

Manufacturing Design and Technology

- Module code: M5X01179
- Lecturers: Rachel Alexander, Richard Morgan

Aims

- To enable students to develop an understanding of a wide range of variables relating to both primary and secondary manufacturing processes.
- To enable the student to recognise typical process defects and to propose appropriate preventative and remedial methods of dealing with these defects.
- To enable the student to critically appraise a range of factors affecting the design process and to apply suitable techniques to arrive at design solutions.
- To enable the student to develop appropriate solutions to engineering problems, using new or existing design techniques.

Ironmaking

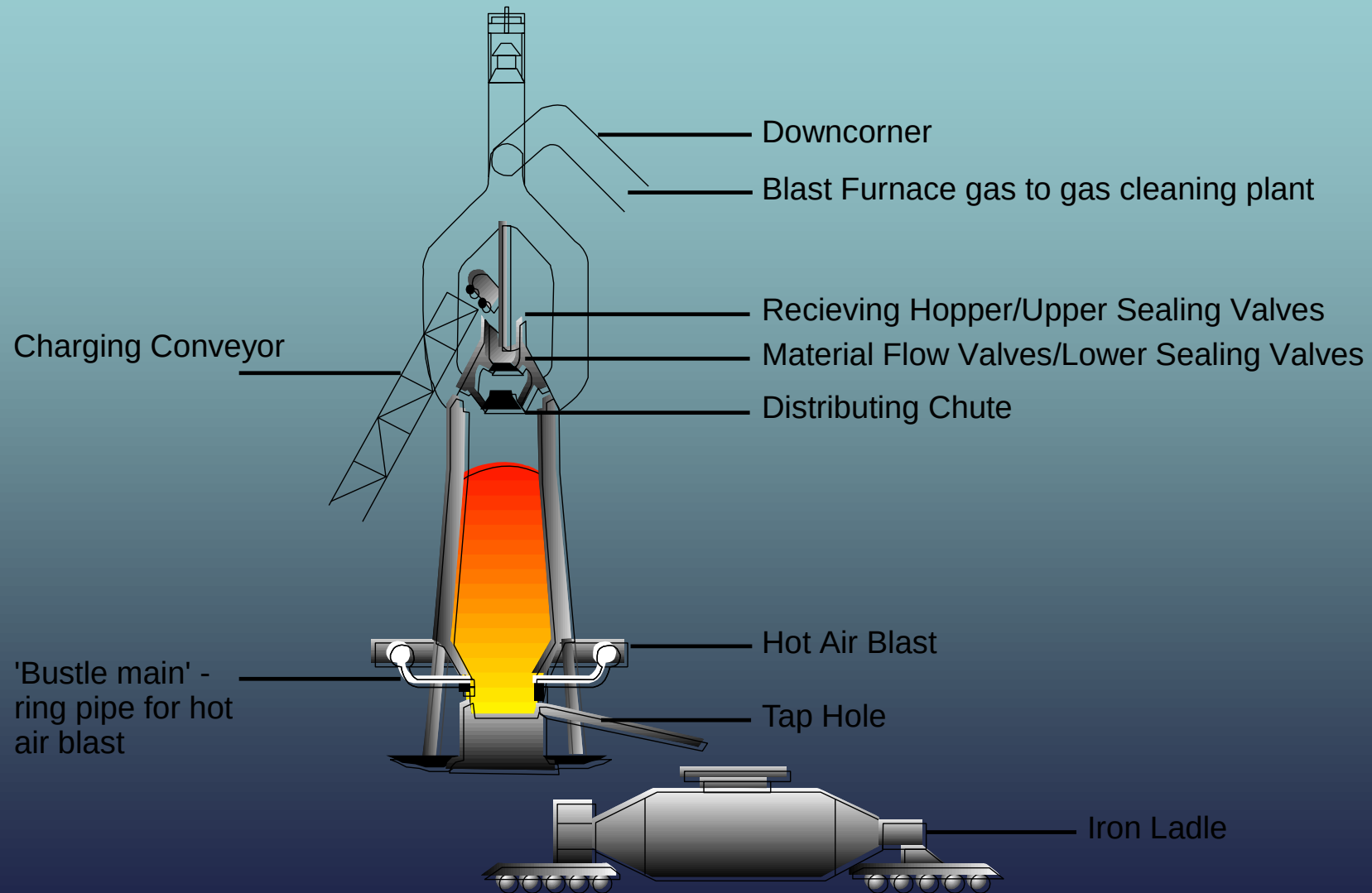
Raw Materials

Raw Materials is used in the steel making process

- Iron Ore is imported from:-
 - Australia
 - Canada
 - Brazil
 - South Africa
- Coal is imported from:-
 - USA
 - Australia
 - Canada
- Limestone comes from:-
 - South Glamorgan
 - Cumbria
- Olivine Sand is imported from:-
 - Norway



Blast Furnace Schematic



Blast Furnace and Torpedo



Blast Furnace

- Two working Blast Furnaces
- They produce approx 70,000 tonnes of hot metal (Iron) per week
- To every 1 tonne of liquid iron produced 2 tonnes of air is needed
- Raw materials are fed through a revolving chute (Paul Wurth Top) at the top of the furnace
- Oil or coal can be injected into the furnace to reduce coke requirements. At higher injection levels oxygen is required, which also increases productivity.
- Blast air temp to the furnaces is 1050-1200°C. The blast air is preheated in Blast Furnace Stoves
- Oxygen in the blast reacts with carbon from coke to produce Carbon Monoxide. This reacts with the raw materials to produce iron and slag. It “scavenges” the oxygen from the raw materials.
- The iron produced runs the bottom and collected in the torpedo ladles
- Slag is never wasted it is used for cement products

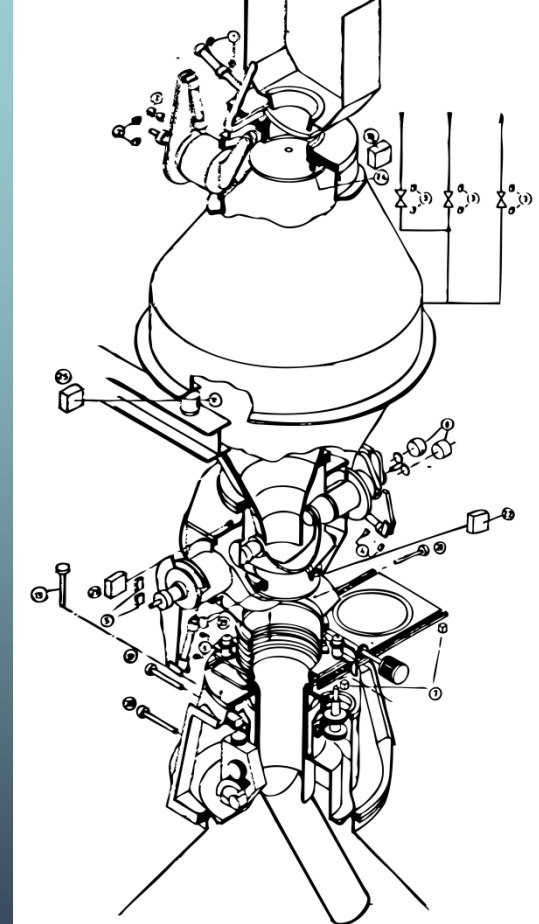
The rotating chute inside a blast furnace (Paul Wurth Top)



Picture credit: Marc Holmes

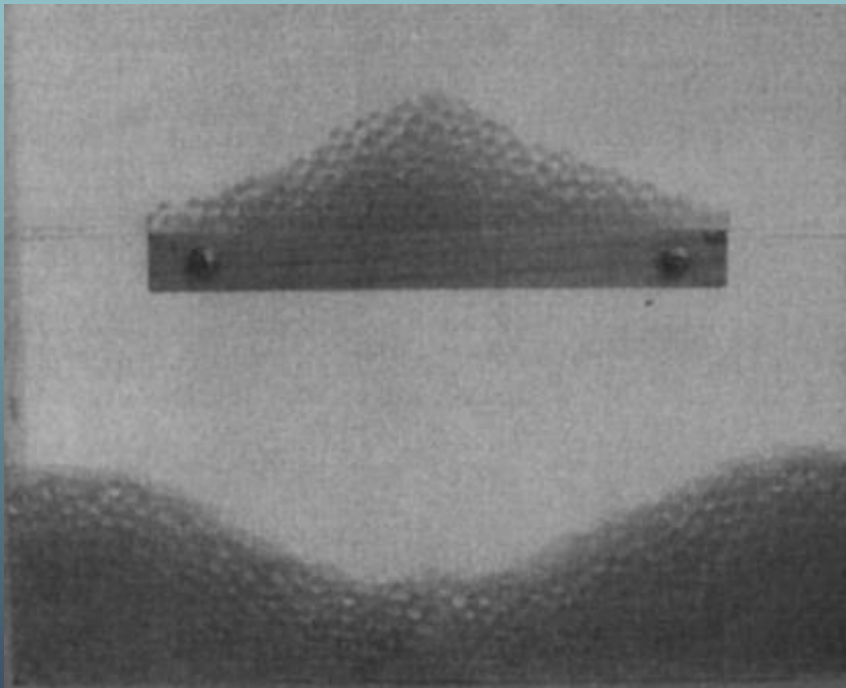
Bell Less Top Charging System

- Common charging system used to charge granular materials into the furnace in patterns.
- Has the ability to alter flow rate, chute rotation speed and chute angle, all linked to weight in hopper
- Different chute options available
- These patterns decide the granular flow in the furnace
- In turn, these patterns affect the gas flow in the furnace

