Joint Doctoral Projects in the area of process metallurgy of iron-making and Steelmaking/Non-Ferrous Extraction

IIT Madras Supervisor:
Assistant Professor Ajay Kumar Shukla

URL : https://mme.iitm.ac.in/shukla/

Swinburne University of Technology Supervisors
Associate Professor M Akbar Rhamdhani
Prof Geoffrey Brooks
URL: https://goo.gl/VuoHph https://goo.gl/c3CCqb

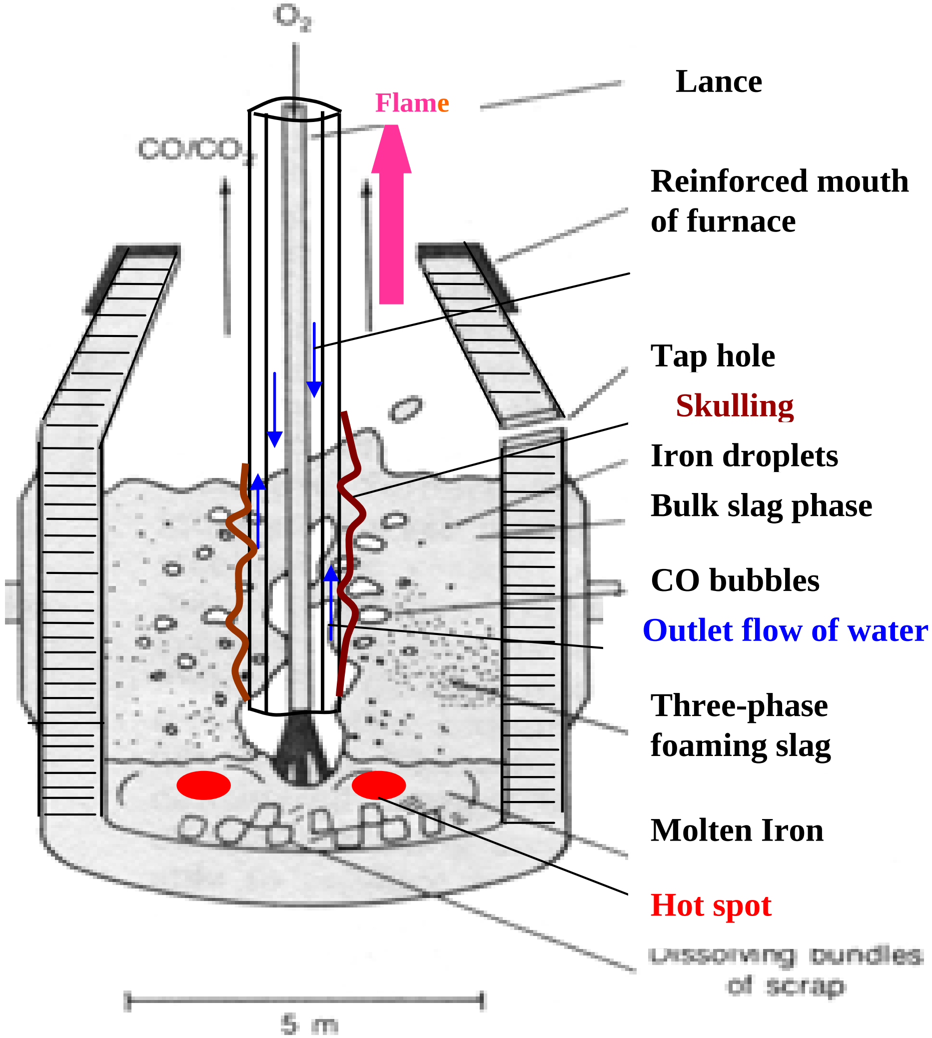
JDP Projects:

- **Simultaneous Heat and Mass Transfer in Oxygen Steelmaking**
- **Clever Chemistry of E-Waste Processing in Copper Smelting**
- **Solar Thermal Processing of Iron Ores**

