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Particle technology research in CST in ASTRI and at the University of Adelaide

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Solar PACES Workshop, 19 April, 2017

Particle Receiver Technology in ASTRI

ASTRI
AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

Horizon 1

Support for commercial plant

- O&M
- Materials, cycling, etc

Horizon 2

SCO_2 turbine

- Na receiver
- ~ 600°C Turbine In
- ~8 hours storage
- ~ $25MW_e$

Horizon 3

SCO_2 (+ Air Brayton topping?) or Solar Fuels

- > 850°C
- ~8 hours storage
- ~ $50MW_{th}$

Particle receivers

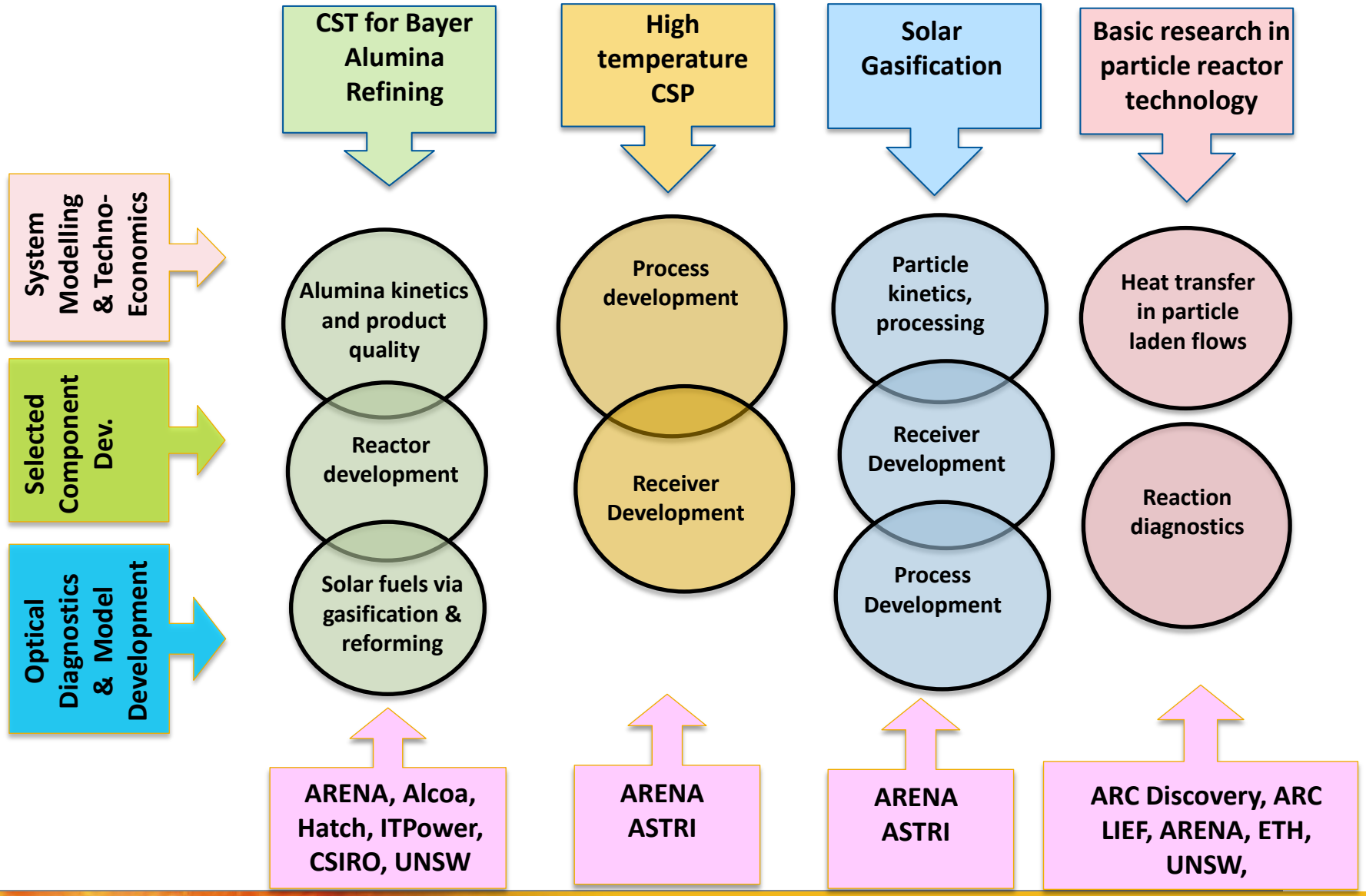
ARENA
Australian Government
Australian Renewable Energy Agency

CSIRO
Australian National University
The University Of Queensland Australia
The University of Adelaide
University of South Australia
QUT
Flinders University