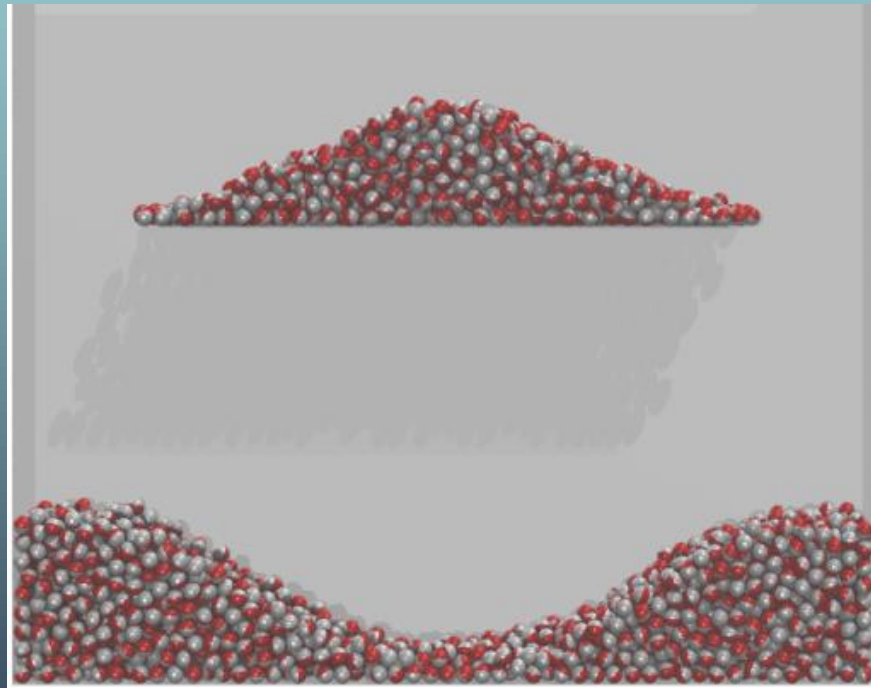


Comparison of DEM code to Glass ball test

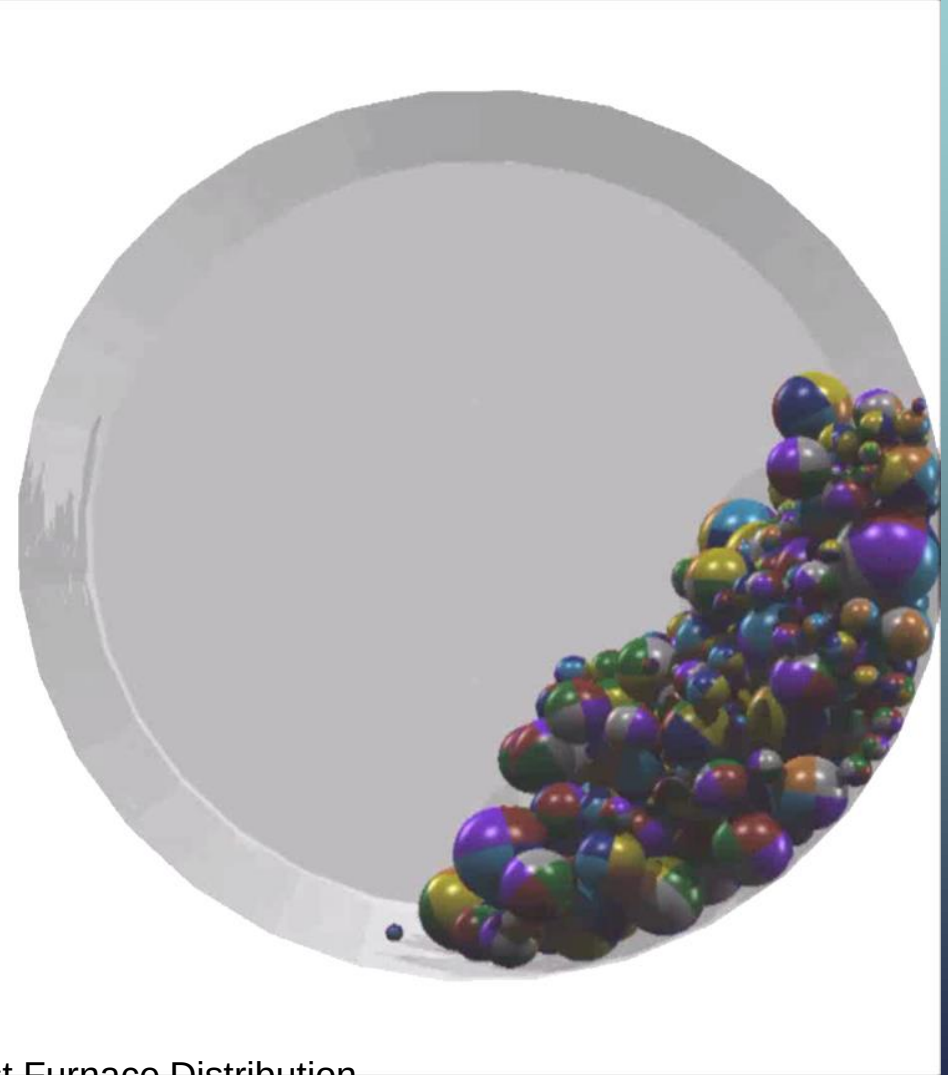
Laboratory Test



Simulation Results



Validated / Calibration for Burden



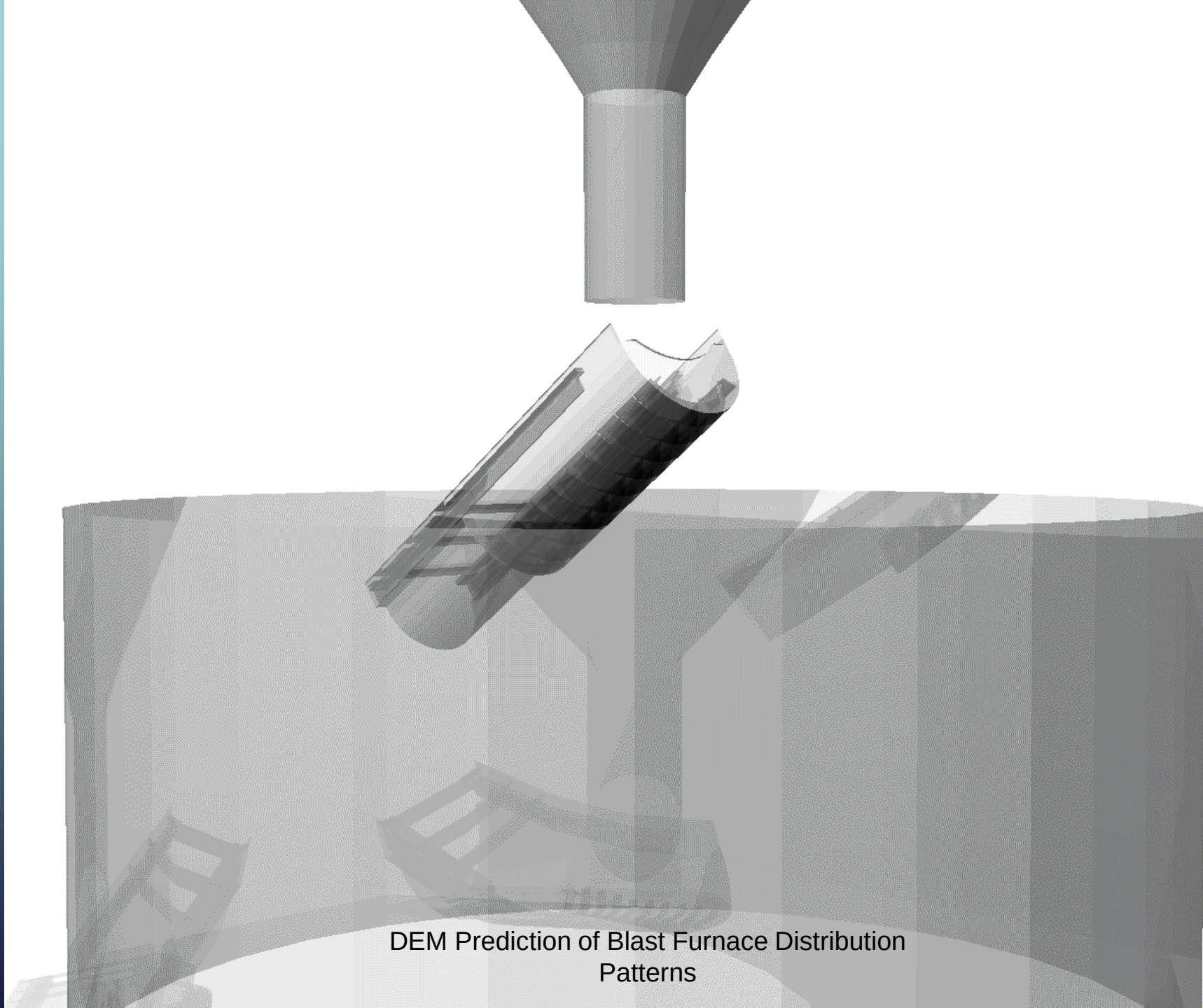
Validation / Calibration for Burden

Laboratory Test



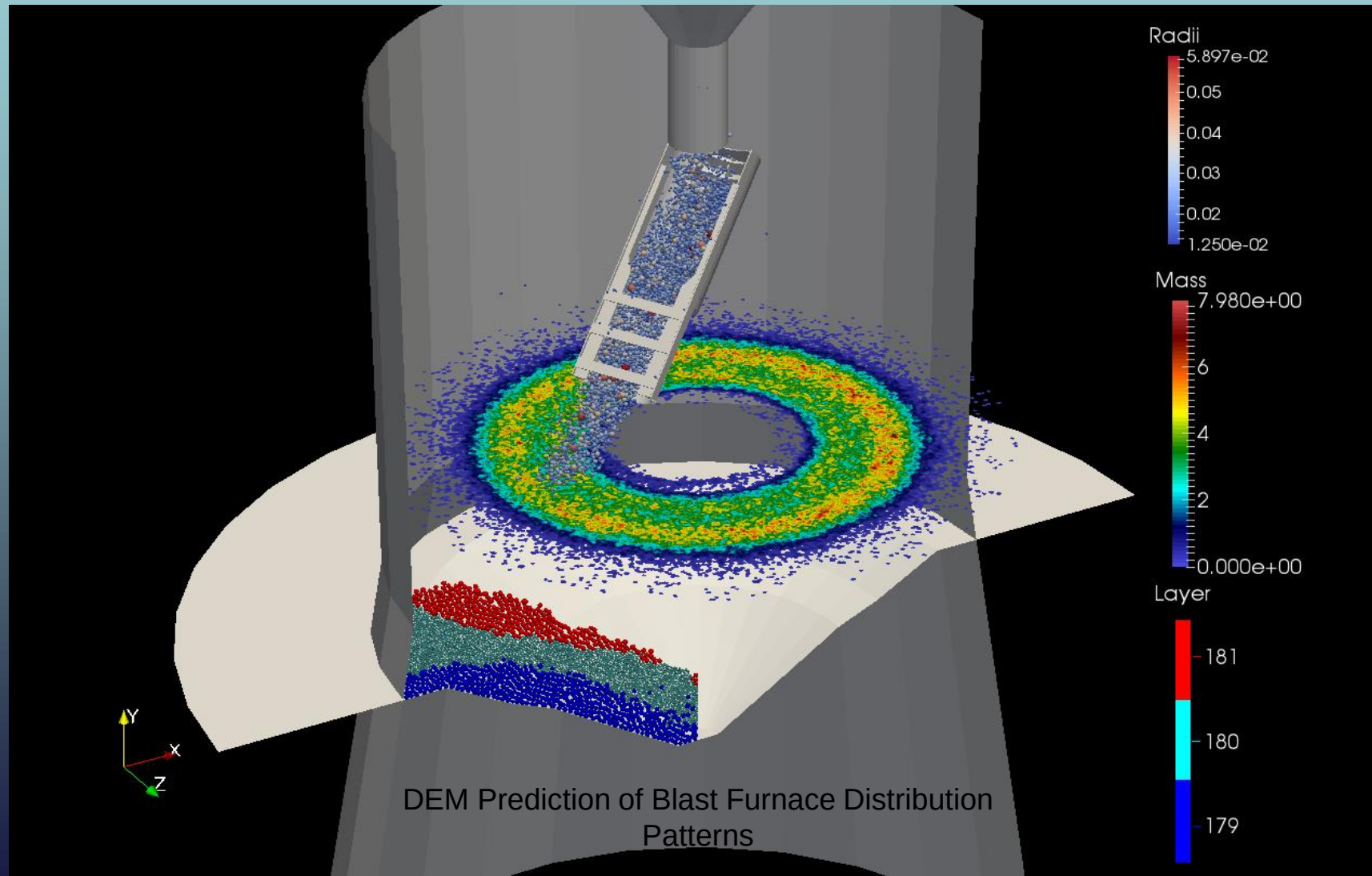
Simulation Results

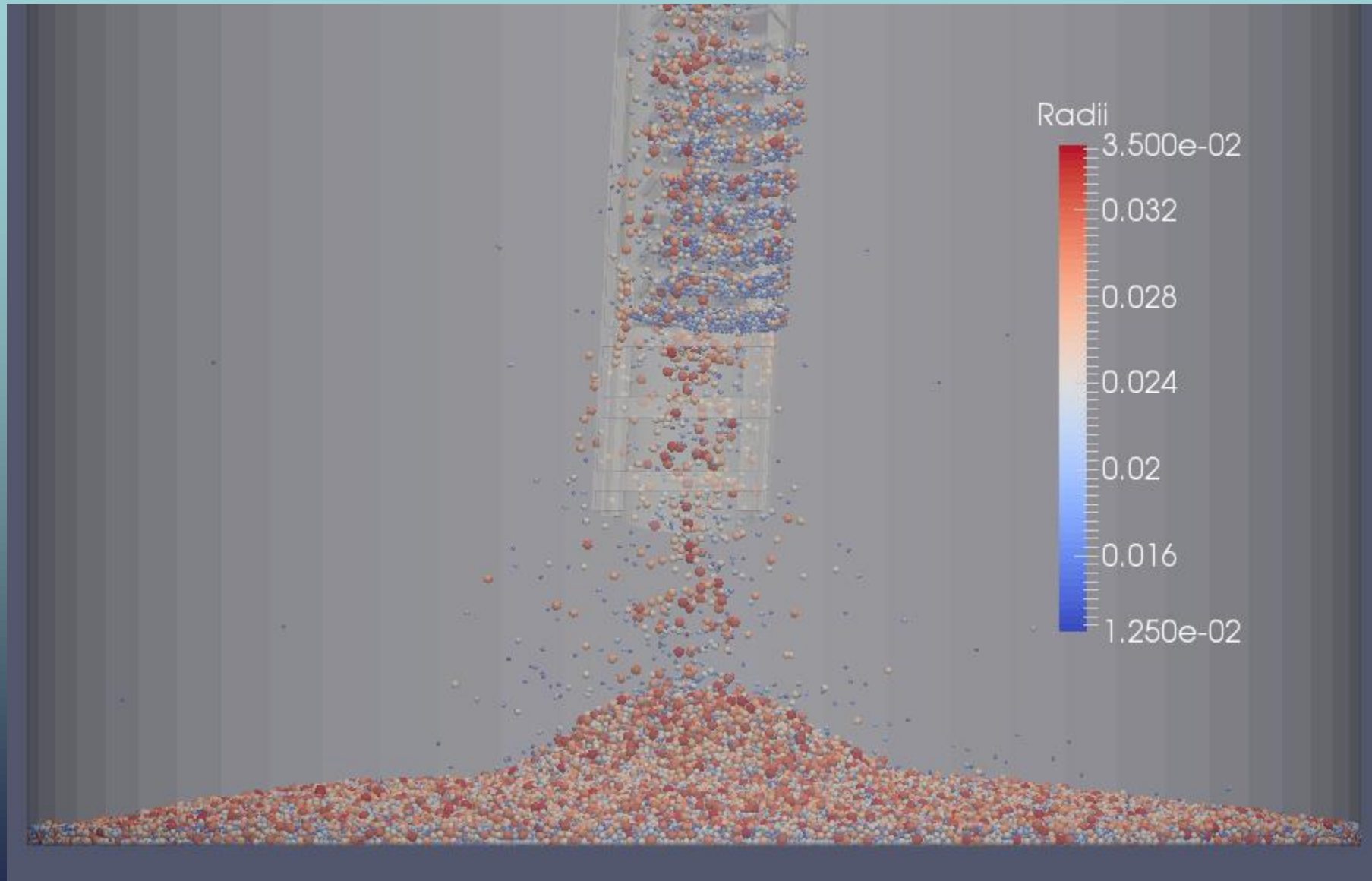




