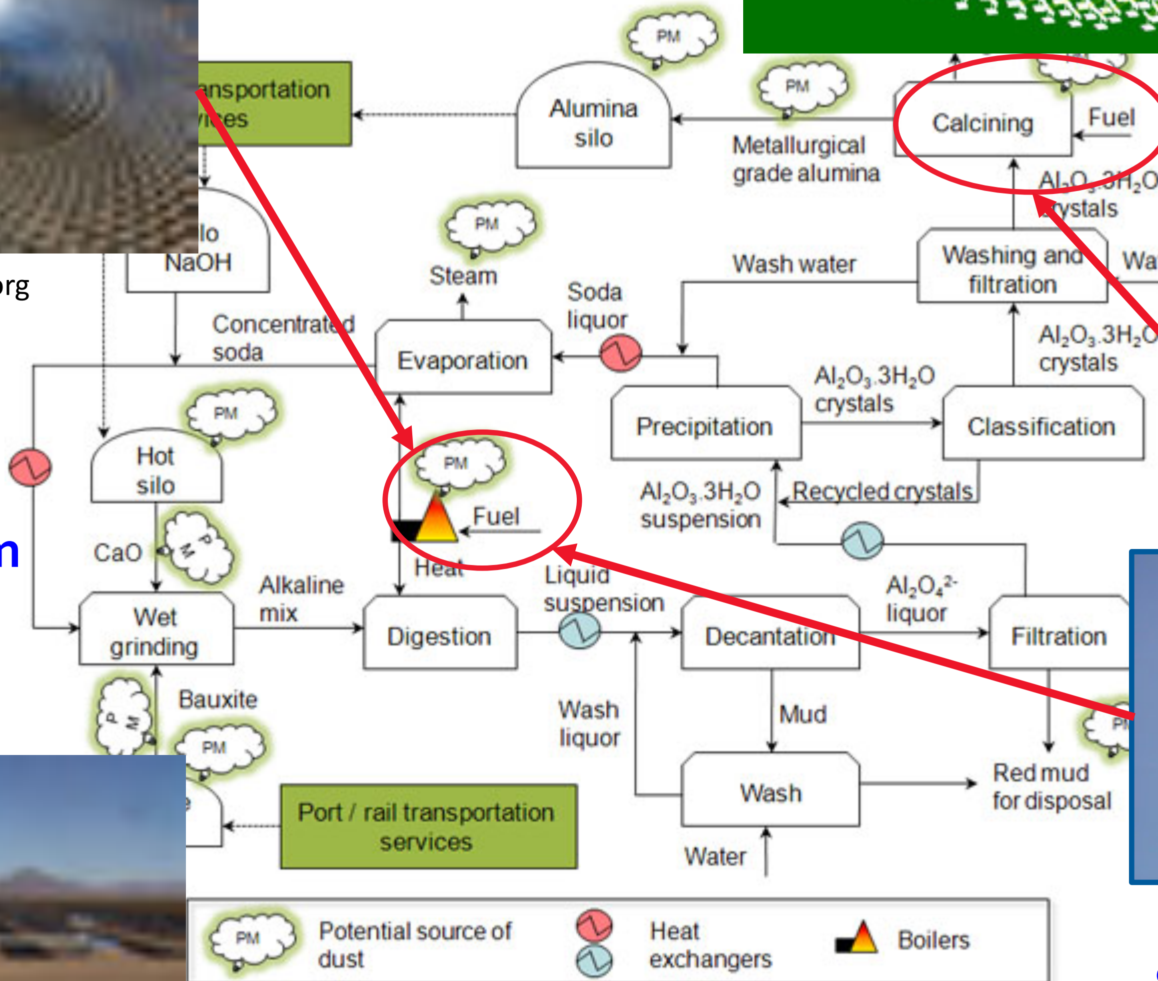
Objectives of the overall program

1. To develop an integrated suite of hybrid technologies targeting 29% - 45% solar share in the Bayer alumina refining process.
2. To establish a technologically realistic pathway for introducing different types of CST into the process, as follows:
   a) 'Low temperature commercially-ready CST technology;
   b) 'Solar reforming of natural gas;
   c) 'High temperature solar calcination of alumina in a novel hybrid reactor
3. To advance each of the above technologies toward commercial implementation into the Bayer process;
4. To develop a commercialisation plan for each technology platform, individually or collectively.

Program targeting a viable path t



www.solarpaces.org



flow pattern in Bayer process; various plants may use certain variants not represented here.

Solar Calcination from 900 – 1000°C

Solar Steam >360°C

www.itpthermal.com

www.csiro.au

Solar reforming of natural gas

Solar Hybridised Bayer Process: Sub-programs

Process & Techno-economic Modelling

- Identify viable technology paths
- Compare with alternative options

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Low temp steam / CHP

- Develop implementation proposal
  - ➢ Evaluate integration
  - ➢ Compare all options

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Solar Reforming

- Develop proposal for pilot testing
  - ➢ Address process integration
  - ➢ Preferred storage options

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Calcination

- Demonstrate at lab-scale ready for future on-sun demonstration
  - ➢ Direct / Indirect