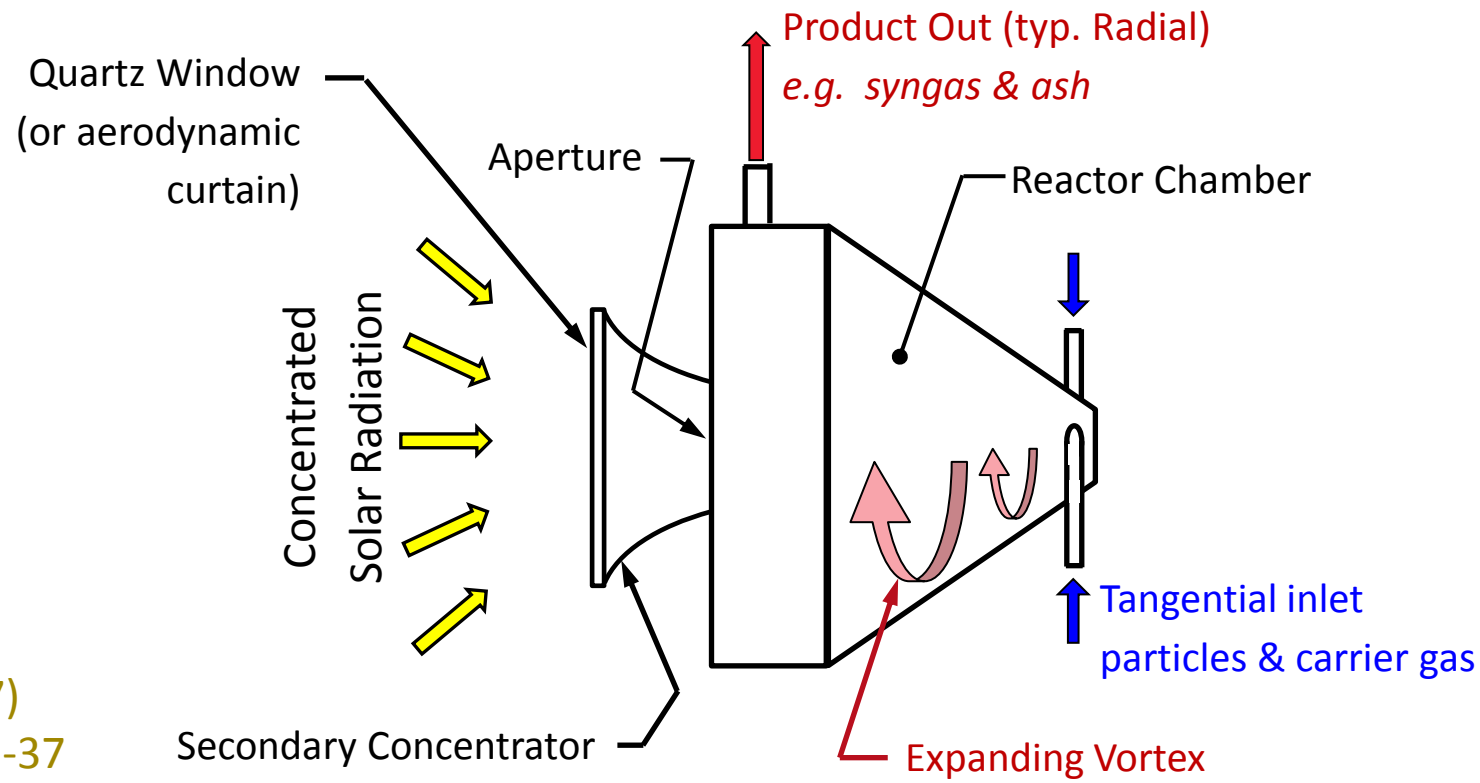
ASTRI approach to high temperature

- **Parallel development of alternative options for down-selection:**
  - **Solar expanding vortex receiver**
  - **CSIRO – Falling particle receiver**
  - **Other concepts at earlier stage**
- **Seeking to leverage through global collaboration:**
  - **More effective outcomes**
  - **Shared resources**
  - **Reduced development time**

CET Research Programs involving CSP particle technology



Solar expanding vortex reactor

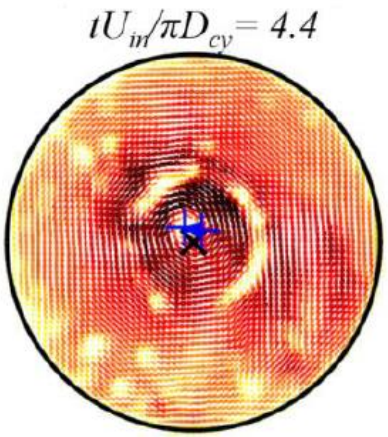


Chinnici, et al., (2017)
Solar Energy, **141**, 25-37

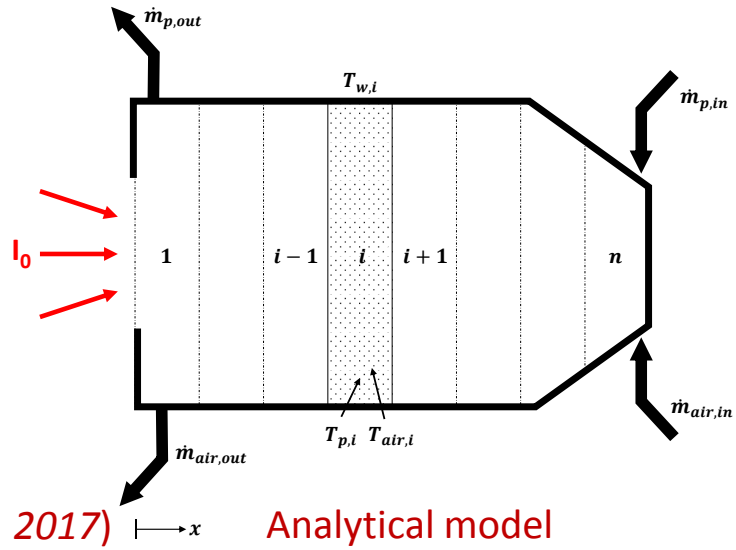
Advantages	Disadvantages
• High thermal efficiency • Direct irradiation – low exergy loss • Suited to applications with transporting gas, e.g. Calcination	• Limited to applications with transporting gas • Requires either: ➢ Window e.g. for reduction processes ➢ Aerodynamic curtain, with some convective losses through aperture

Current programs with Vortex Receiver/Reactors

Alumina calcination (CET / ETH)
Davis et al. (*Green Chem, submitted*)



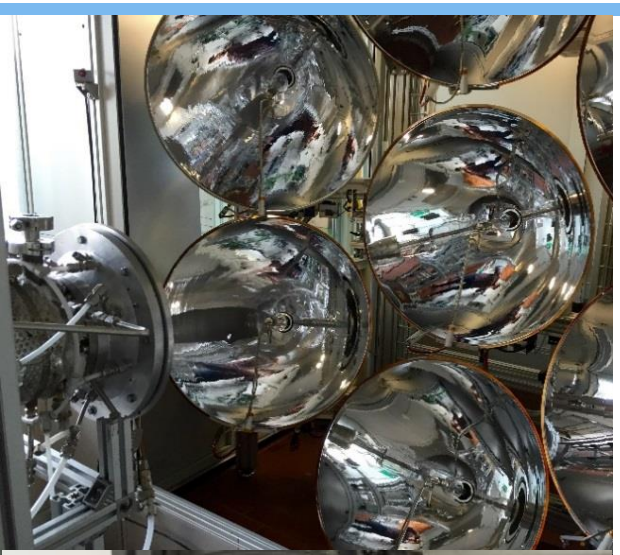
PIV measurements
Chinnici et al. (*Solar Energy, 2017*)