Simultaneous Heat and Mass Transfer in Oxygen Steelmaking Process

Ajay Kumar Shukla, M Akbar Rhamdhani and Geoffrey Brooks

Basic Oxygen Steelmaking process

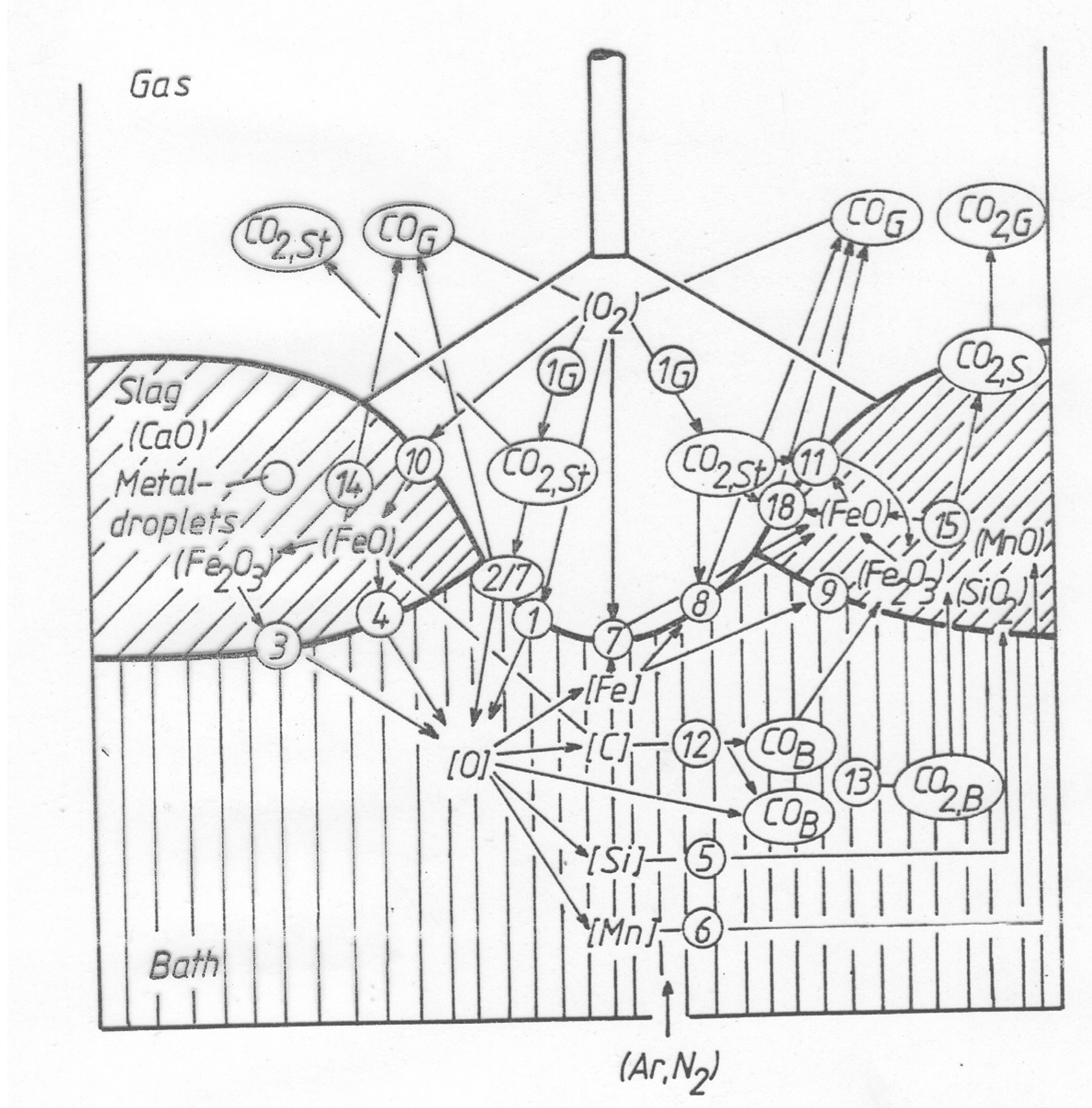


Physical state of the Basic Oxygen Steelmaking Process in the middle of the blow

- **Oxygen Steelmaking is very complex process which involves dynamic interaction between atoms, ions and molecules existing all together at the interface of slag metal and gas phases at high temperature in liquid state.**

- **Liquid slag formation in enough volume demands the dissolution of lime at faster rate which is achieved by dissolution of flux charged in solid lime form assisted by high level of FeO is required initially to promote dissolution of lime and slag formation.**

- **The excess heat of the process is controlled by melting and dissolution of coolants like scarp, DRI and iron-ores.**