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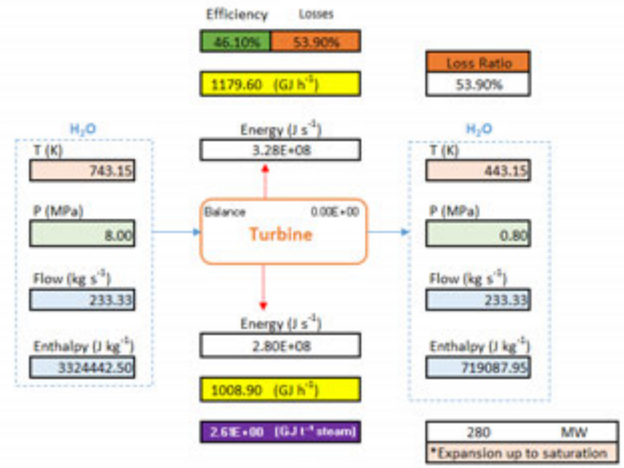
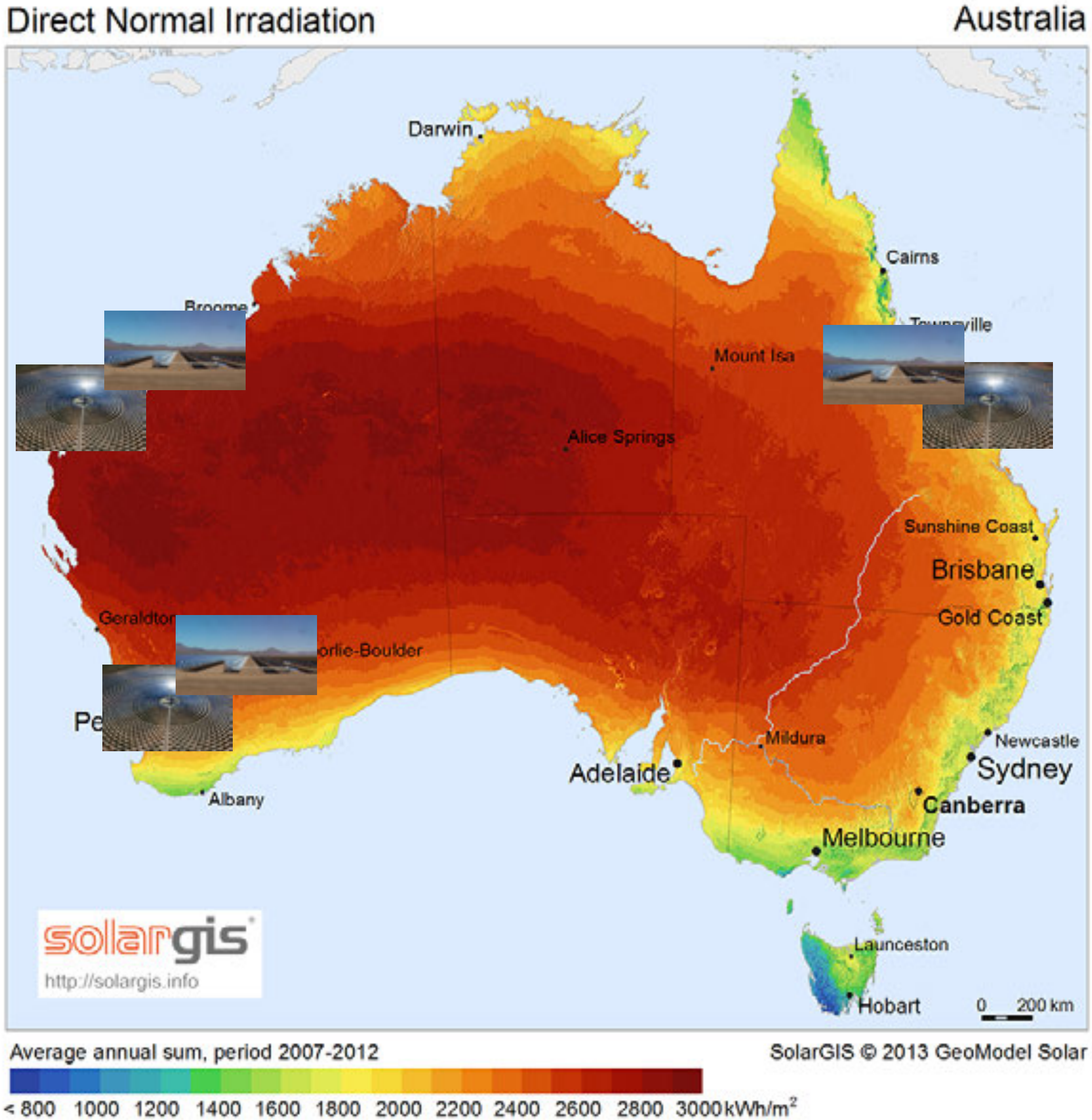
Program 1 – Solar steam

- Energy demand (inc. thermodynamic properties of steam and water) - Microsoft Excel model +The CoolProp database (2014 version)
- Annual performance - System Advisor Model (SAM, Version 2017.1.17)