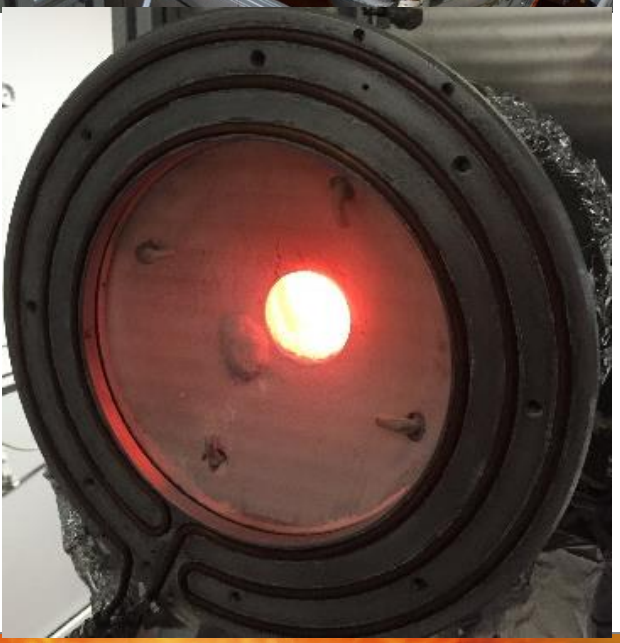


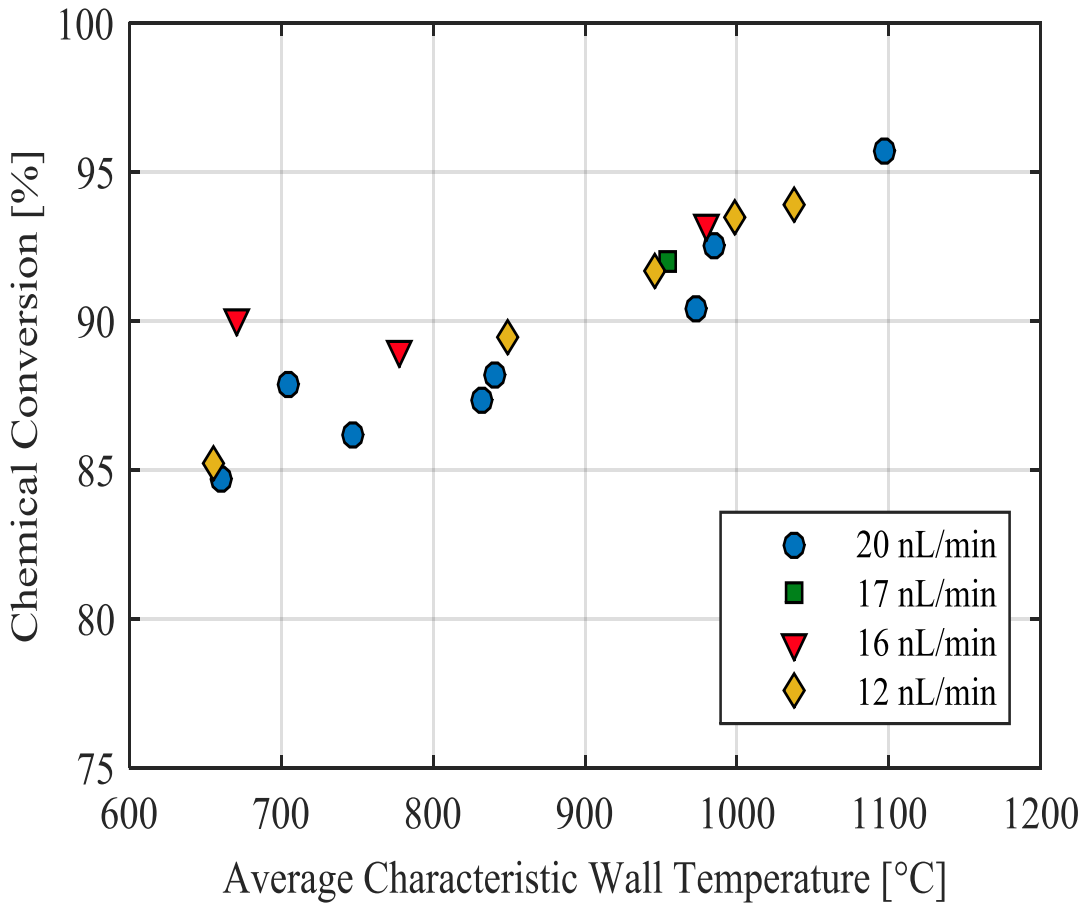
Analytical model

Program	Status
Flow field measurements with PIV	First campaign completed, 2nd in progress (Lau)
CFD Model development	Validated with available data (Chinnici)
Analytical heat transfer model	Under development (PhD Davis)
Residence time measurement	In preparation (PhD Davis)
System modelling	In progress (Guo, for fuels / Davis for Power)
Hot testing	First campaign completed, 2nd in progress (Davis)
Aerodynamic Curtain	In progress