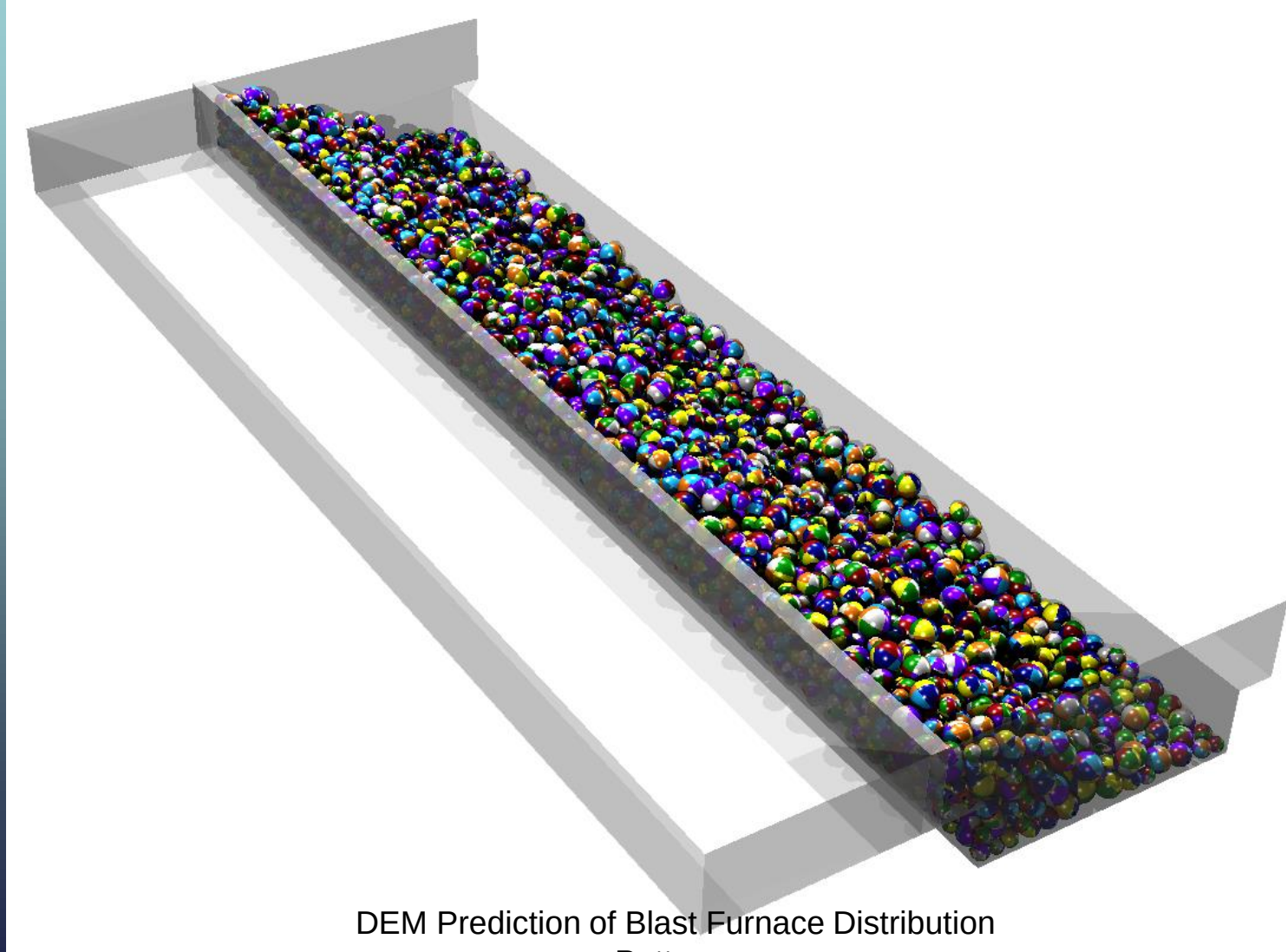
DEM Prediction of Blast Furnace Distribution
Patterns

Overlay of: 3D chute simulation, Paintball trajectory info and slice model



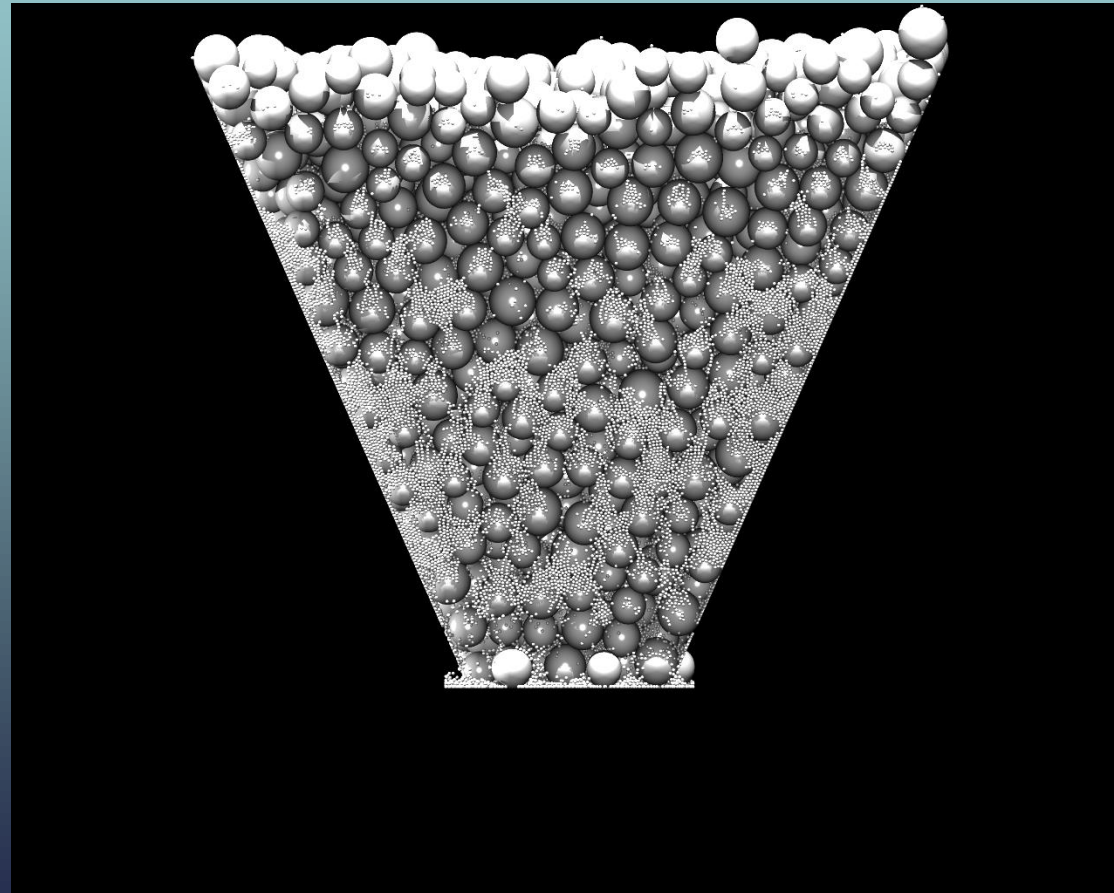


ESI – Additive Layer Manufacture – Spreading Simulation



DEM Prediction of Blast Furnace Distribution
Patterns

ASTUTE powder hopper issue

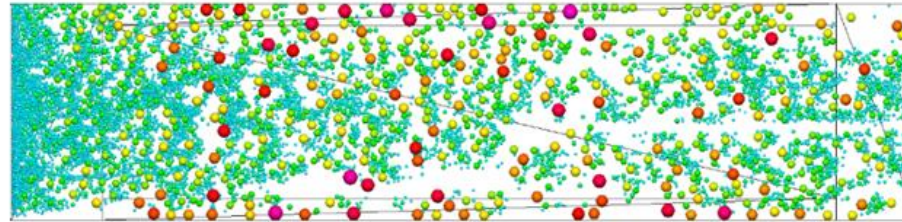


ESI – Additive Layer Manufacture – Spreading