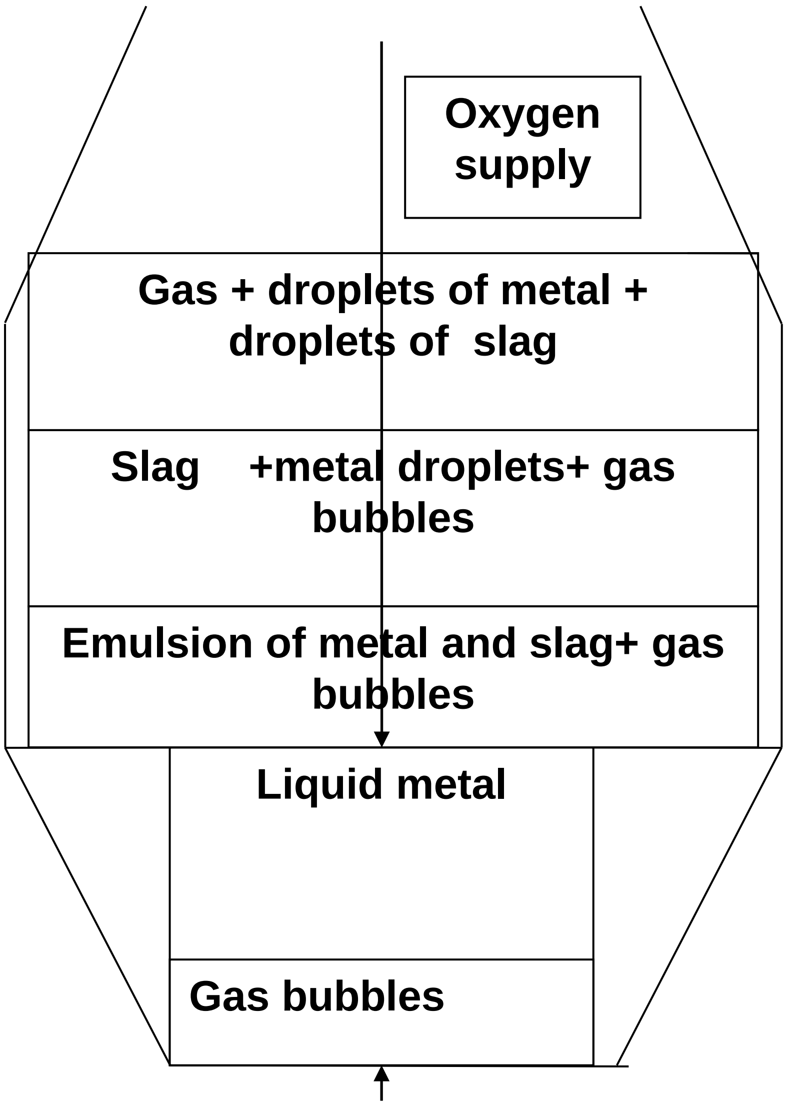


Sequence of reactions in an oxygen steelmaking system

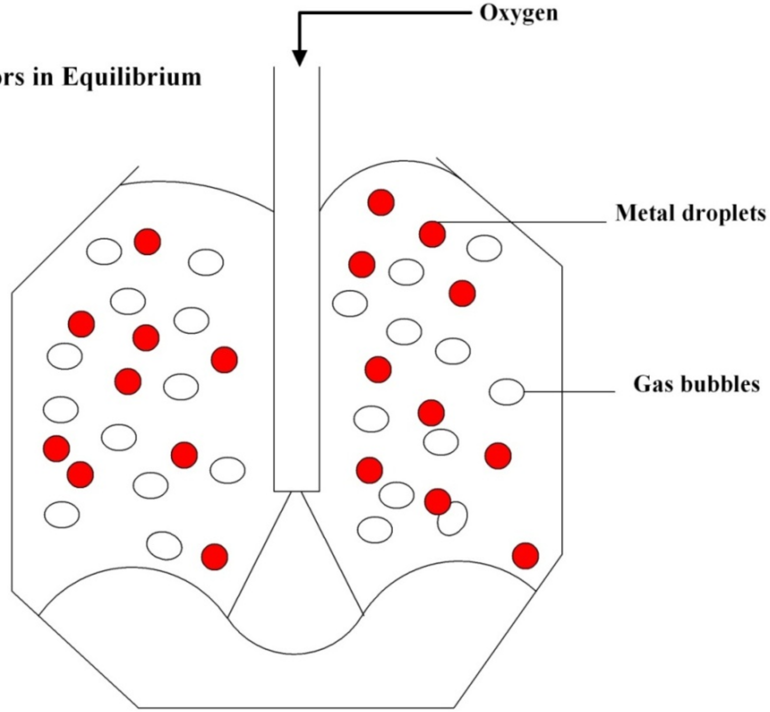
Let the metal phase contain [C], [Si],[P] and [O] in dissolved state.

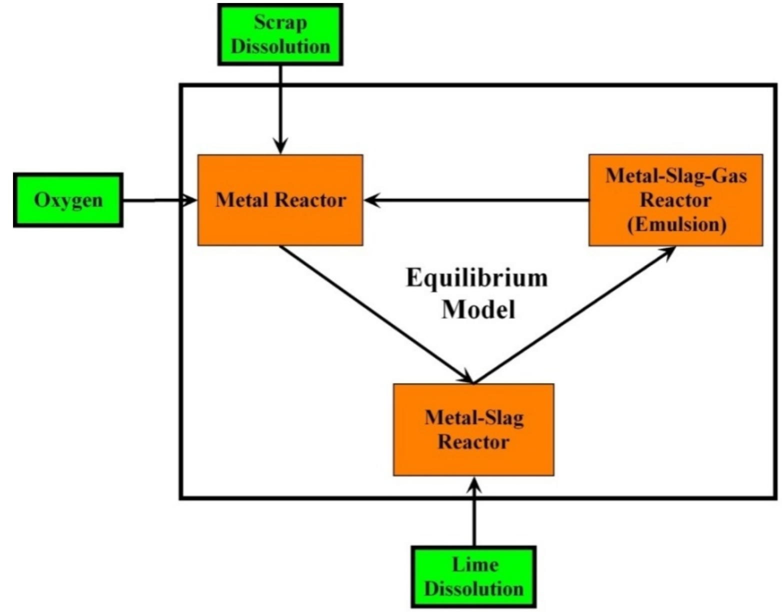
The slag phase contains CaO, FeO, SiO_2 and P_2O_5.

The gas phase contains CO,CO_2 and O_2.



Different Reactors in Equilibrium Model



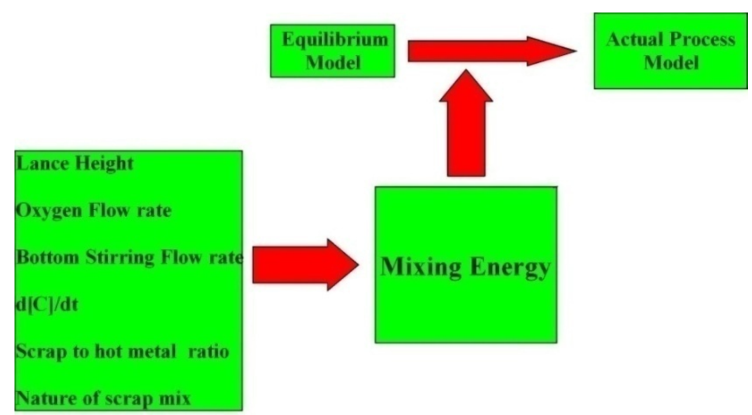


Interaction of different modules of Equilibrium Model

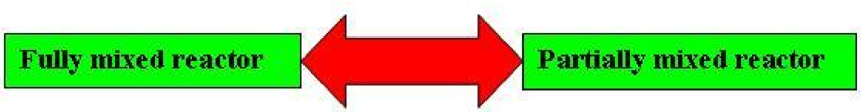
Metal Reactor : Under jet impact zone
Oxygen saturated metal droplets thrown in slag phase
Oxygen rich metal carried away by jet impact deep into metal bath