Solar-only Calcination

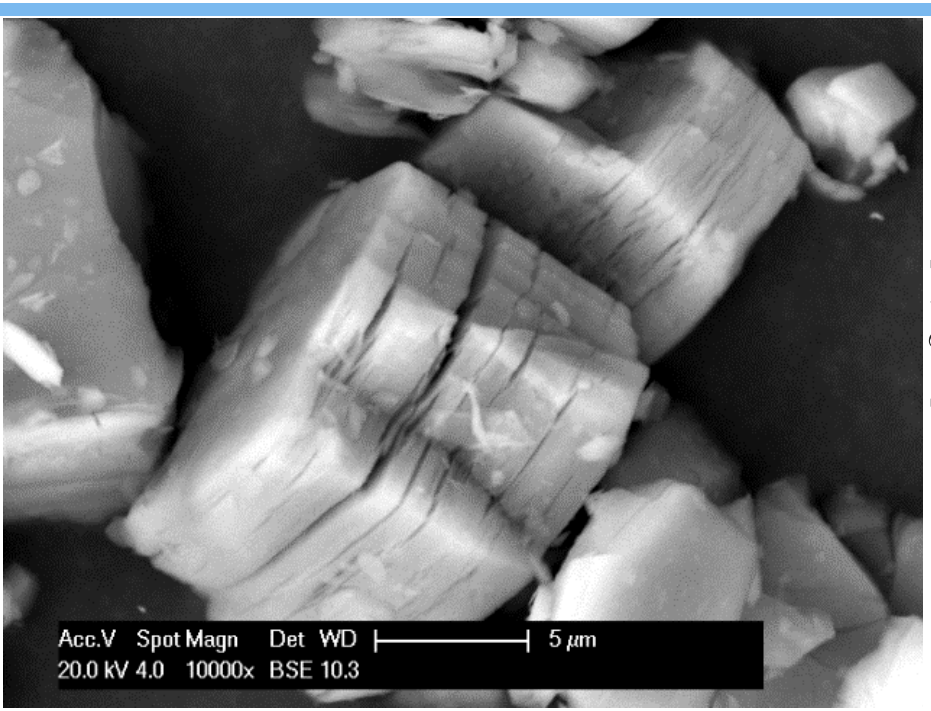




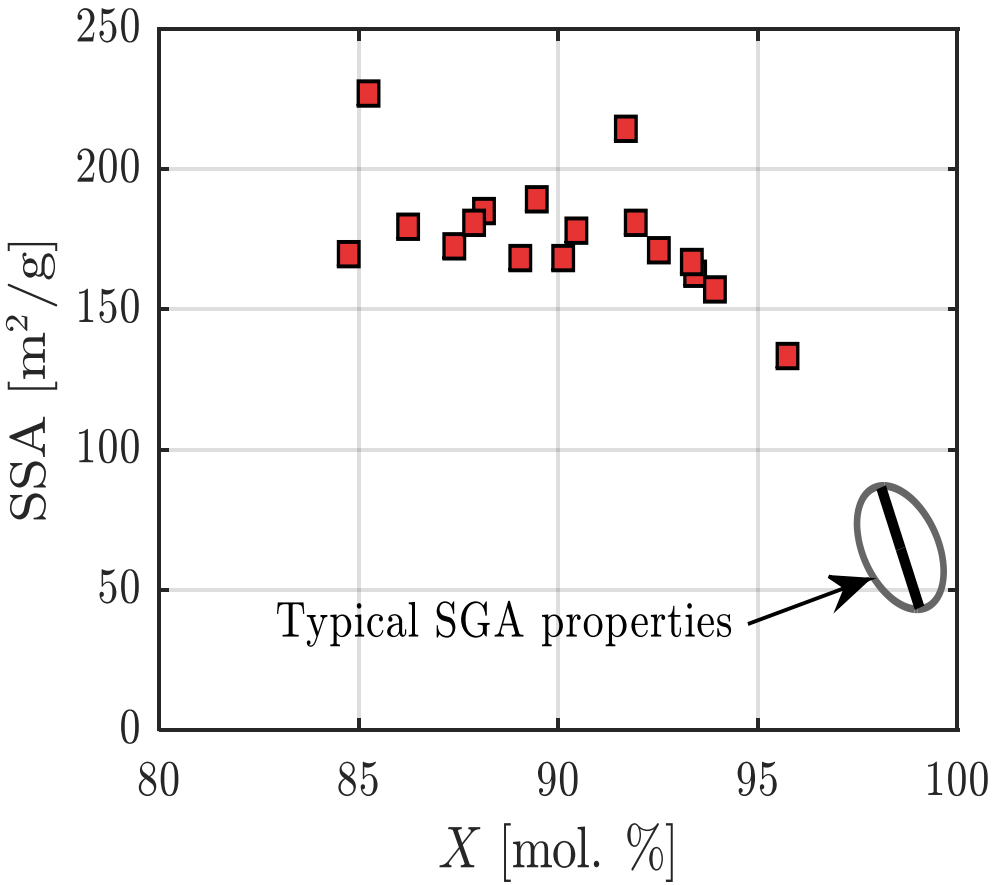


Davis, Miller, Saw, Steinfeld, Nathan (2016),
High Temperature Processing Symposium