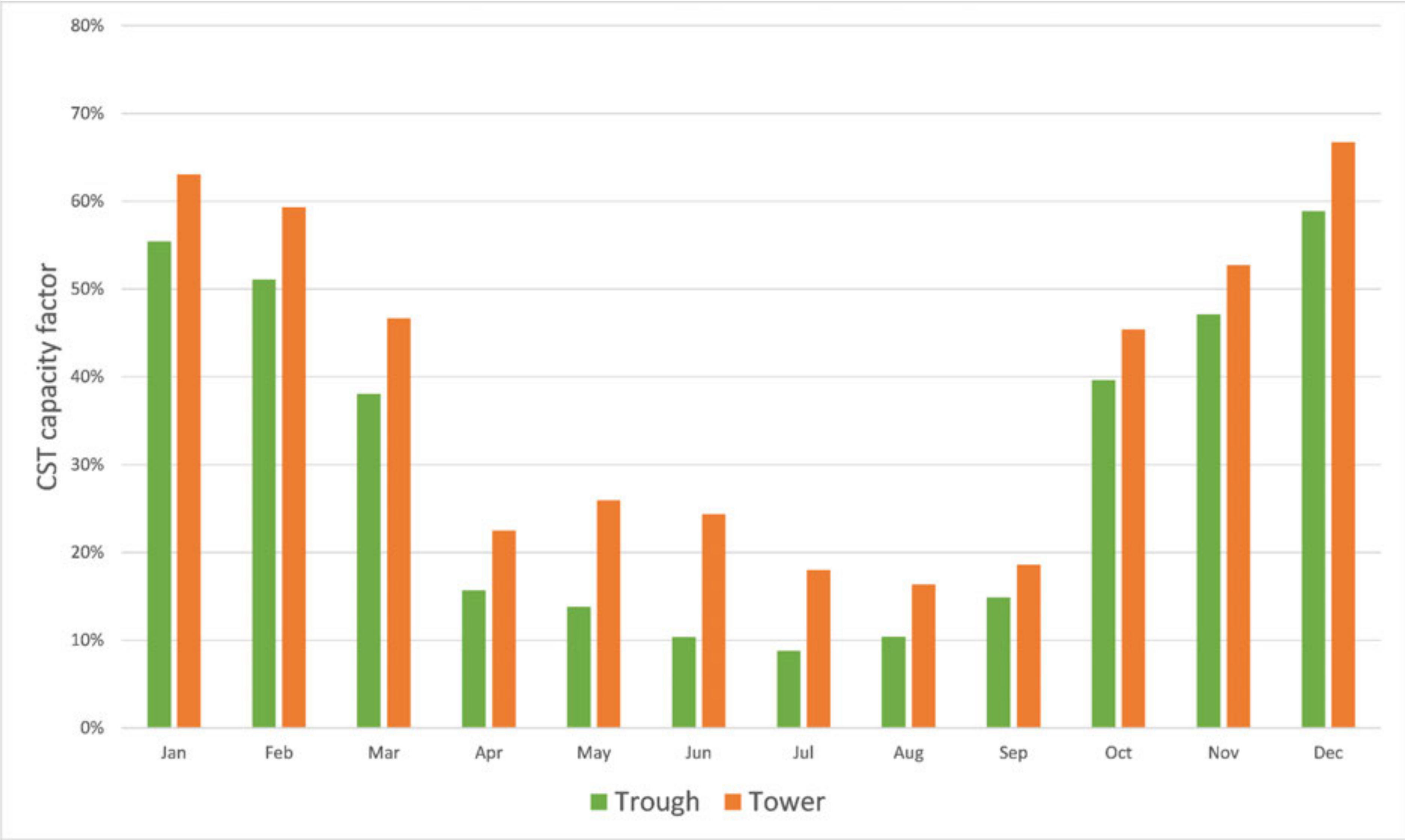


	Parabolic Trough	Tower
Heat transfer fluid	Therminol VP-1	Nitrate Salt
Receiver	Siemens UVAC 2010	Tubular receiver
Concentrator	Siemens SunField 6	N/A
Thermal storage medium	Molten Salt	Nitrate Salt
Steam temperature	360°C	470°C, 80 bar
Addition heating	Boiler (→ 470°C, 80 bar)	N/A