Metal Slag reactor : Metal droplet-slag interface
Bulk metal-slag interface

Metal-slag-gas reactor : Emulsion containing rising gas bubbles and liquid slag



Relationship between Equilibrium Model and Actual Process Model



Fully mixed reactor:

- Computational thermodynamics

Partially mixed reactor:

- Computational thermodynamics
- Computational kinetics
- Computational fluid dynamics

Suggested Mathematical Modeling approach:

- **Multi-zone approach with mass transfer consideration between different zones**
- **Although lot of work has been done in this field where mainly three zones of thoroughly mixed regions namely bulk slag and bulk liquid metal and slag-metal emulsions were considered.**
- **However assumption of uniform temperature and composition with bigger volumes may not be a correct idea. Therefore in the proposed project, similar kind of multiple numbers of smaller size zones will be considered who will interact with each other.**
- **Thermodynamic equilibrium will be considered at the interface of slag/metal/gas and mass transfer coefficients will be defined by multicomponent mixed transport theory.**
- **Metal droplet surface area will be calculated by earlier developed models.**
- **Lime dissolution kinetics and scrap dissolution kinetics to be considered by heat and mass transfer controlled approach in a comprehensive manner.**
- **The mass transfer coefficients as well as heat transfer coefficients will be estimated as a function of mixing energy to the system applying well established correlations or using velocity fields in reactor if CFD calculations are available.**
- **It is suggested that such model should be developed in MATLAB consideration thermodynamics database available in literature. For liquid hot metal/steel, interaction parameter model proposed by Wagner and for slag Quadratic Formalism model suggested by Darken will be used.**
- **The heat loss from the converter under combined influence of radiation (from top), and conduction through lining will be estimated using a separate heat transfer model.**
- **The integration of all modules will result in comprehensive dynamic control model of oxygen steelmaking which can predict temperature, weights and compositions of all the phases and behavior of the reactor can be predicted under various operating conditions.**
- **The industrial data will be required to tune the model (esp. mass transfer coefficient and various other factors) so that it can be used as the guiding tool for the specific shop.**

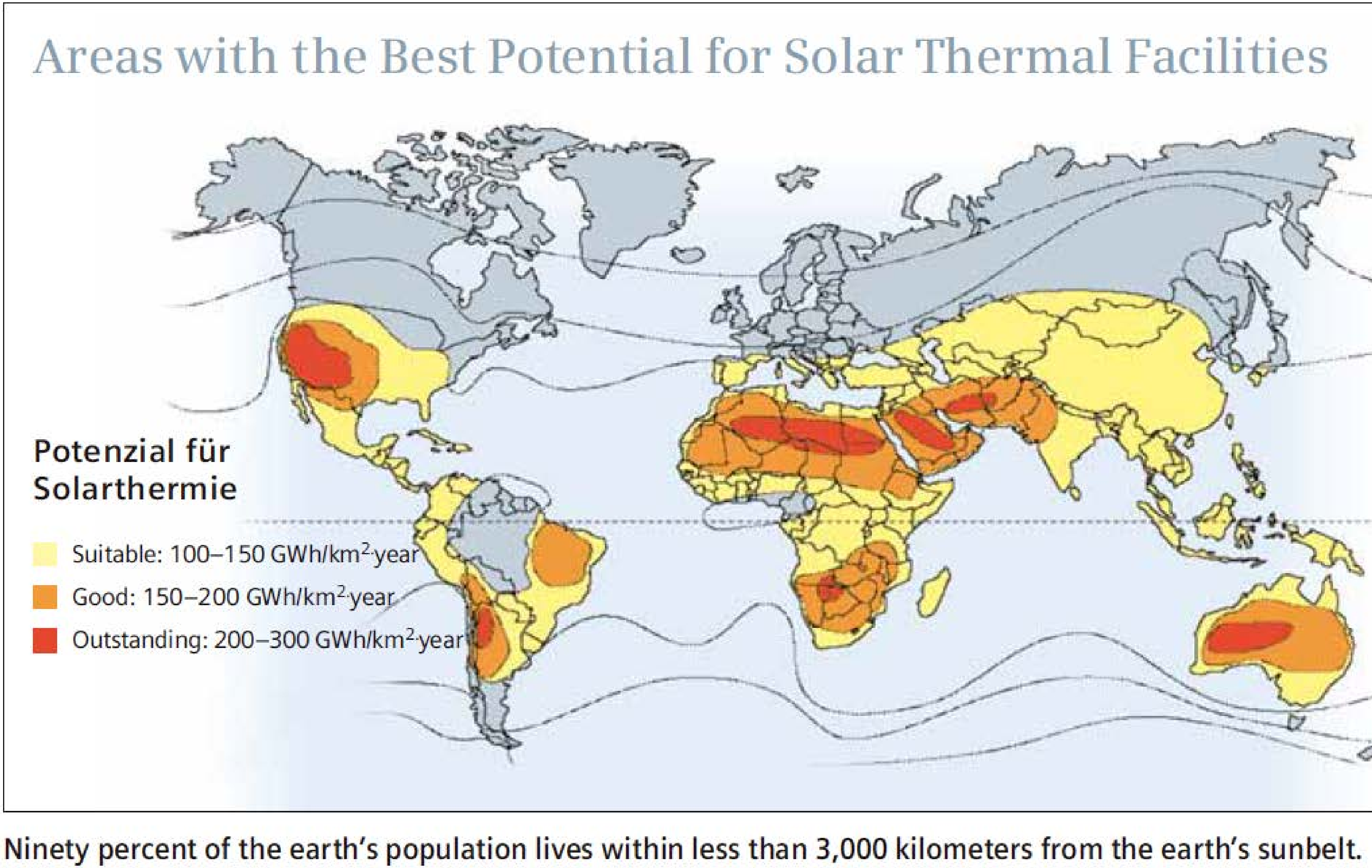
Potential for Solar Thermal Processing of Australian Ore