Product Quality Improvements



SEM Micrograph
10,000 × magnification

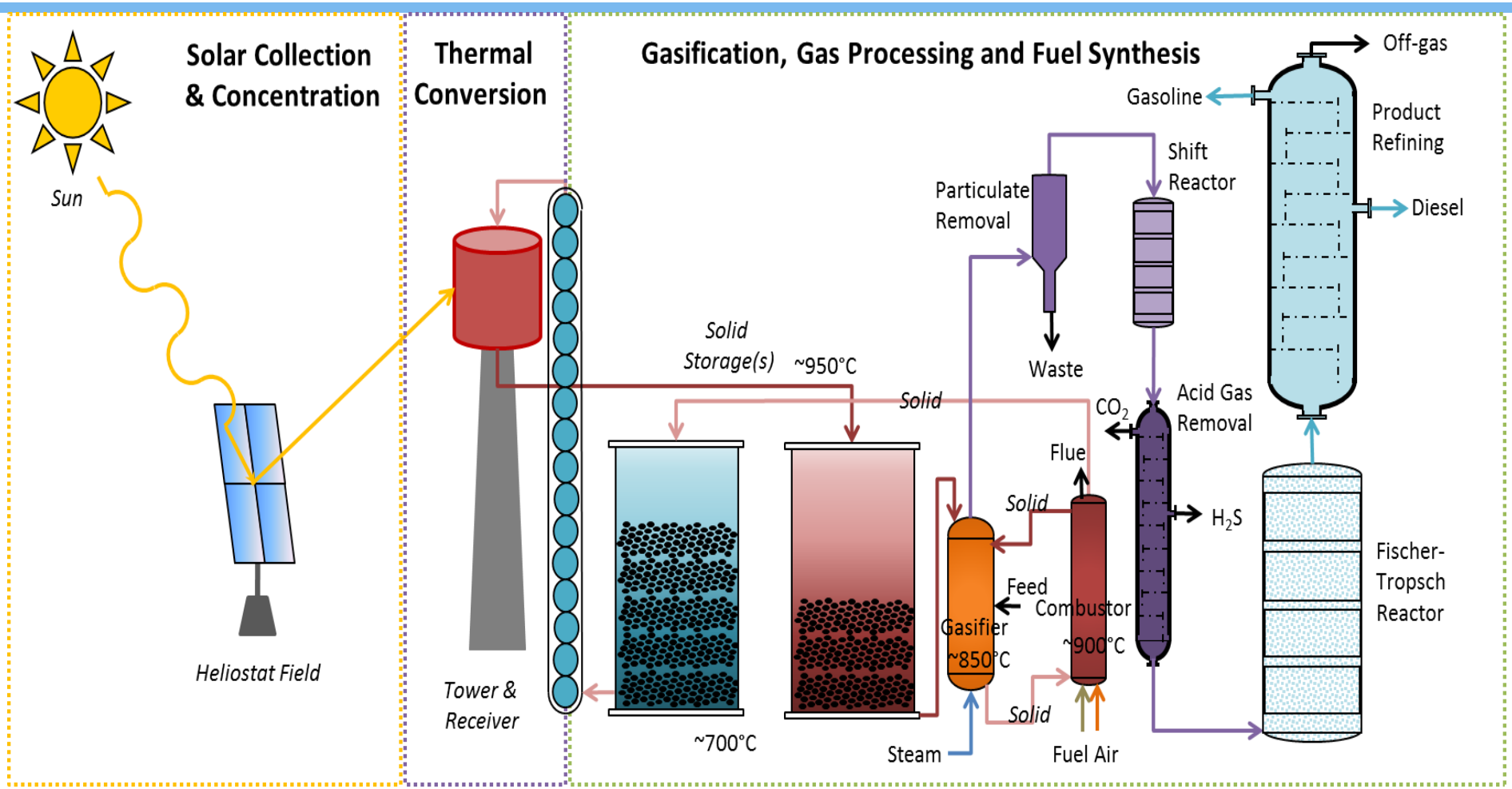


What we have learned: Solar Expanding Vortex Reactor

- **Cycle must be able to utilise or recover high temp air**
  - **E.g. alumina calcination**
- **High heating rates can have process benefits**
  - **Potential for improved quality in alumina calcination**
- **An unstable precessing vortex core can be generated**
  - **Modelling (e.g. with CFD) is more challenging**

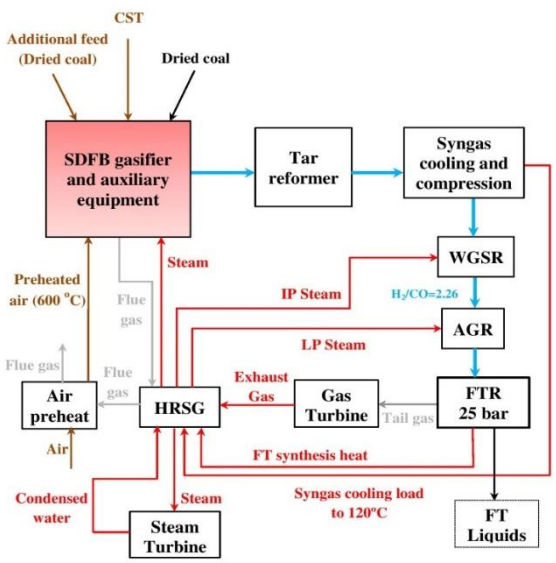
Alwahabi , Nathan, Kueh, Cannon, *Optics Express (under review),* 2016,

Solar hybridised dual bed gasification - One configuration

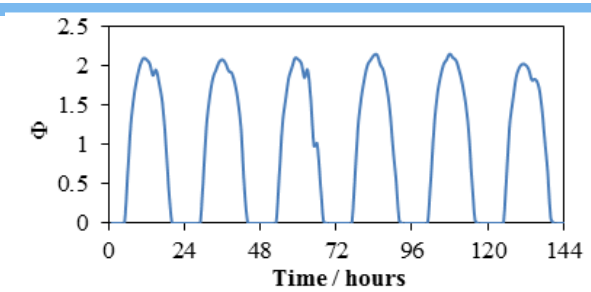


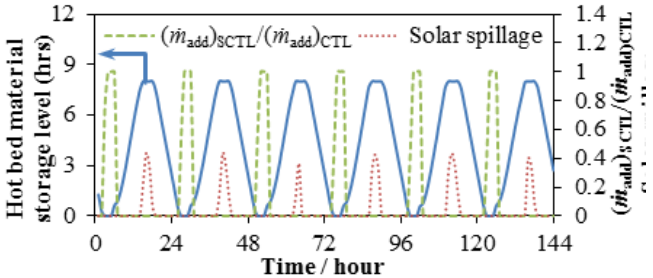
$T_{receiver} \approx 950°C$; $T_{gasifier} \approx 850°C$;

Current programs with SHDBG



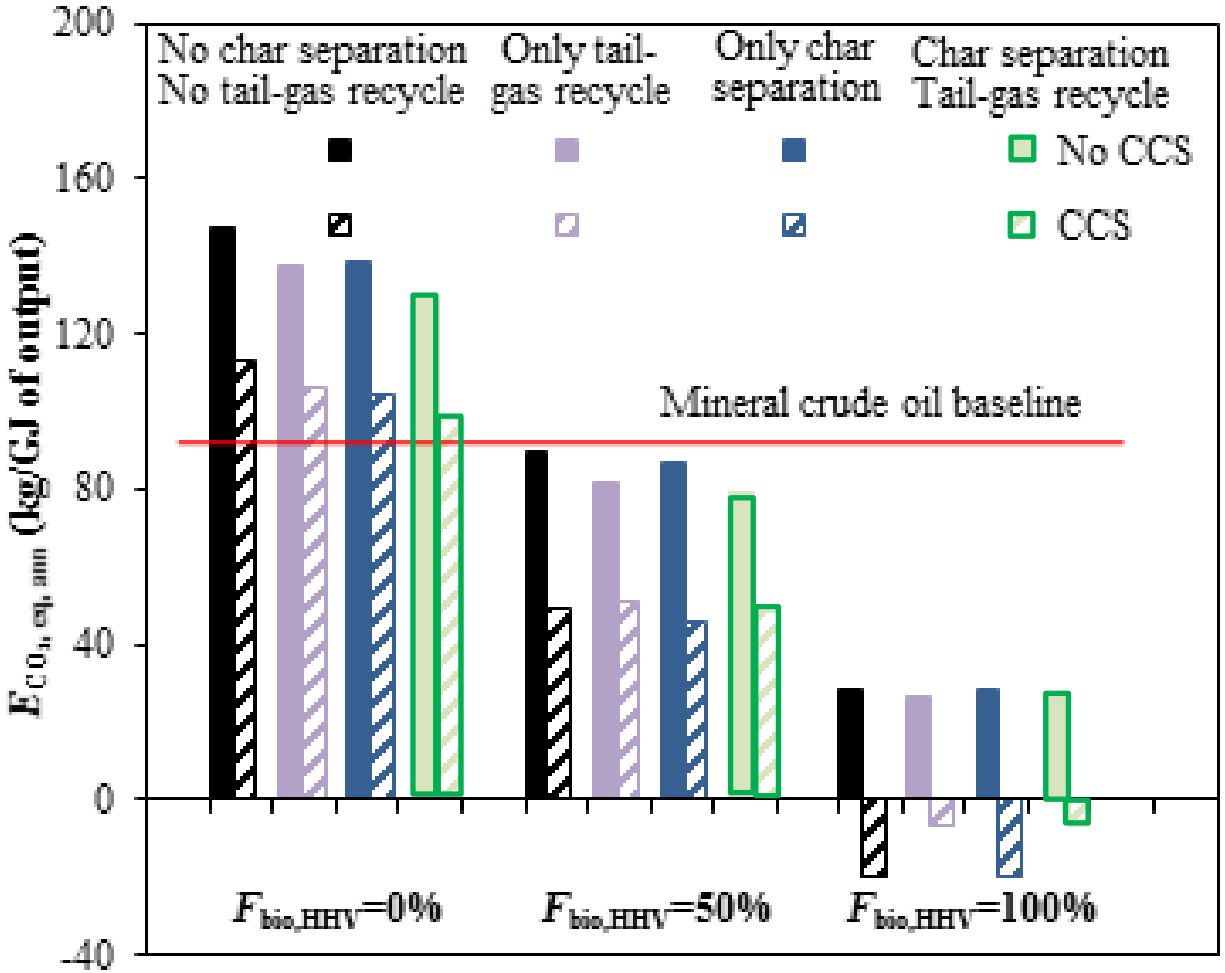
Psuedo-dynamic modelling
Guo et al., (2015), *Energy Fuels*, 29, 2738-2751.