Table displacement [μm]

First layer powder particle distribution on processing table

30



Coating direction



50

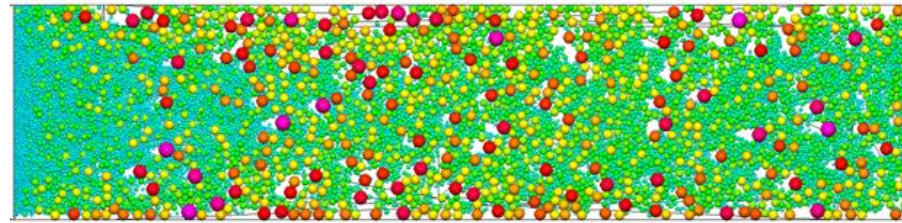


Figure 6: First layer particle distribution on processing table for two displacements

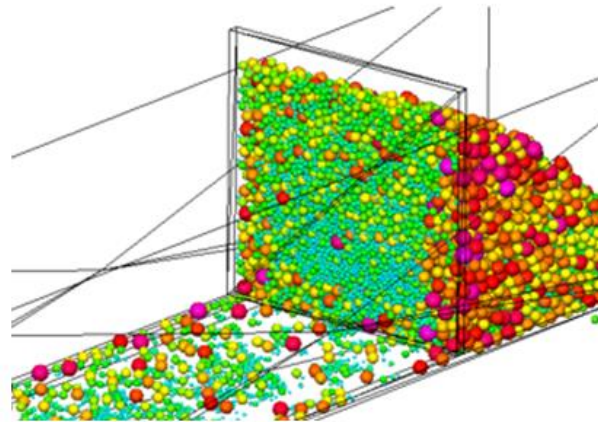


Figure 7: Magnification of gap between coating arm and the processing table for a vertical table displacement of $30\ \mu\text{m}$