Ben Ekman, Geoffrey Brooks & M. Akbar Rhamdhani

Faculty of Science Engineering and Technology
Swinburne University of Technology
Melbourne Australia

Solar Thermal Technologies

(a) Parabolic Trough, (b)Compact Linear Fresnel, (c) Power Tower and (d) Parabolic Dish.
(Arena 2013 Hybridisation-of-Fossil-Fuel-Energy-Generation-in-Australia Report)



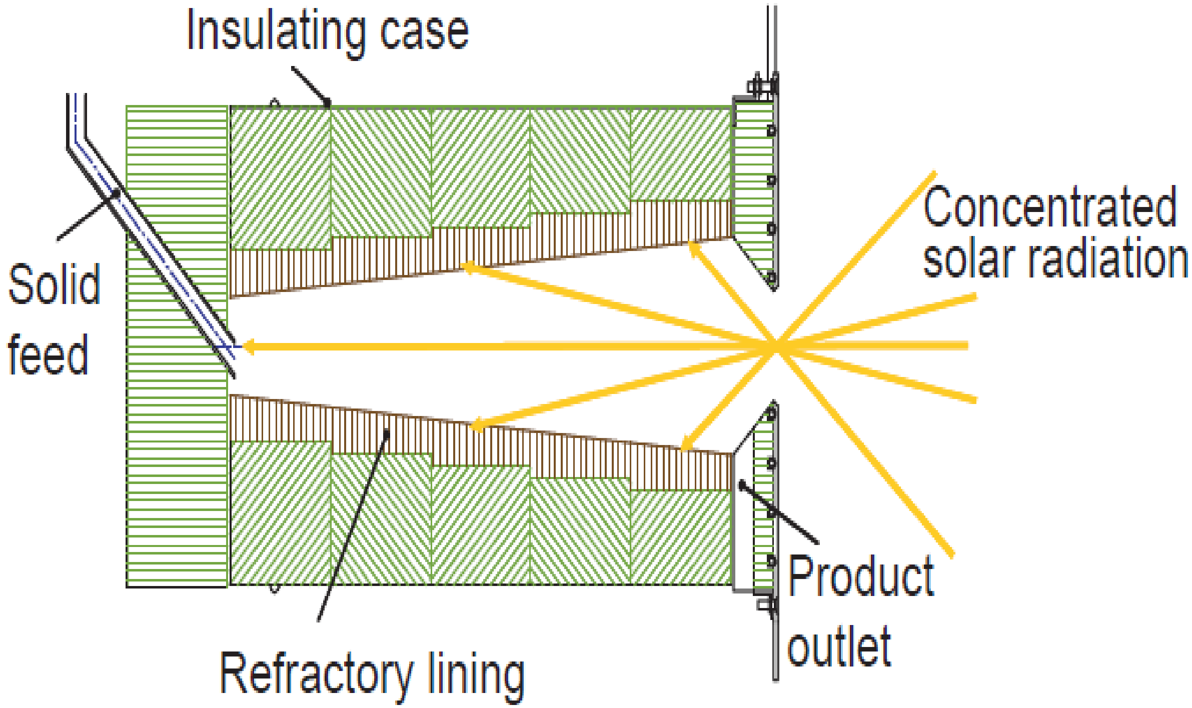
ARENA commissioned report 2000kWh/m^2 cut off for economic feasibility for hybridisation of power plants

Siemens: Solar Thermal Power

Testing of 10KW Solar Lime Reactor

Meier A. et.al. Energy 2004

Reactor Designs - Issues



- Balancing solar flux in and radiation losses
- Diffusion of solar flux by dust/gas
- Optimising heat efficiency with geometric/practical limitations

Steinfeld A., Solar Energy 78, 2005.