Program	Status
Process modelling (pseudo dynamic) - Aspen-HYSYS	First campaign completed (Guo et al, 2017)
System analysis: Parasitic losses, component analysis	In progress (Guo et al.)
Feedstock assessments	Under development (PhD He)
Analytical modelling & hot testing of receiver	As per SEVR (PhD: Davis)
Hydrodynamic testing of dual beds	In progress (Saw et al)
Supply chain assessments (including torrefaction)	In progress (Roy et al)
Scale up	In planning

Well-to-wheel emissions for coal-biomass blends



APPROACH:

- Continuous operation by hybridisation
- Pseudo-dynamic model
- 12 month time series
- Farmington, New Mexico

KEY ASSUMPTIONS:

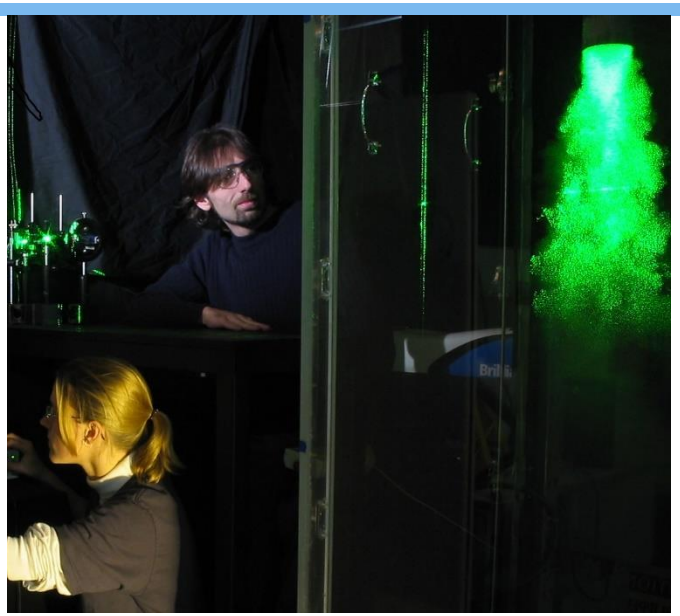
- Carbon closure for Biomass = 85%
- Conversion = 80%
- Char separation – 80%
- 16 hr thermal storage

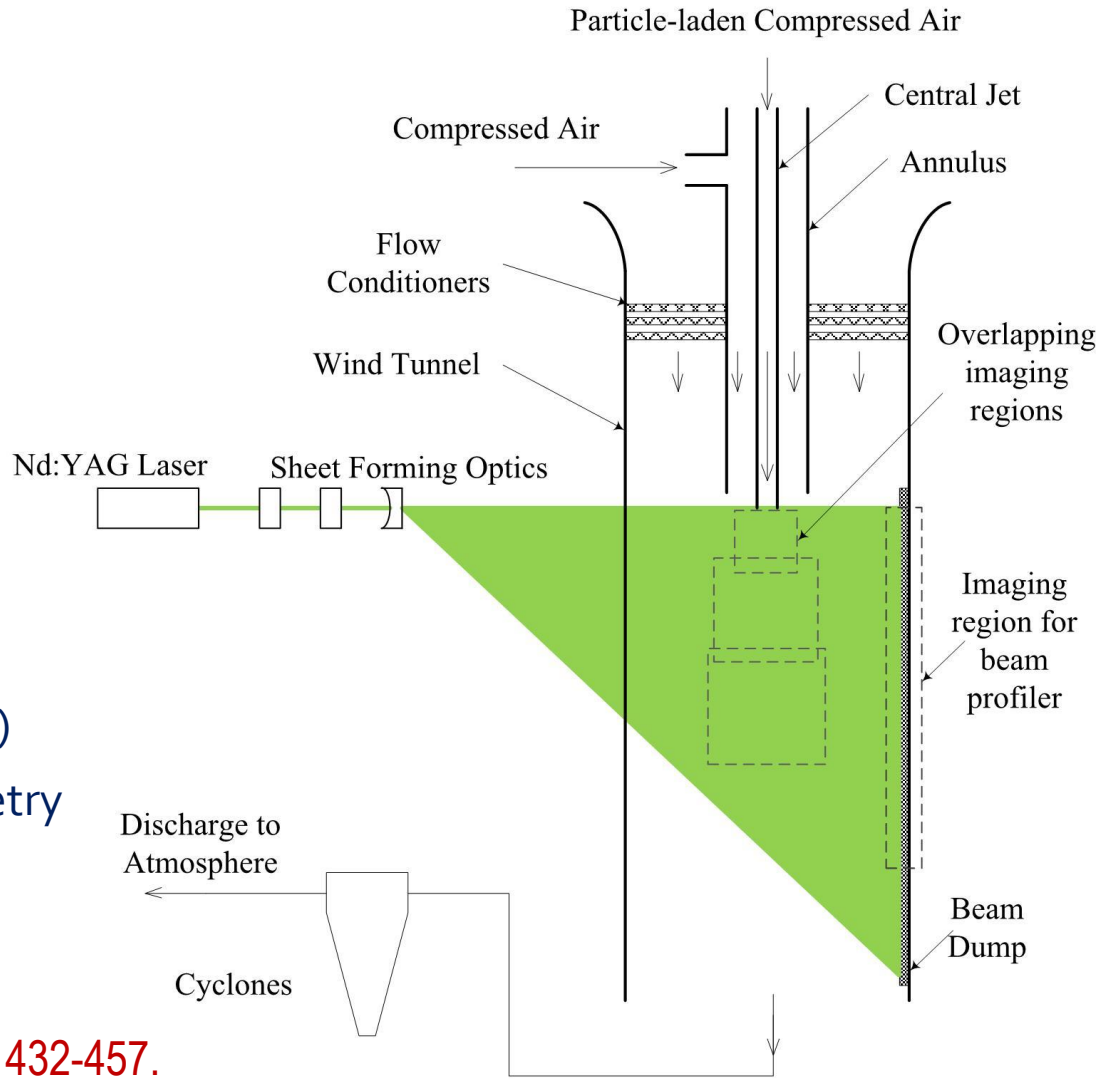
Guo et al., (2017), *Energy Fuels*, 31 (2), 2033-2043