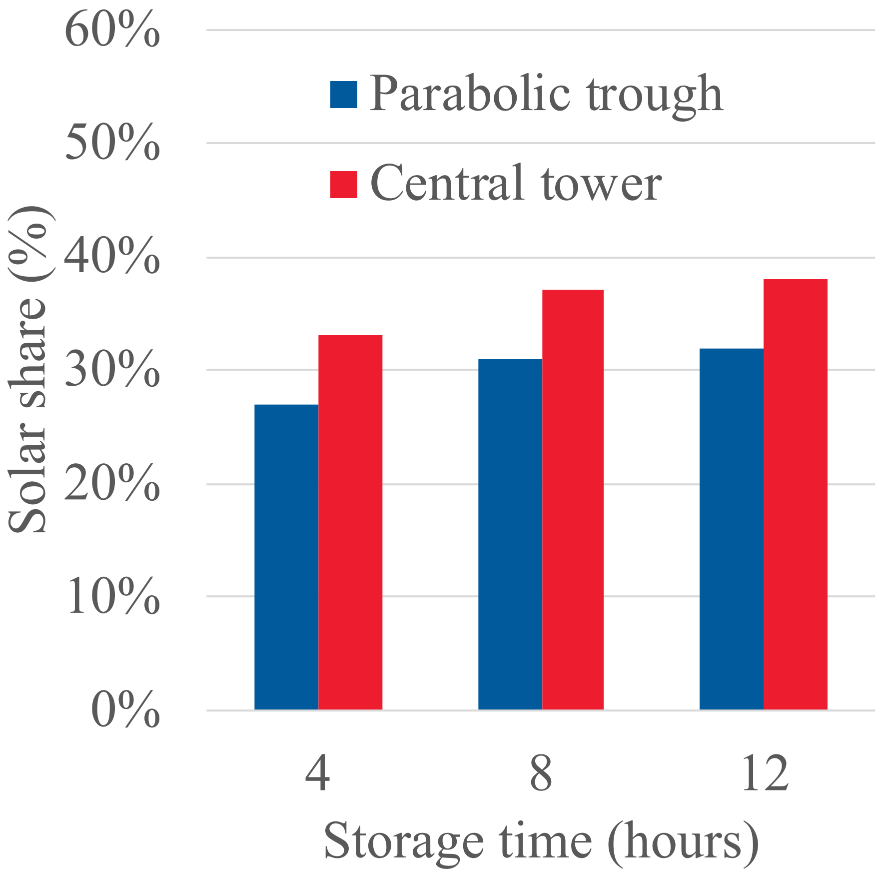
Program 1 – Solar steam



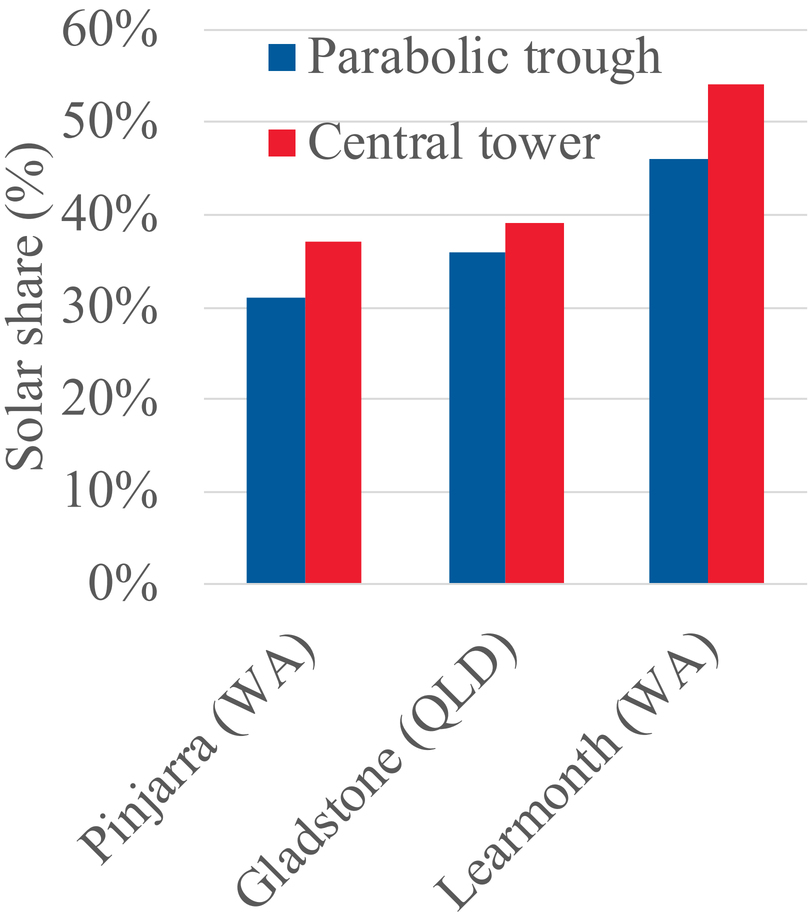
Program 1 – Trough vs Tower



Program 1 – Effect of storage and DNI on solar share



Location – Pinjarra (WA)

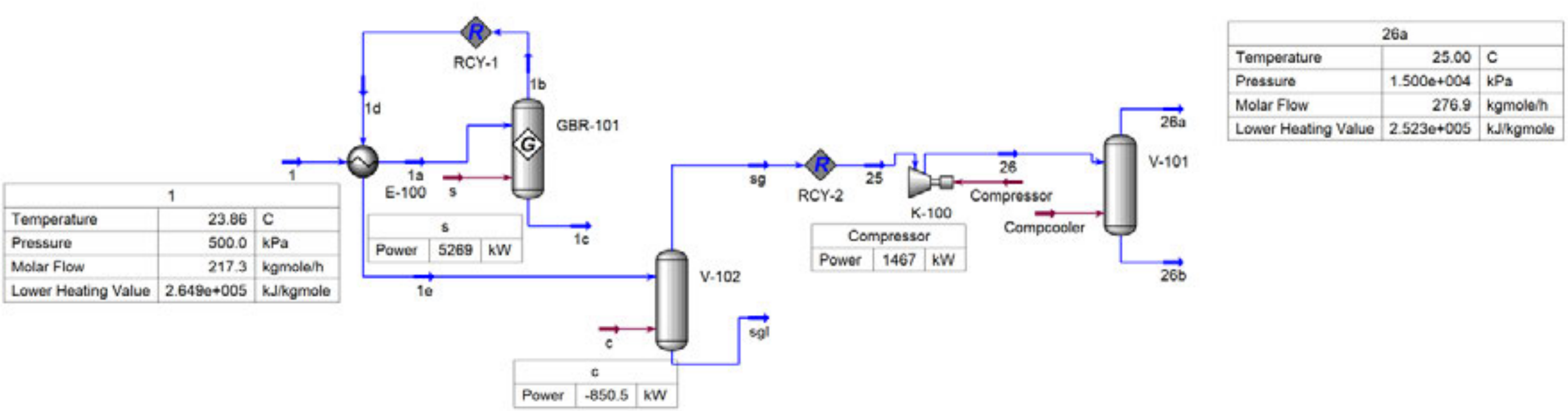


Storage time - 8 hrs

Solar multiple - 2

Program 2 - Solar steam reforming of natural gas