Solar Processing of Iron Ore Composites

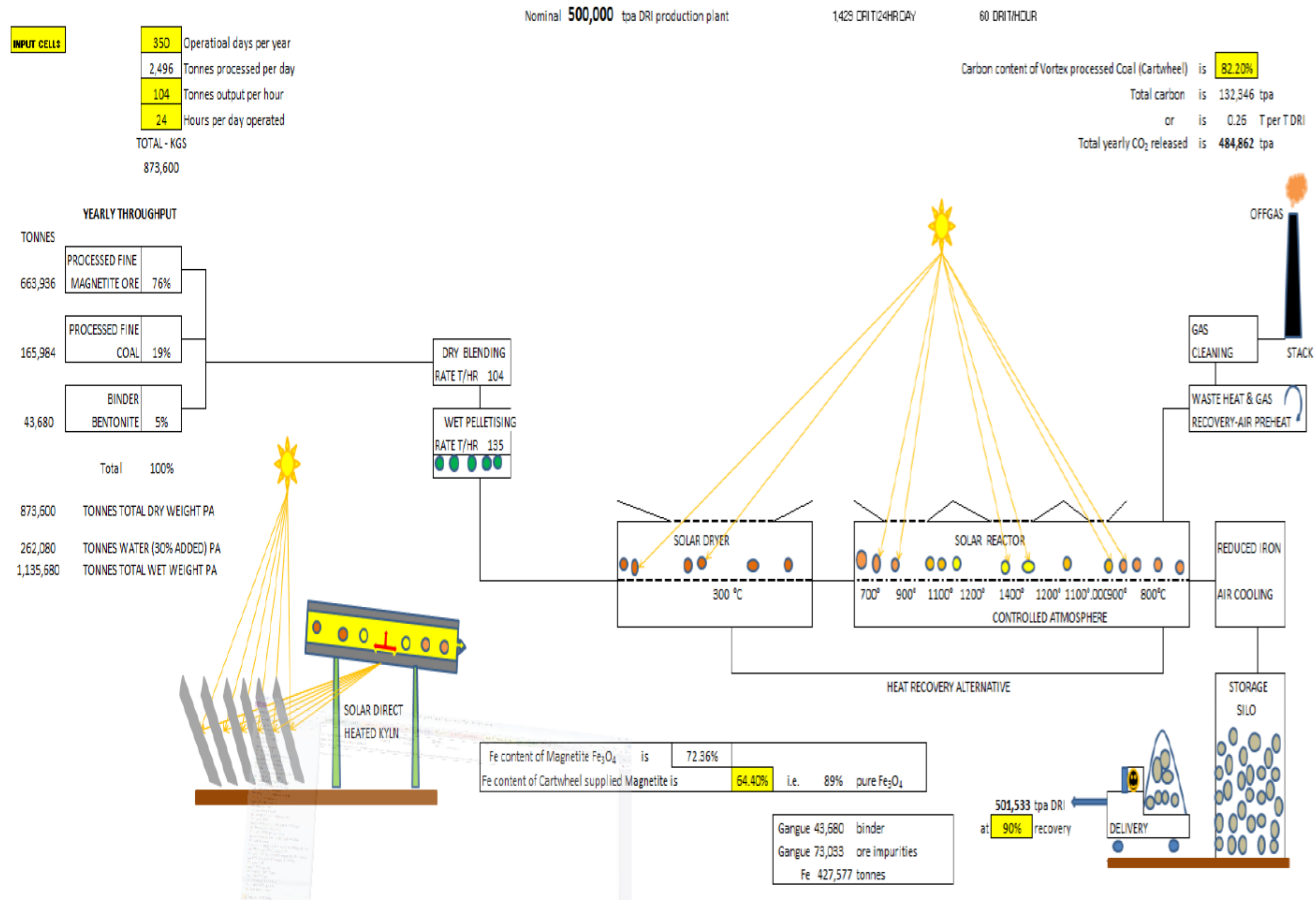
- Two abundant resources together – iron ore & solar flux
- Low grade carbons and iron ore fines
- Replacing carbon required for heating with solar
- Work to date (i) optimising composite pellets
  (ii) testing under solar flux
  (iii) flowsheet development

Composite Pellet: Solar Smelting

42 kW Solar simulator and reactor at Swinburne

Partially reduced iron ore composite pellet

SOLSMELT - COMPOSITE PELLET FLOW CHART FOR DRI



Conclusions

- Solar thermal energy has excellent potential for the processing of materials
- Optimising reactor efficiency is important
- Hybrid designs should be considered
- Solar route to DRI looks promising
- Pyrometallurgists and solar specialists need to work together

Clever Chemistry of E-Waste Processing in Copper Smelting

IIT Madras Supervisor:

Assist Prof Ajay Kumar Shukla

Swinburne University of Technology Supervisors:

Assoc Prof M Akbar Rhamdhani

Prof Geoffrey Brooks

Clever Chemistry of E-Waste Processing in Copper Smelting

Understanding of the thermodynamics behaviour of strategic and valuable elements (e.g. Au, Ag, Ru, Eu, In, etc) during copper smelting and their correlation to slag structure → basis for developing suitable slag chemistry

- Measurements of thermodynamic properties including distribution ratio (L_M) of strategic and valuable elements
- Investigation of the structure of the slag using FTIR/Raman spectroscopy and its effect on the elements
- Development of model that directly correlate the L_M with the degree of polymerisation