What we have learned: Solar Hybridised Dual Bed Gasification

- **Process offers significant potential advantages**
  - Moderate temperature of ~850 °C compatible with CST
  - Continuous processing from hybrid greatly simplifies FTL
- **Value proposition of solar identified**
  - Targeting biomass residues / co-products
  - Increases output from limited resource
- **Ongoing challenges**
  - Need to demonstrate a viable system to introduce CST into process
  - Need to identify viable feed-stock paths
  - Need to identify economically attractive scenarios

Detailed investigations of particle laden jets





In-situ measurements of relevant well-characterised flow:

- Velocity: PIV & hot wire (gas phase)
- Particle concentration: Nephelometry
- Ray tracing & cluster detection
- Particle temperature (PLIP)

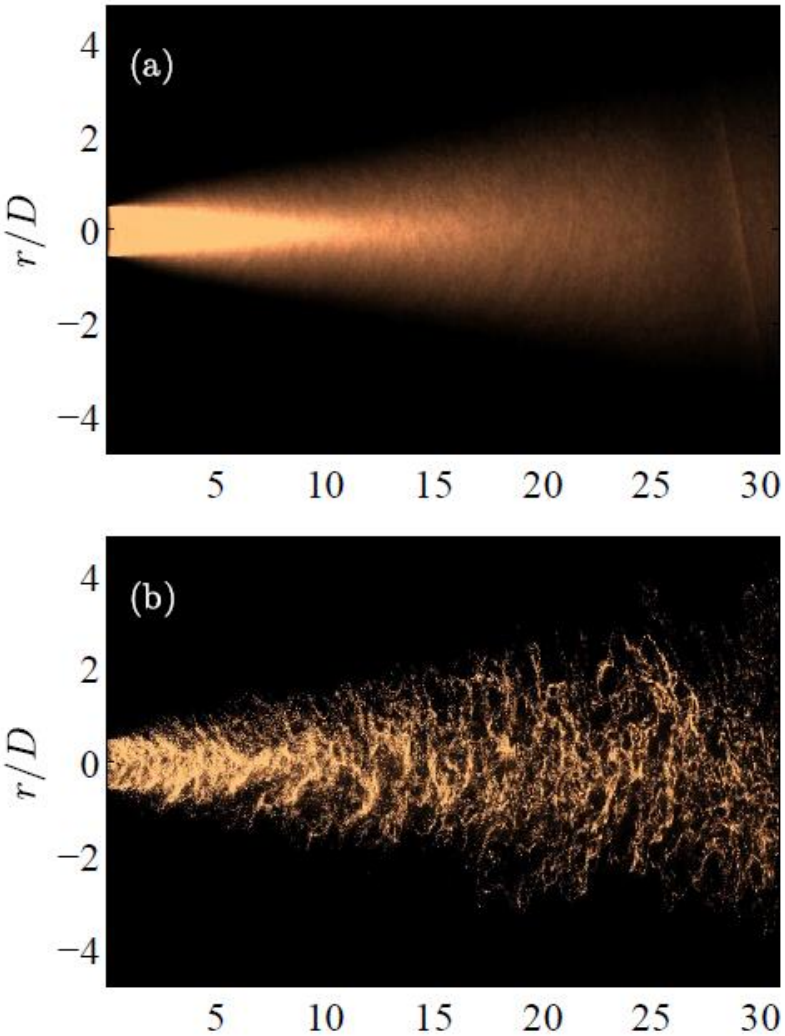
Lau & Nathan, 2014, *J. Fluid Mech.*, **757**, 432-457.

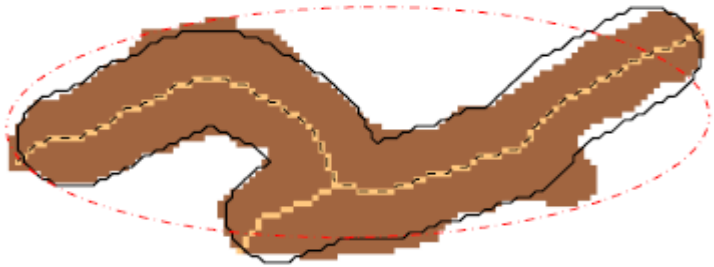
Experimental Program

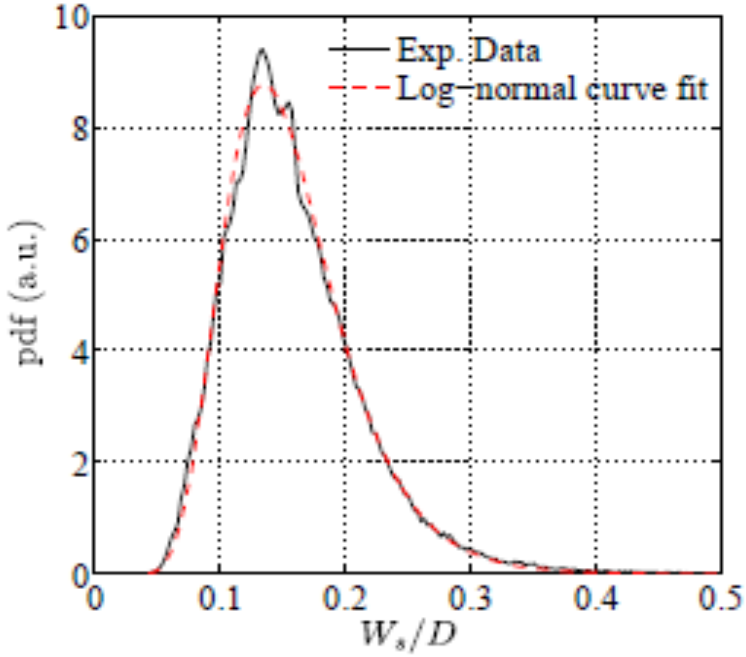
Reynolds number, Re_D	Single-phase		Particle-phase (spherical, mono-disperse particles)				Gas-phase (with spherical, mono-disperse particles)		Particle-phase (fibrous particles)	
	Velocity (X-wire)	Velocity (PIV)	Velocity (PIV)	Concentrtion (nephelom)	Clusters	Particle Temp (PLIP)	Velocity (PIV, correlations with concentration	Temp (PLIF)	Velocity (PIV)	Concentration (PN)
10,000	In progress	Published (JFM 2014, JFM 2016)			Published (IJMF, 2017)	Scheduled (2017)	Scheduled (May 2017)	Planned (2018)	Scheduled (August 2017)	
20,000										
40,000										