ESI – Additive Layer Manufacture – Spreading Simulation

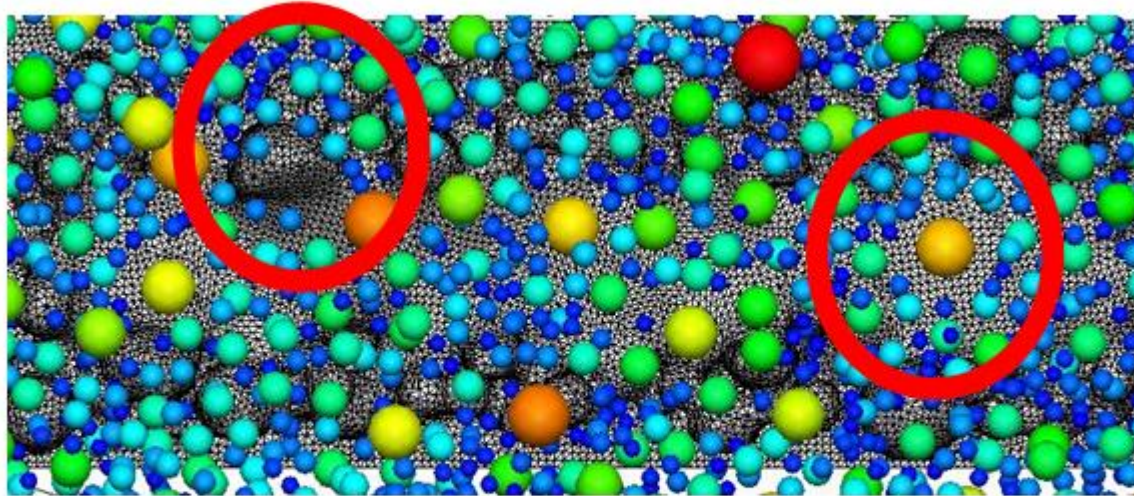
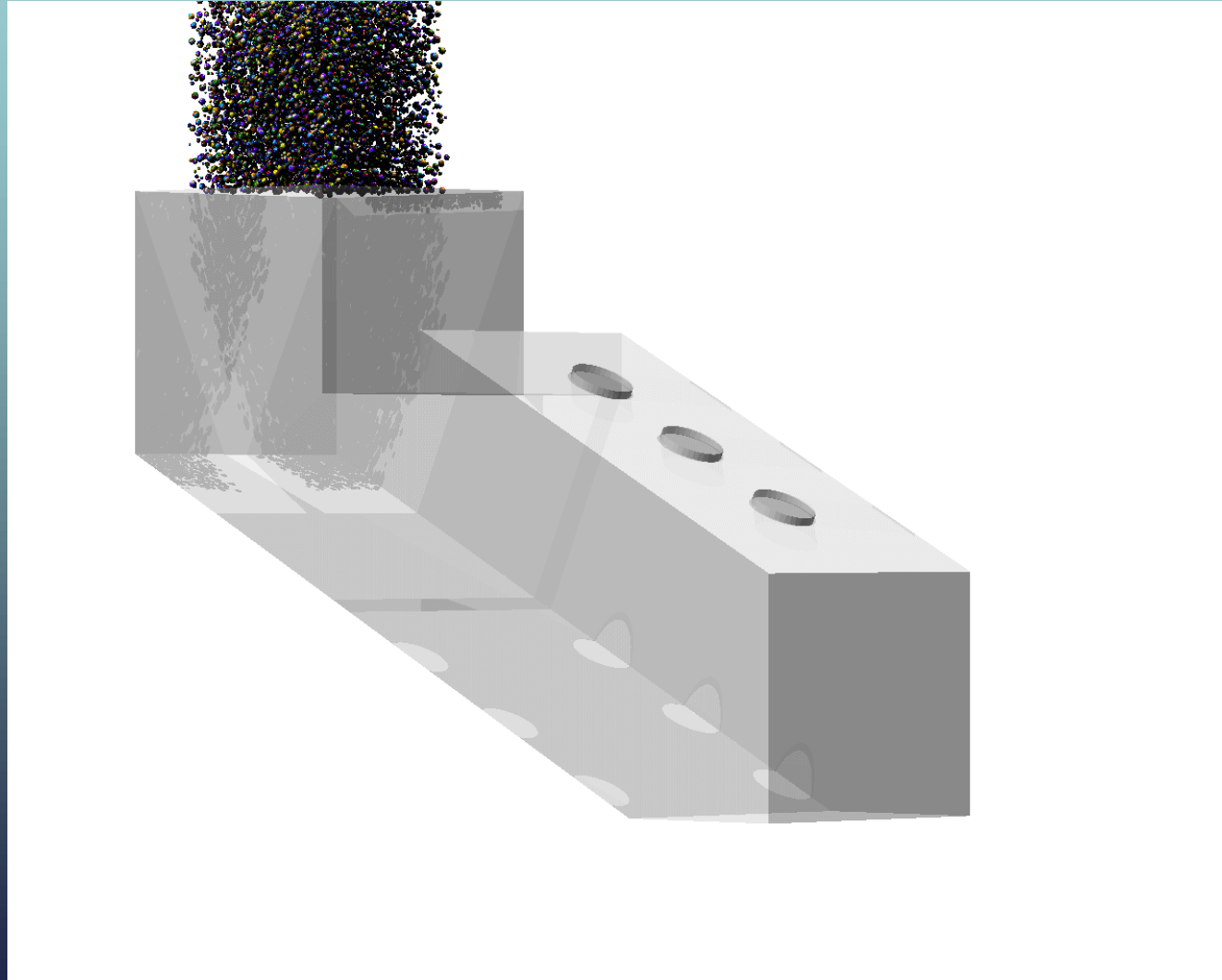
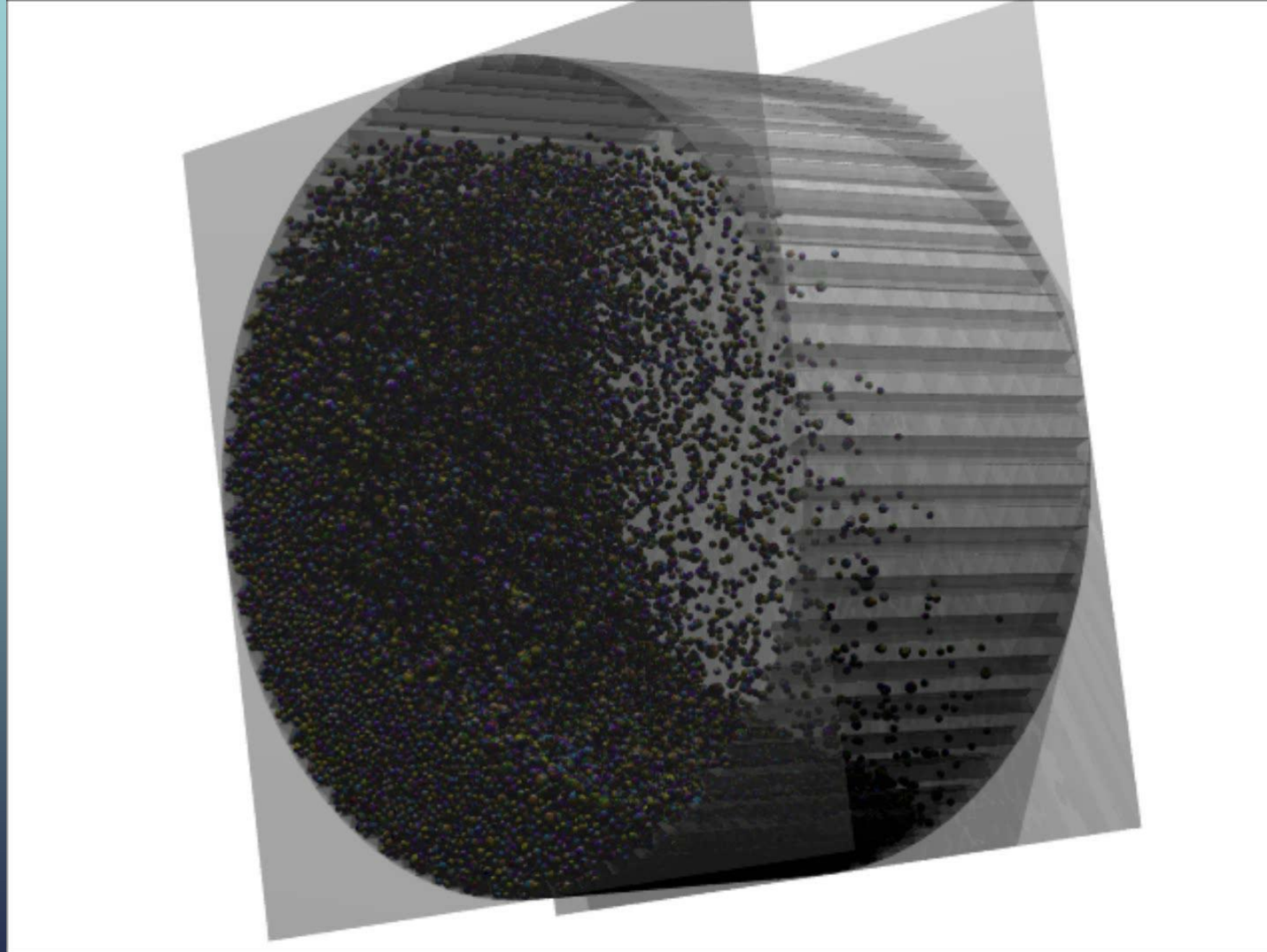