- UNISIM is a process modelling software that assumes steady state in an integrated environment
- In these cases, the reformer was assumed to be operated at 800°C and 0.8MPa with a steam to carbon ratio of 2:1
  - Steam reforming with syngas storage (see below)
  - Steam reforming – No storage
    - Syngas cooled to 25°C
    - Syngas maintained at 400°C



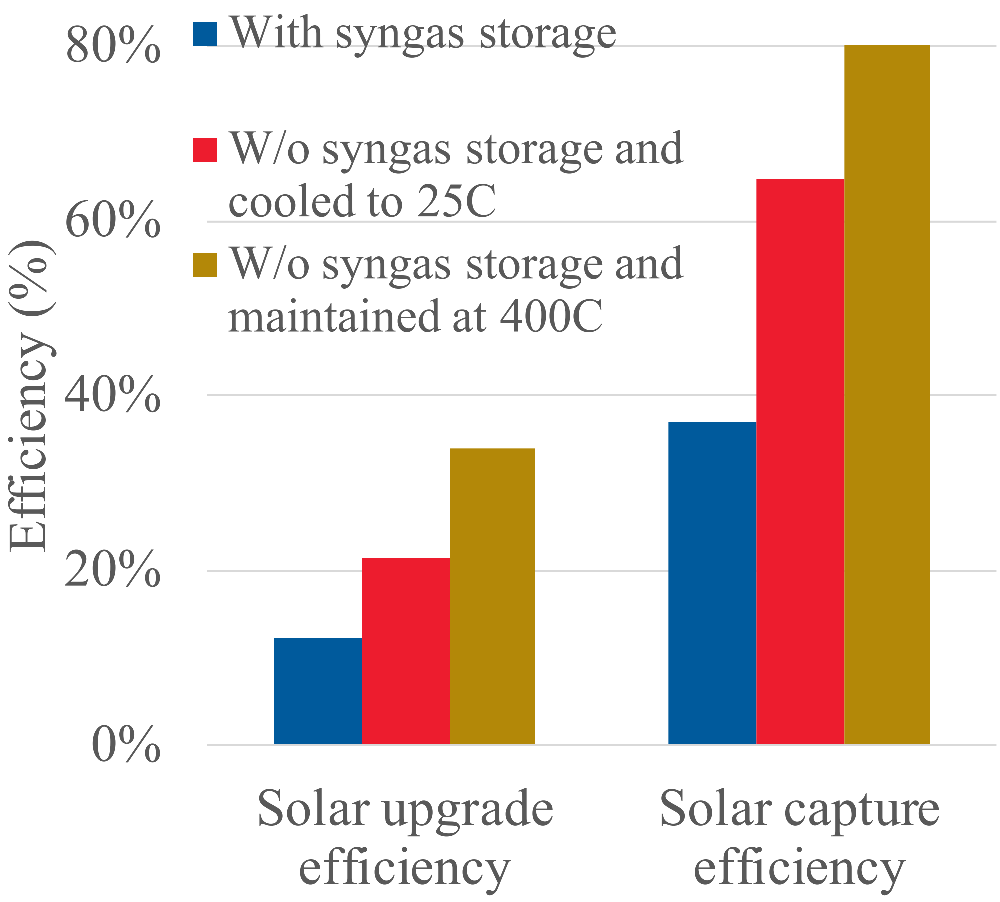
Program 2 - Solar steam reforming of natural gas