1 Ton of E-Waste

=

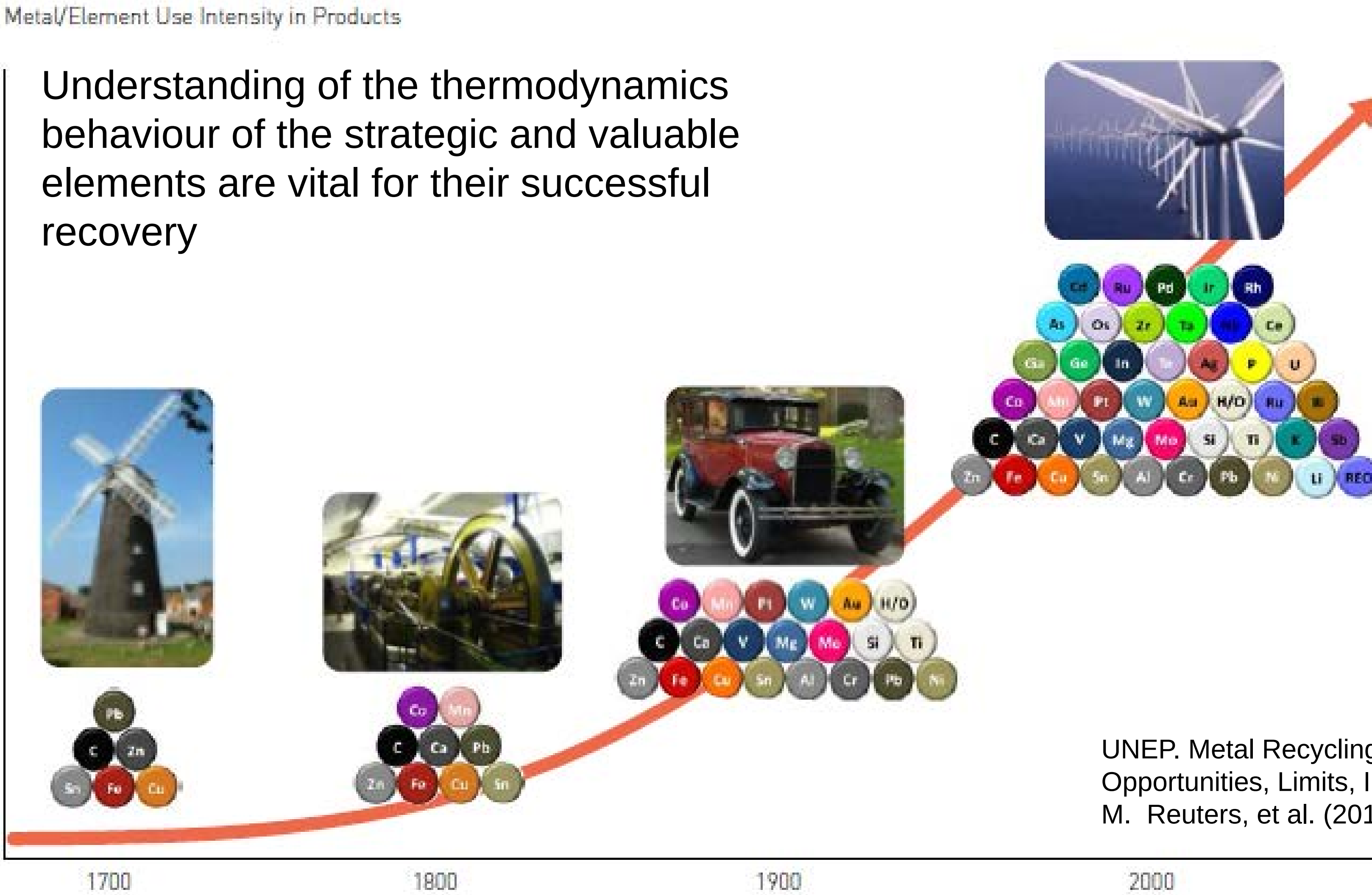
100 g (Pd)

200g (Au)

100 kg (10%) (Cu)

3 kg (Ag)

Increased Materials Complexity → More Difficult to Recover Valuable Metals



Understanding of the thermodynamics behaviour of the strategic and valuable elements are vital for their successful recovery

UNEP. Metal Recycling – Opportunities, Limits, Infrastructure, M. Reuters, et al. (2014)

Introduction to Swinburne

Research

- Top 3% of Universities in the World for research
- Top 75 in the field of Physics research by ARWU 2014
- Top 100 under 50 by Times Higher Education Rankings

Teaching

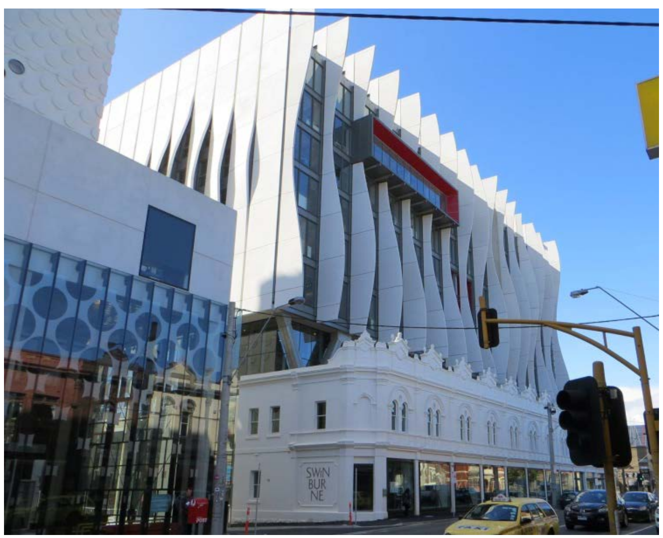
- Dual sector University
- Rated one of Melbourne’s top teaching & research universities by the Good Universities Guide 2014 with 5 star ratings for overall satisfaction and research intensity


Melbourne City

Relevant Major Infrastructure

Advanced Technology Centre ($140M)

Multidisciplinary platforms for research, include:
– Smart Structures Lab
– Laser Assisted Manufacturing Lab
– Virtual Design Lab
– Polymer Processing & Characterisation Lab
– Nanofabrication Lab
– High Temperature Processing



Advanced Manufacturing & Design Centre ($100M)

Swinburne's new home for design and innovation

– Factory of the Future
– Design Factory
– Pilot Plant facility for micro-photonics/solar materials

Laboratories and Facilities

- **The Robert Simpson High Temperature Processing Laboratory**
  - Induction Furnace 30kVA
  - High Temperature Furnaces 1700^{o}C low vacuum
  - STA equipped with Mass Spec
  - High Temp Optical Microscope
  - Online Image and Vibration Analysis
  - Cold Modelling Laboratory – Laser Diagnostics and High Speed Photography
- **Design for Resource Efficiency Studio (Factory of the Future)**
  - Pre-processing equipment (sizing, sorting, etc)
  - Benchtop quick characterisation (XRD, XRF)
  - Thermochemical, LCA, Flowsheeting packages
- **Solar Thermal Laboratory**
  - Solar Simulator Hybrid-Furnace