Figure 11: Powder layer spread on previously processed surface

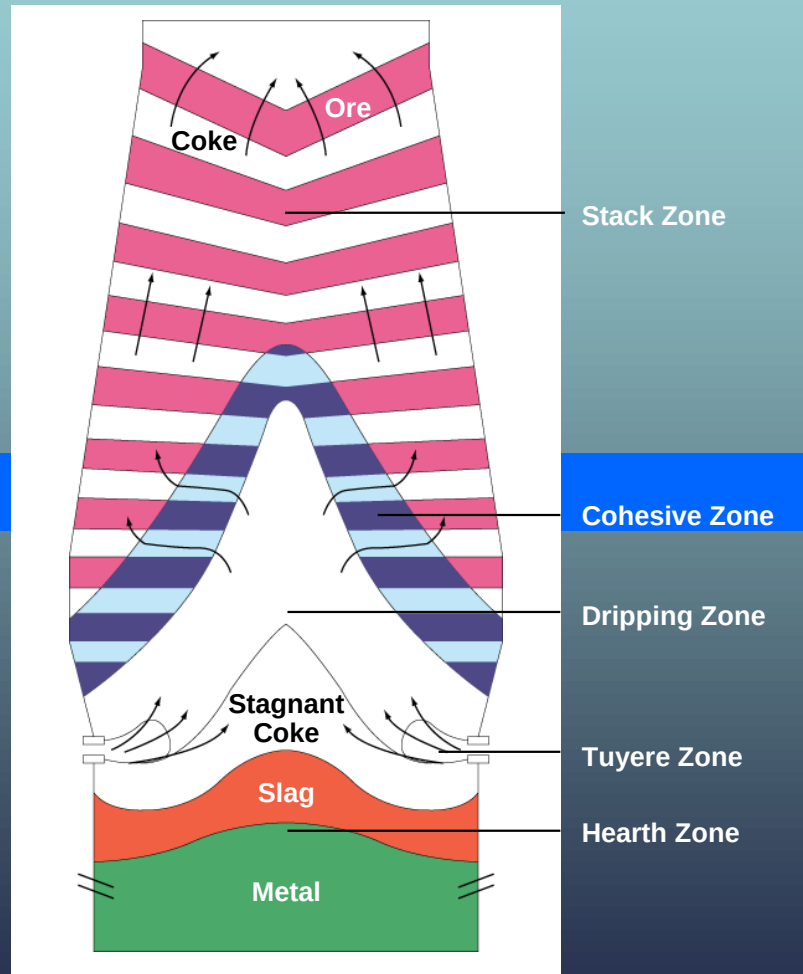
Vale – Nickel Pellet Chute – simulation



FLSmith: Ball mill simulation 3D



Schematic Diagram Showing The Five Internal Zones in a Blast Furnace



Energy Balance

Input

Coke/injected fuels ~90%

Hot Air Blast / O₂ ~10%

Output

Chemical Reactions 30-45%

Top Gas 30-40%

Liquid Iron 15-20%

Liquid Slag 3-5%

Heat Losses ~3%

Hot Metal Chemistry

C	Mn	S	P
4.5%	0.4%	0.025%	0.075%

Key Requirements of Raw Materials

- **Coke**

- Strong at high and low temperatures
- Reactive to be able to readily convert to CO
- Consistently sized, with minimal fines

- **Sinter, Pellets and Lump Ore**

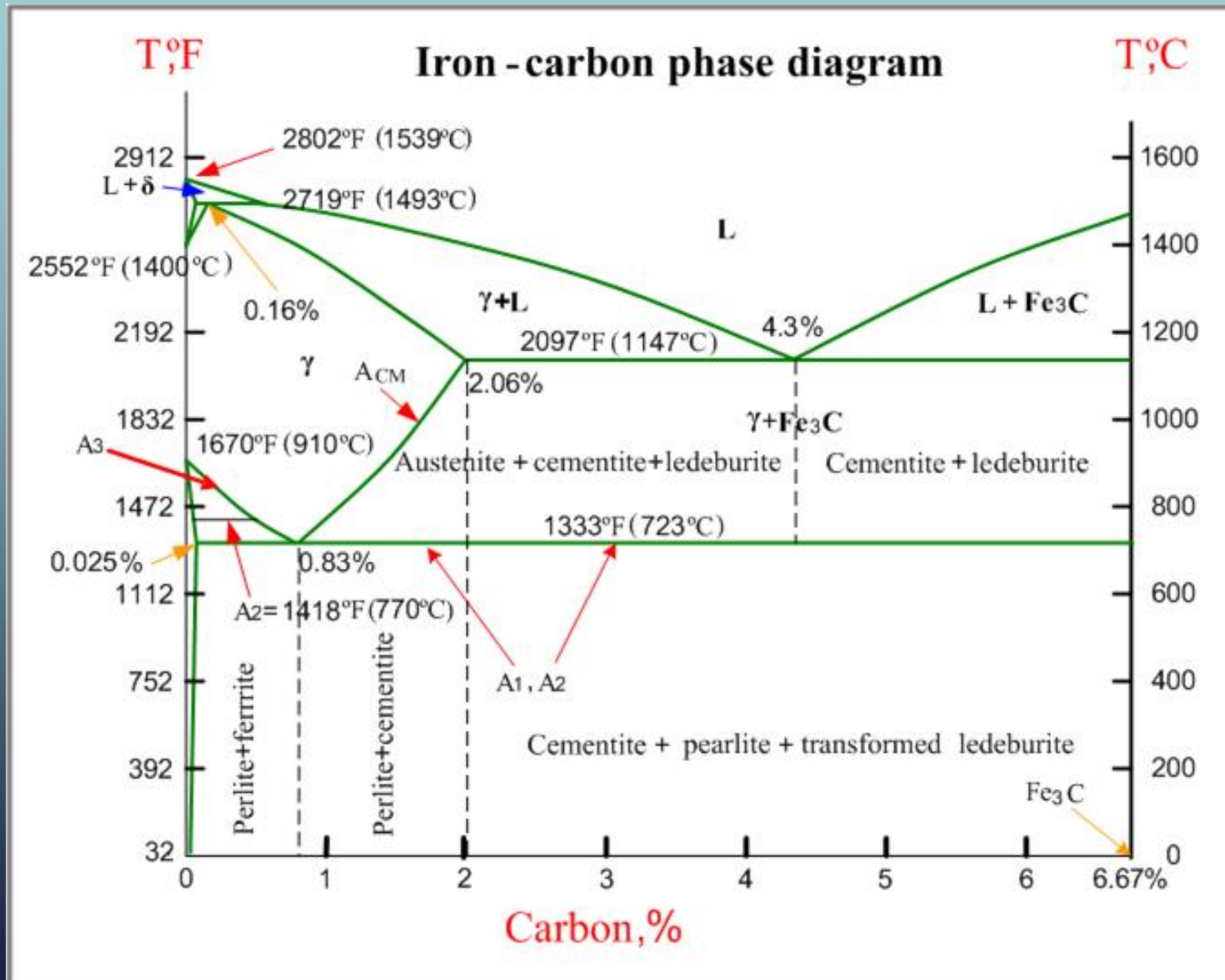
- Strong at high and low temperatures
- Reducible to be able to readily convert to iron
- Consistently sized, with minimal fines

Process evolution in the steel industries

Contents

- History of Iron and Steelmaking
- Modern Ironmaking
- Principles of Steelmaking
- Development of tonnage steelmaking processes
- Ingot and continuous casting
- Control of gas and inclusions in steel
- Production of special and alloy steels
- Trends in process adoption

Iron and Steel



History of Iron and Steelmaking



Stone Age



Bronze Age



Iron Age

- Iron came into general use in the “Iron age”

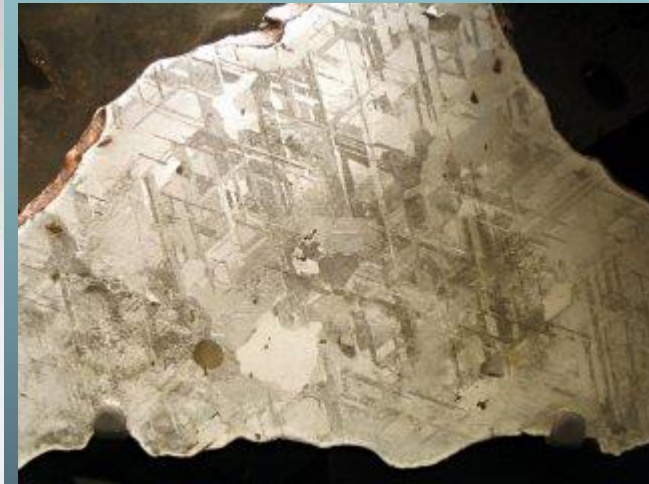
History of Iron and Steelmaking

- However, Iron has been found in archaeological sites dating well before the iron age.
- Where did this iron come from?