- Solar upgrade efficiency

$$\eta_{sue} = 100\left(\frac{Qout}{Qin} - 1\right)$$

- Solar capture efficiency

$$\eta_{sce} = \frac{Qout - Qin}{Q_{Solar,in}}$$

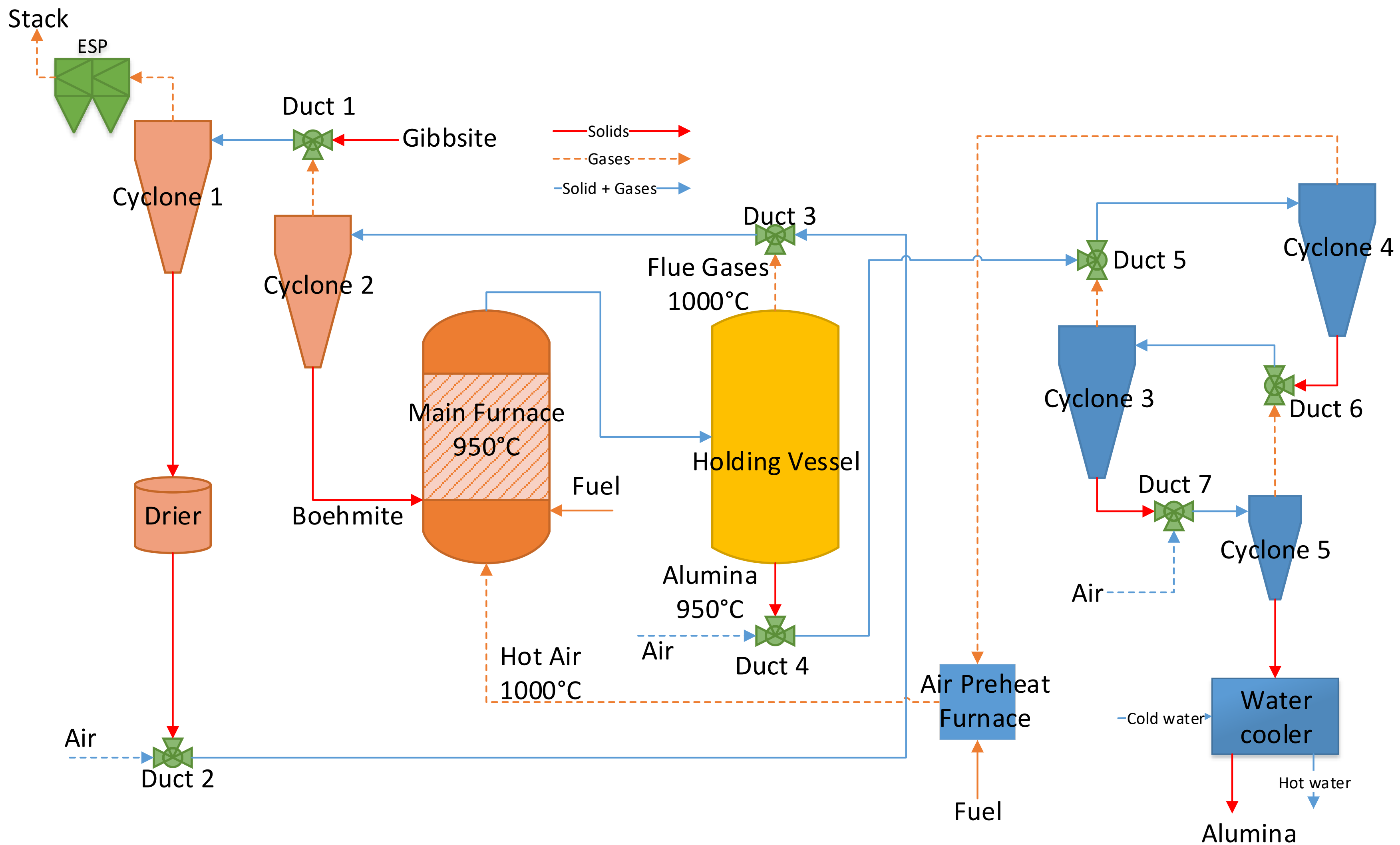


Program 3 - Direct solar calcination of alumina

Assumptions

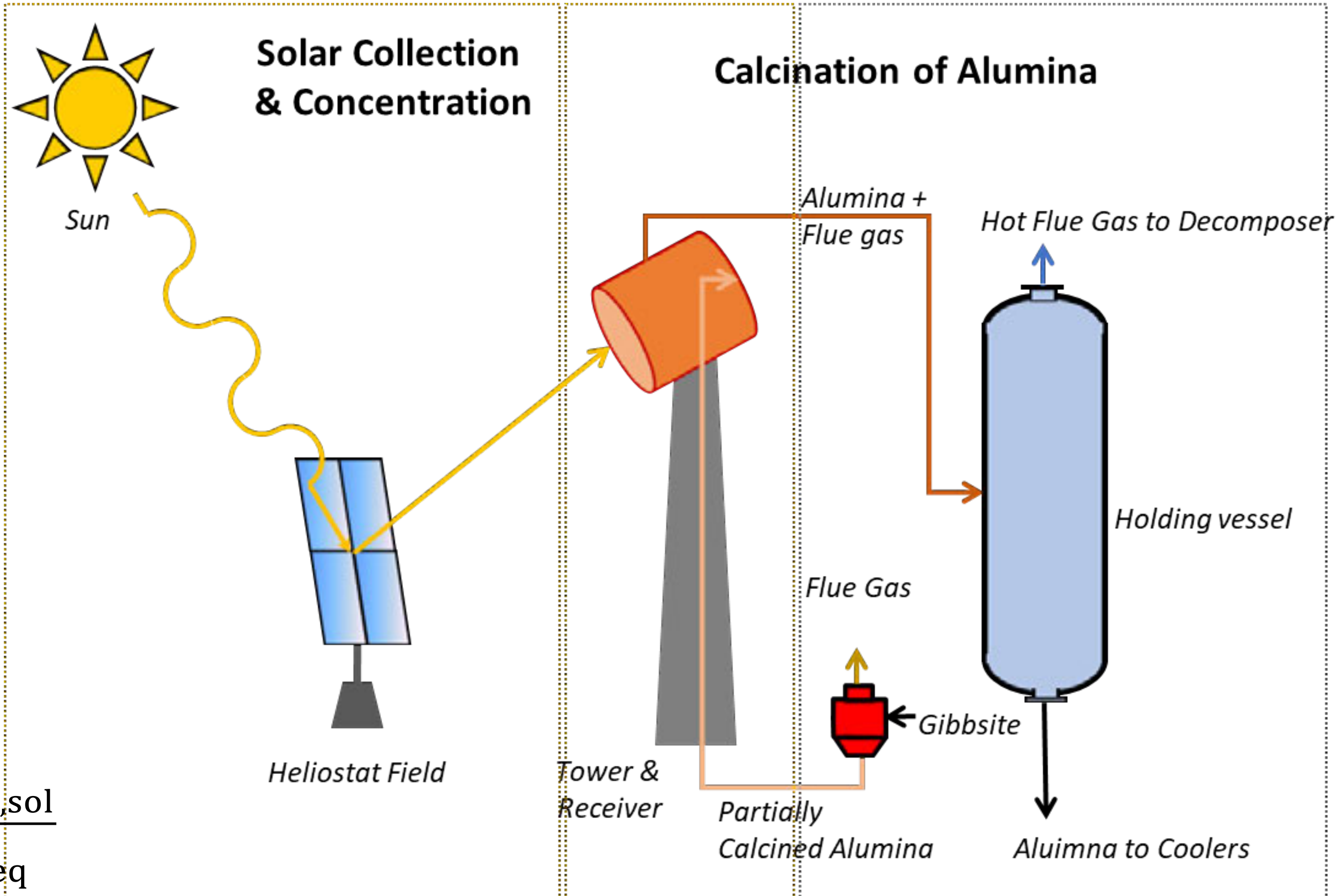
- Natural gas is simplified to be pure methane
- 100% conversion of gibbsite to alumina
- Gibbsite undergoes partial calcination before the particles enter the main furnace removing the chemically bound water molecules as per the following reaction:
  - $2Al(OH)_3 \rightarrow 2AlOOH + 2H_2O$
- Gibbsite undergoes complete calcination in the main furnace
  - $2AlOOH \rightarrow Al_2O_3 + H_2O$
- The main furnace is to be operated at 950°C
- 10% excess air is provided to the main furnace to ensure complete combustion of the natural gas
- 5% energy loss occurs from each individual unit operation