1. Lau, T.C. and Nathan, G.J. (2017) "A method for identifying and characterising particle clusters in a two phase jet", I.J. Multiphase Flow, **8**, 191-204.
2. Lau, T.C. and Nathan, G.J. (2016) "The effect of Stokes number on particle velocity and concentration distributions in a well-characterised, turbulent, co-flowing two-phase jet, *J. Fluid Mech.*, **809**, 72-110.
3. Lau, T.C.W. and Nathan, G.J. (2014) "Influence of Stokes number on the velocity and concentration distributions in particle laden jets", *J. Fluid Mech.*, **757**, 432-475.

Quantifying particle clustering

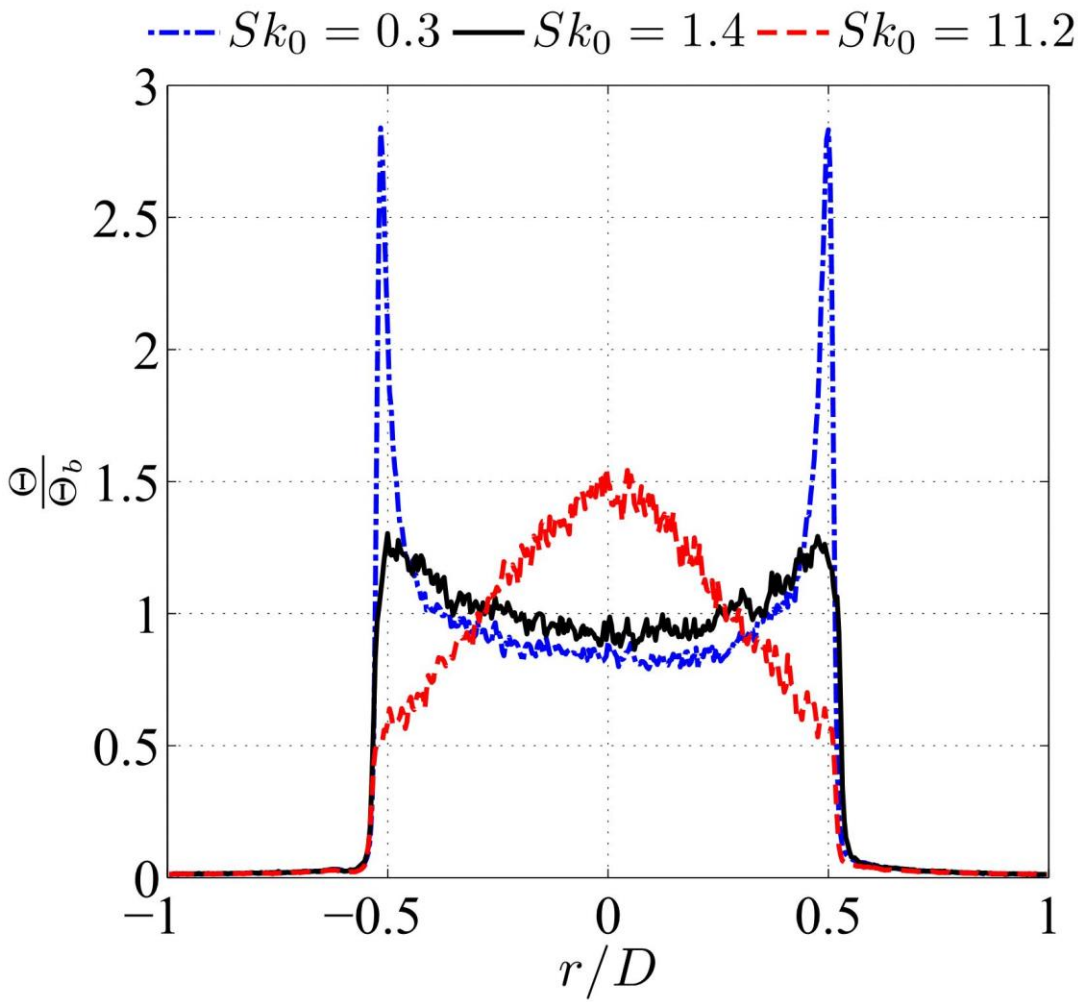






Lau & Nathan (2017), *I. J. Multiphase Flow,* **88**, 191-204.

Exit Concentration Profiles from "long" pipe



Lau & Nathan, 2014, *J. Fluid Mech.*, **757**, 432-457.

What we have learned: Two-way coupled particle laden flows

- **Well-characterised inflow conditions - challenging**
  - Fully developed two-phase flow: Yet to be fully specified
  - Approached for L/d > 320 with turbulent 2-way coupled flow
- **Stokes number influences radial mass flux distribution**
  - Particles preferentially distributed to walls for $Sk_0 \sim 0.3$
  - Particles preferentially distributed to axis for $Sk_0 > 10$
- **Stokes number influences particle clustering**
  - Strong for $Sk_0 \sim 0.3$
  - Weak for $Sk_0 > 10$
- **Diagnostic tools are emerging to advance understanding**
  - Experimental and numerical

Potential Collaborations

Joint development of high temperature particle receiver(s)

- Back-to-back comparisons under different reference conditions
- Shared facilities and resources

Joint development of suspension flow particle receiver systems

- Coordinated programs with complementary facilities & scales
- Investigation of complementary applications

Joint investigations of heat transfer in particle receivers

- Utilising complementary facilities at different scales
- Coordination through international working group

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Thankyou!

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