History of Iron and Steelmaking



History of Iron and Steelmaking



- Meteorites – identified by high nickel content and Widmanstätten structure

History of Iron and Steelmaking

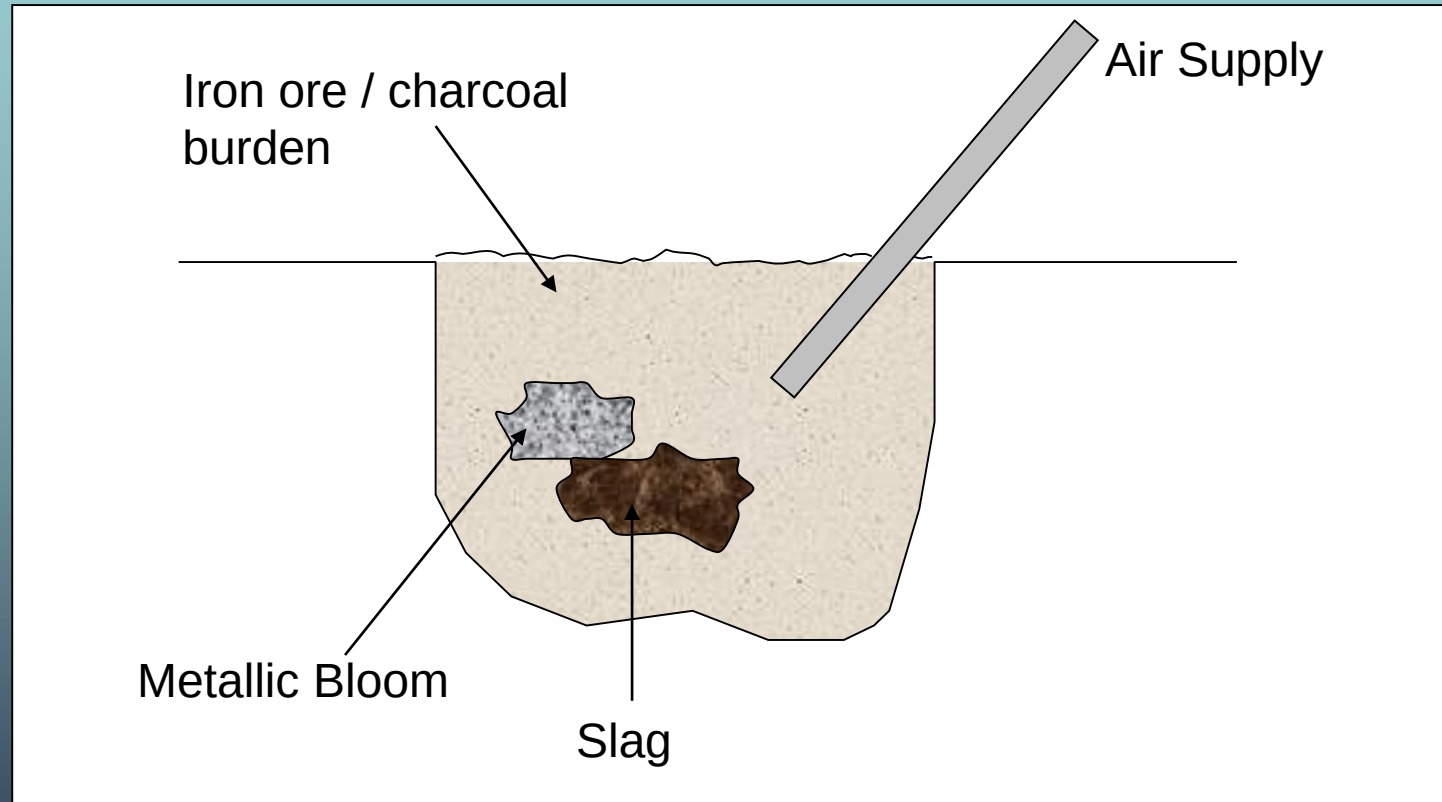


- Iron plate found at entrance to great pyramid of Giza. Produced by direct reduction of iron ore

History of Iron and Steelmaking

- Iron metallurgy began among the Hittite people around 1900BC.
- Technique spread from Turkey around Europe reaching Britain in the 5th century BC.
- Iron produced by directly reducing iron ore (iron oxide) with carbon (charcoal)
- Process probably carried out in clay lined hole with and air inlet

History of Iron and Steelmaking



Pit furnace

History of Iron and Steelmaking

- Burning charcoal with the ore at 1000°C reduces the iron ore
- No molten Iron
- Iron was formed as a “bloom” – a spongy mass of solid iron particles surrounded by and intermixed with slag (slag arises from impurities in the ore – **gangue**)
- Heating and hammering the bloom to remove slag - stringers
- This is known as the “Bloomery process”

History of Iron and Steelmaking

- This iron was very soft so could not be used for weapons – wrought iron
- Iron could be converted to steel by causing the iron to absorb small amounts of carbon
 - Heating the iron with charcoal in the absence of air and then water quenching
 - Excess Carbon in bloomery
- Hot work hard and soft iron together for weapons

History of Iron and Steelmaking



Damascus steel was very hard and sharp –
nano-particles of carbon

History of Iron and Steelmaking

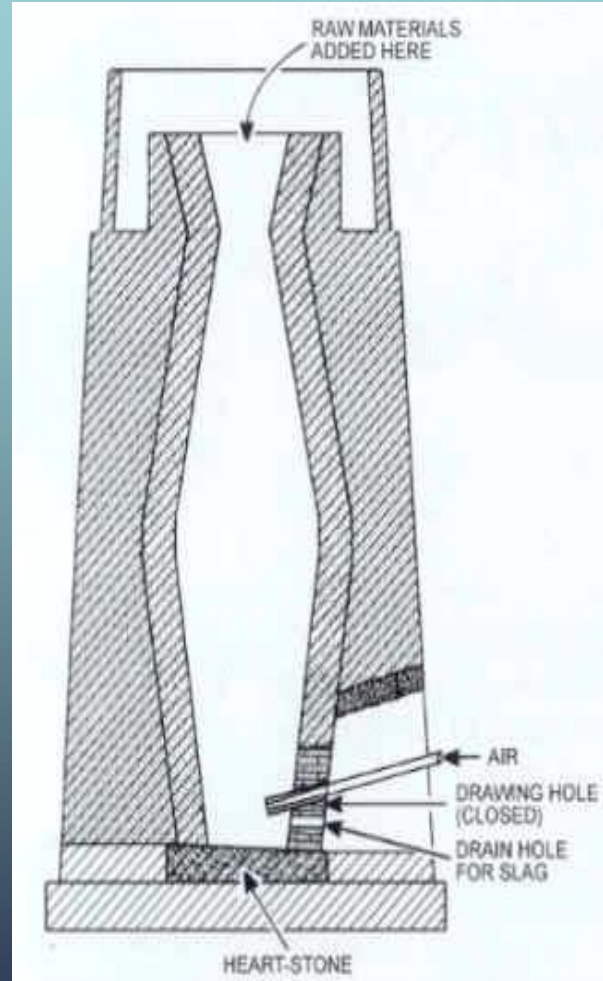
- The techniques used to make Damascus steel probably originated in India
- Vikings and the Japanese develop technique of repeatedly folding, heating and hammering to produce a uniform tough steel
- Produced a fine oxide dispersion through the metal giving it excellent properties