Program 3 - Direct solar calcination of alumina



Flash Calcination Process

Program 3- Direct solar calcination of alumina

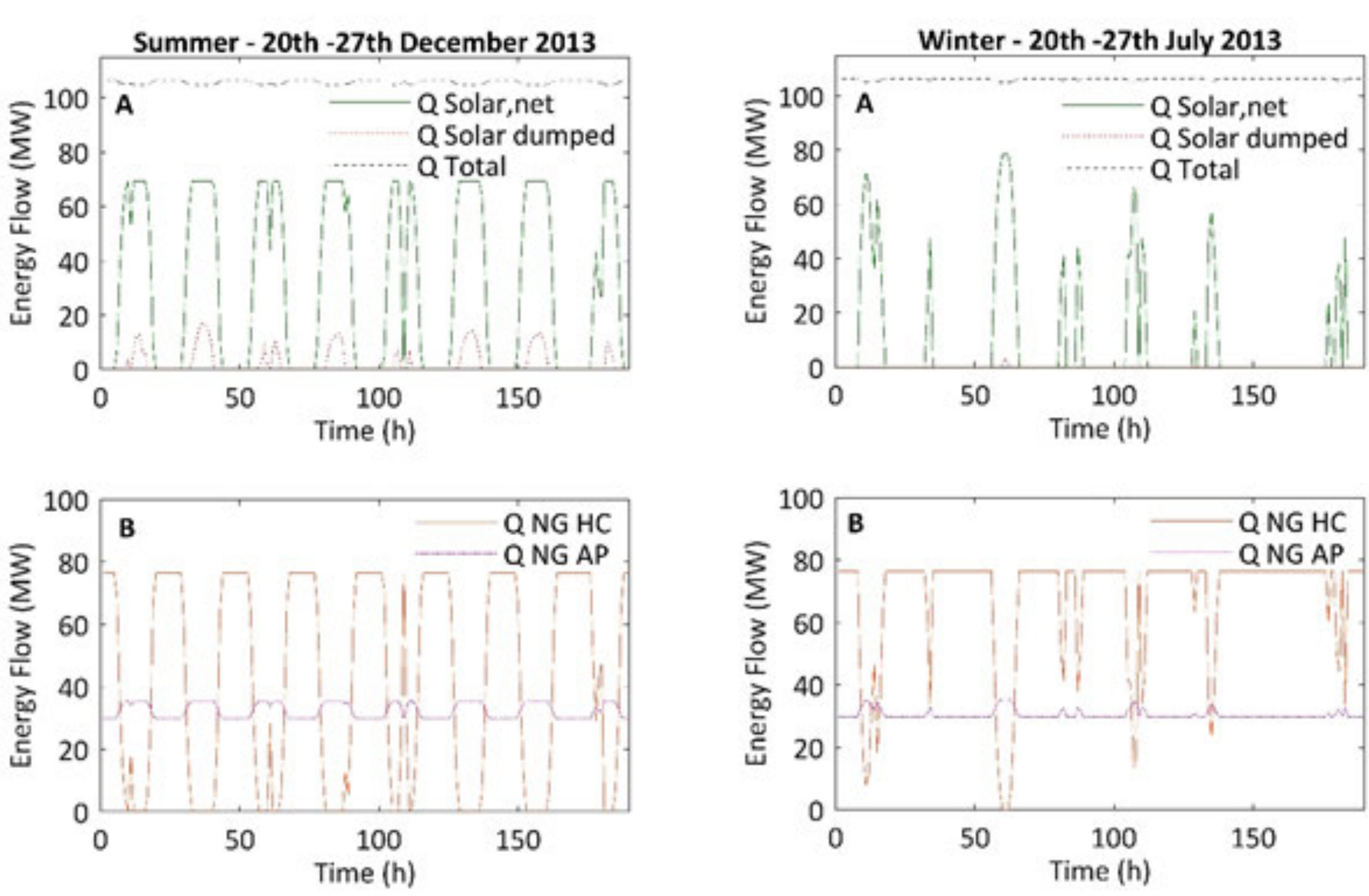


$$\Phi = \frac{\dot{Q}_{\mathrm{net,sol}}}{\dot{Q}_{\mathrm{req}}}$$

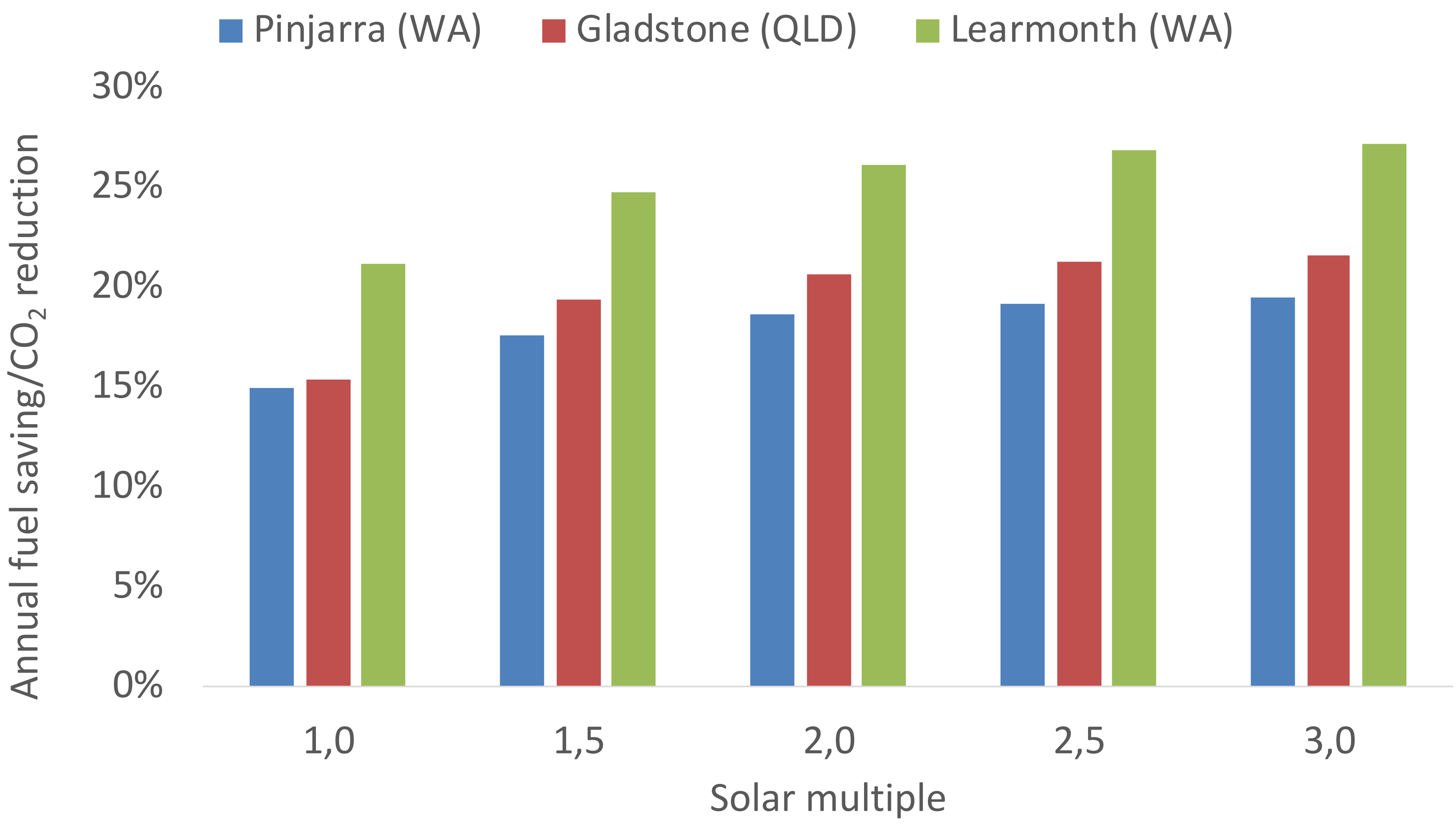
$$\dot{Q}_{\mathrm{net,sol}} = I_{DN} A_{coll} \eta_{opt} - \sigma (T_{rec}^4 - T_0^4) A_{aper} - \dot{Q}_{\mathrm{loss}}$$