Simultaneous Heat and Mass Transfer in Oxygen Steelmaking

IIT Madras Supervisor:

Assistant Professor Ajay Kumar Shukla

URL : https://mme.iitm.ac.in/shukla

Swinburne University of Technology Supervisors:

Associate Professor M Akbar Rhamdhani

Prof Geoffrey Brooks

URL: https://goo.gl/VuoHph https://goo.gl/c3CCqb


Hot metal received from iron-making unit is refined in BOF by blowing pure oxygen gas through the supersonic lance. Oxygen Steelmaking is very complex process which involves dynamic interaction between atoms, ions and molecules existing all together at the interface of slag metal and gas phases at high temperature in liquid state. Liquid slag formation in enough volume demands the dissolution of lime at faster rate which is achieved by dissolution of flux charged in solid lime form assisted by high level of FeO is required initially to promote dissolution of lime and slag formation. The excess heat of the process is controlled by melting and dissolution of coolants like scarp, DRI and iron-ores. In overall sense the process involves so many interlinked complexes and coupled phenomena involving interfacial thermodynamics and mass transfer assisted kinetics which requires mathematical modeling based approach in order to understand the process and predict its behavior and effect of operating parameters in an effective manner. Although lot of work has been done in this field where mainly three zones of thoroughly mixed regions namely bulk slag and bulk liquid metal and slag-metal emulsions were considered. However assumption of uniform temperature and composition with bigger volumes may not be a correct idea. Therefore in the proposed project, similar kind of multiple numbers of smaller size zones will be considered who will interact with each other. Thermodynamic equilibrium will be considered at the interface of slag/metal/gas and mass transfer coefficients will be defined by multicomponent mixed transport theory. Metal droplet surface area will be calculated by earlier developed models. Lime dissolution kinetics and scrap dissolution kinetics will be considered by heat and mass transfer controlled approach in a comprehensive manner. The mass transfer coefficients as well as heat transfer coefficients will be estimated as a function of mixing energy to the system applying well established correlations or using velocity fields in reactor if CFD calculations are available. It is suggested that such model should be developed in MATLAB consideration thermodynamics database available in literature. For liquid hot metal/steel, interaction parameter model proposed by Wagner and for slag Quadratic Formalism model suggested by Darken will be used. The heat loss from the converter under combined influence of radiation (from top), and conduction through lining will be estimated using a separate heat transfer model. The integration of all modules will result in comprehensive dynamic control model of oxygen steelmaking which can predict temperature, weights and compositions of all the phases and behavior of the reactor can be predicted under various operating conditions. The industrial data will be required to tune the model (esp. mass transfer coefficient and various other factors) so that it can be used as the guiding tool for the specific shop. For advanced developers who know FactSage microprogramming, same model also can be developed in FactSage without being worried about thermodynamic data collection from literature.

Solar Thermal Processing of Iron Ores

IIT Madras Supervisor:

Assistant Professor Ajay Kumar Shukla

URL : https://mme.iitm.ac.in/shukla

Swinburne University of Technology Supervisors:

Associate Professor M Akbar Rhamdhani

Prof Geoffrey Brooks

URL: https://goo.gl/VuoHph https://goo.gl/c3CCqb

Concentrated solar energy has great potential for processing of ores. In particular, concentrated solar energy can be used for the processing of iron ores, for example in roasting magnetite ores or in DRI production from composite pellets. In this PhD, the student will evaluate the potential for solar processing of iron ores through high temperature experimentation and mathematical modelling of the systems under study. This project will utilize a 42 kW solar simulator at Swinburne that is designed to produce a controlled solar flux for high temperature experimentation. Mathematical models of the heat transfer and coupled reaction in the system are required to inform the design of industrial scale version of the reactor designs being studied.

Clever Chemistry of E-Waste Processing in Copper Smelting

IIT Madras Supervisor:

Assistant Professor Ajay Kumar Shukla

URL : https://mme.iitm.ac.in/shukla

Swinburne University of Technology Supervisors:

Associate Professor M Akbar Rhamdhani

Prof Geoffrey Brooks

URL: https://goo.gl/VuoHph https://goo.gl/c3CCqb

Industrially, strategic and valuable metals (Au, Ag, Pt, Pd, Ge, etc) from electronic wastes and other secondary resources are recovered by embedding them into base metal production circuits (e.g. copper smelting). The copper acts as metal collector to absorb selected strategic metals which can be recovered in further process. The industrial process is not yet optimised for maximum recovery of as many strategic metals as possible. This is due to the lack of information on the thermodynamic behaviour of the strategic elements at the conditions commonly used (or beyond) in the base metals production. These include the distribution ratio (ratio of elements in different phases, which controls the recovery of the valuable metals) at different oxygen potential and temperature, and suitable slags chemistry for maximum recovery.

In the project, measurements of the thermodynamic properties including distribution ratio (L_M) of strategic elements at conditions relevant (and beyond that of used) in copper smelting conditions will be carried out. At the same time the structure of the slag will also be characterised using FTIR/Raman spectroscopy for determining the degree of polymerisation. A model then will be developed to directly correlate the L_M with the degree of polymerisation. Understanding of the partitioning behaviour of the strategic elements and its correlation with slag structure will facilitate the development of improved process. For example by operating in an effective manner beyond the current conditions to maximise the metals recovery. Industry can also improve the process by devising a strategy such as applying a multistage process and tailoring different slag chemistry systems to make sure that strategic elements that have contradict optimum conditions can be all recovered.