History of Iron and Steelmaking

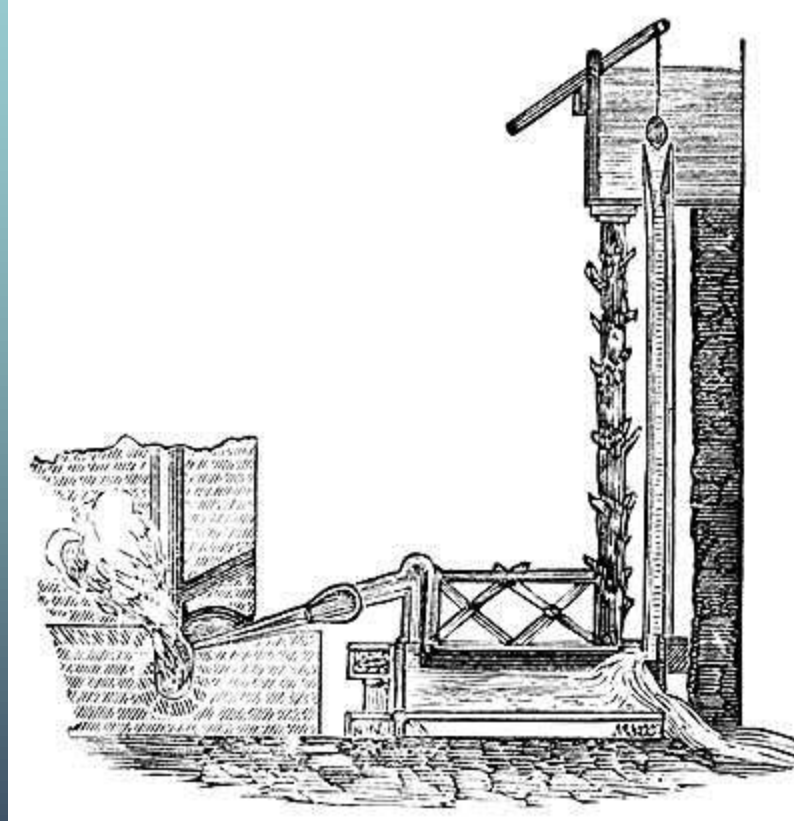
- With time the scale of the Bloomery operation began to grow
- The bed of iron ore and charcoal was developed from a simple pit into a deeper enclosure with protective walls to concentrate the heat
- This led to the introduction of the Stuckofen furnace across Germany and Austria in the 14th century
- 3-5m tall round or oval shaft
- Ore and carbon fuel charged at top and air introduced at bottom of furnace
- As the ore passed through the furnace it became directly reduced to form a bloom in the hearth

History of Iron and Steelmaking



- Stuckofen furnace

History of Iron and Steelmaking



- Catalan furnace – improved air blast

History of Iron and Steelmaking

- Large furnaces
- Higher temperatures
- ore reduced higher up in the furnace
- This iron then absorbed more carbon and other impurities
- lowered the melting point of the impure iron to 1200°C
- This temp could be attained in the hearth
- Thus, **Molten iron** with around 5% Carbon content collected in the hearth
- Forerunner of blast furnace – produced cast iron rather than Bloom iron

History of Iron and Steelmaking

- The Bloomery process was a **direct process**. Directly reduced the iron ore to iron
- These new furnaces produced much more impure iron that was brittle and unforgeable – cast iron
- These furnaces were an intermediate step in producing the final metal, an **indirect process**

History of Iron and Steelmaking

- The impure iron produced in the furnace had to be refined to lower the Carbon and impurity levels to make steel
- Original process was called a “finery”
- The cast iron was remelted on a hearth full of charcoal with air blown in by bellows
- Oxidised impurities and produced a bloom

History of Iron and Steelmaking

- The finery reduced C levels from 5% to almost zero – wrought iron
- Necessary to introduce low levels of C once again to make steel
- Heating bars of wrought iron in chests containing charcoal for a week.
- “cementation process”
- Carbon diffused into the steel to give strength
- Some C reacted with Oxygen to produce CO forming blisters on the surface of the metal
- Known as “Blister steel”

History of Iron and Steelmaking



- By mid 17th century blast furnaces were producing 2/3 tonnes of iron per day
- Further development through the 18th and 19th centuries increased the size, complexity and output

History of Iron and Steelmaking

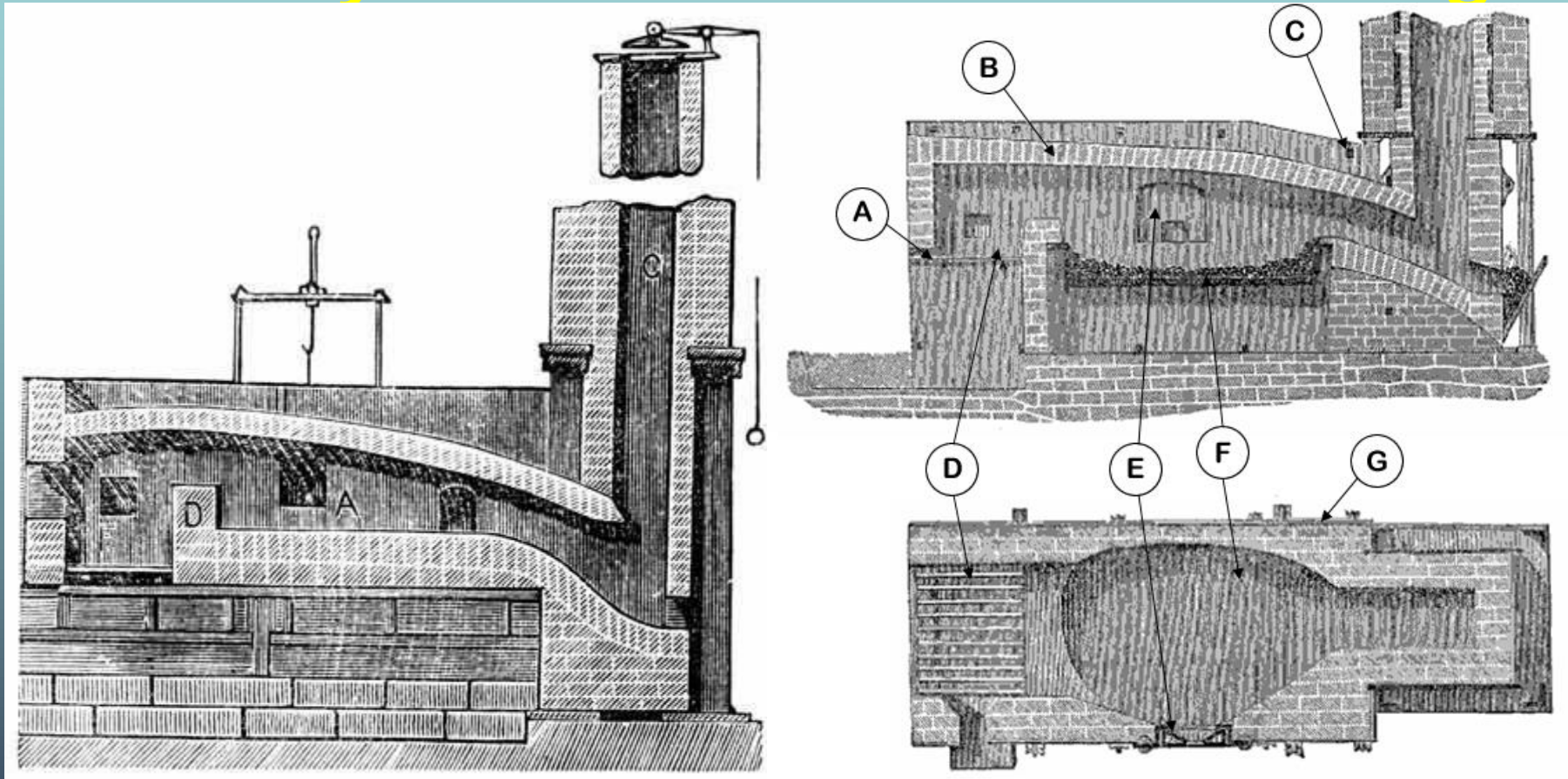


- Replacement of charcoal with coke. Abraham Darby first used this commercially for iron making in 1709
- Steam engine development improved blowing capabilities over water driven bellows
- Use of hot waste gas from furnace to pre-heat the air blast

History of Iron and Steelmaking

- Product of these improved furnaces was called Pig Iron
- Pig Iron was converted to wrought iron using the Puddling process from 1784
- Puddling was an updated version of the finery
- In a finery the pig iron was refined with charcoal as burning coal led to sulphur absorption by the iron
- The puddling furnace burnt coal on a grate separate from the hearth where the pig iron was melted
- The hot combustion gases passed over a bridge, oxidising the sulphur before being reflected down onto the metal

History of Iron and Steelmaking



- Puddling furnace

History of Iron and Steelmaking

- 300-500lbs of pig iron was melted on the hearth and oxidised to eliminate Carbon and other impurities
- As oxidation proceeded the iron became pasty and solid and formed into large, spongy lumps
- These balls of iron were lifted from the furnace using tongs and then forged and rolled to produce wrought iron
- By about 1850 the puddling operation could be controlled to prevent complete decarburisation making a basic steel

History of Iron and Steelmaking



- The importance of cast iron and wrought iron at this time can be demonstrated by the construction of the Crystal Palace for the Great Exhibition of 1851 in London
- It used 3800 tonnes of cast iron and 700 tonnes of wrought iron

History of Iron and Steelmaking

Use of cast iron began to diminish as the slow puddling process was replaced by revolutionary methods of tonnage steelmaking

1. In 1856 Henry Bessemer patented the converter process where an air blast was forced through the pig iron to oxidise impurities. 8/9 tonnes of steel produced in 20mins compared to 36 hours for puddling
2. William Siemens invented the open hearth process that updated puddling furnaces to use hot exit gases to preheat incoming air into the furnace
3. Siemens then developed electric arc furnaces capable of refining and melting steel

History of Iron and Steelmaking

- With these new tonnage making steel routes the two stage process of steel production became established
- Reduction of iron ore to form pig iron
- Controlled oxidation of the pig iron to remove carbon and impurities to produce steel