$\eta_{opt} = \eta_{ref,coll}\ \eta_{sb}\ \eta_{itc}\ \eta_{aa}\ \eta_{ref,CPC}\ \eta_{cos}$

Program 3- Direct solar calcination of alumina



Program 3- Direct solar calcination of alumina

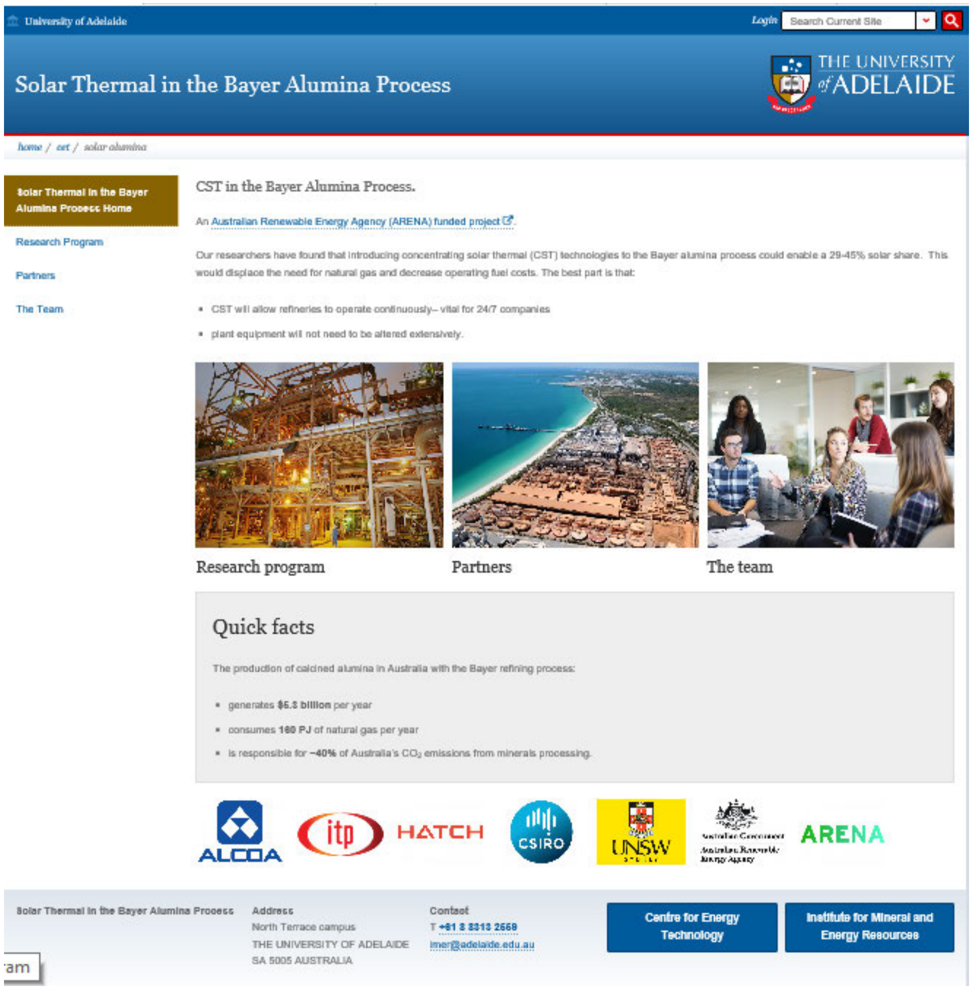


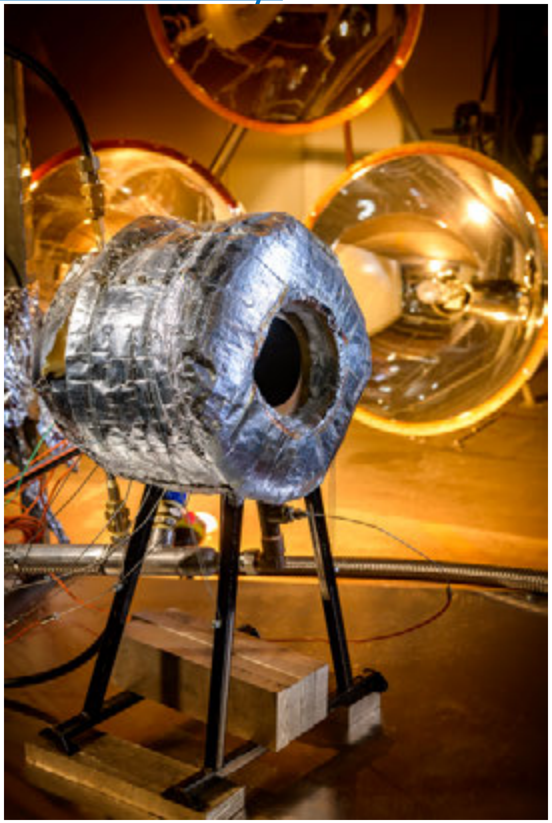
Summary

- A minimum of 30% solar share can be achieved. Both storage capacity and DNI location have an effect on the solar share of the proposed CST technologies
  - the solar share of central tower system > parabolic trough due to improved winter performance;
  - the solar reforming of natural gas without syngas storage with the heat recovery is limited to 400°C has the highest solar upgrade and capture efficiencies;
  - the limited annual fuel saving even for the case of a solar multiple of 3 is because this configuration does not provide any thermal storage.
- Future work
  - Economic evaluation
  - Alternative configurations

Project website

- https://www.adelaide.edu.au/cet/solar-alumina/





Session 3-A: **Chinnici et al.** First-of-a-kind Investigation of Performance of a Directly-Irradiated Windowless Vortex-based Particle Receiver

Acknowledgement

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Thank you !

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