Coal Quality Workshop

Thermal Coal and Coking Coal

June 2023

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WHITEHAVEN COAL

1. What is coal? – coal rank and forms
2. Sampling and testing
3. Thermal coal and power generation
4. Met coal and steel making
5. Coal blending

FORWARD LOOKING STATEMENTS

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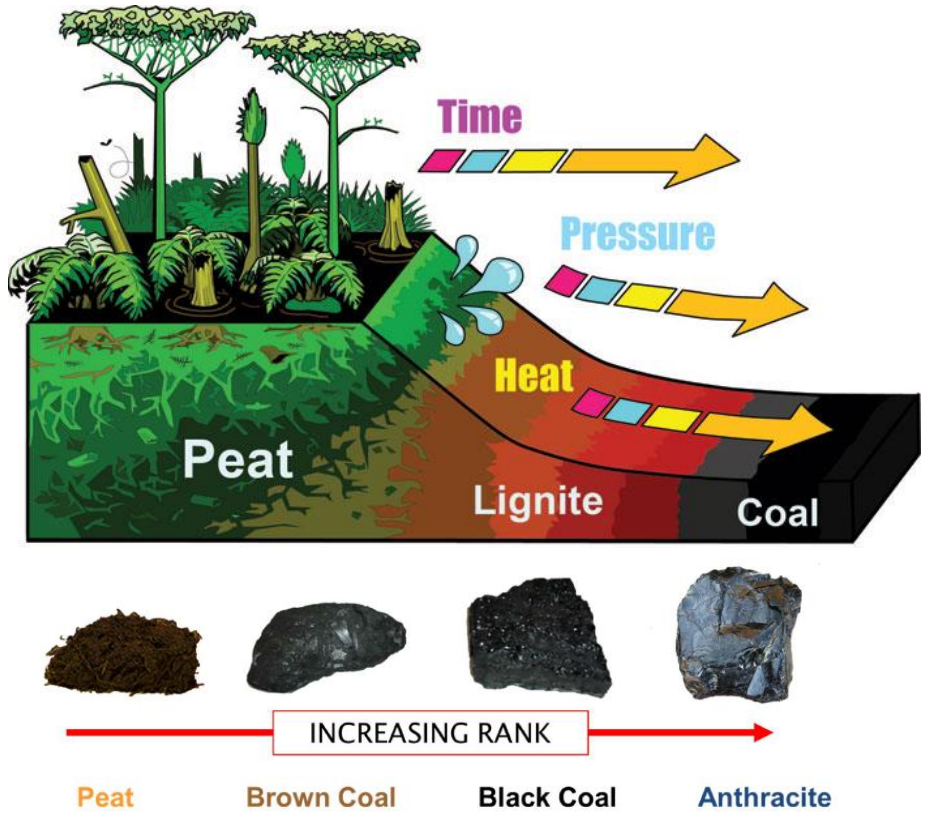
1

What is coal? – coal rank and forms

What is coal?

Definition (AS 2418-1995)

A sedimentary rock composed predominantly of solid organic material, with a greater or lesser proportion of mineral matter. Coal is derived from the accumulation of plant remains in a sedimentary basin, and is altered to solid rock by heat and pressure applied during the basin's development. The different coal varieties are products of different parent materials, different conditions of accumulation, and different tectonic histories.



Heat and pressure transforms the peat into various coal forms

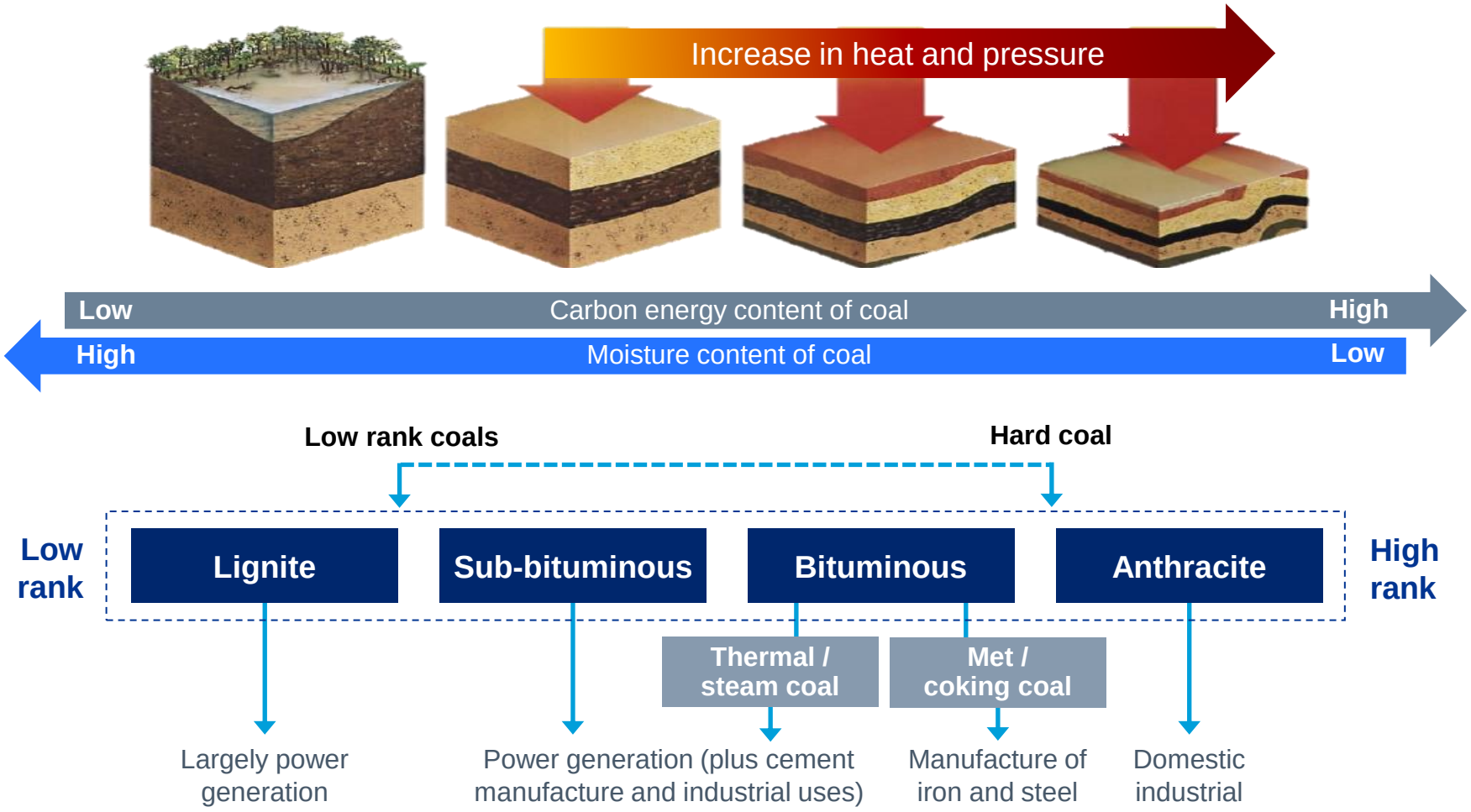
Plant debris accumulates in a slowly subsiding swamp to form peat

Burial leads to compression and loss of water

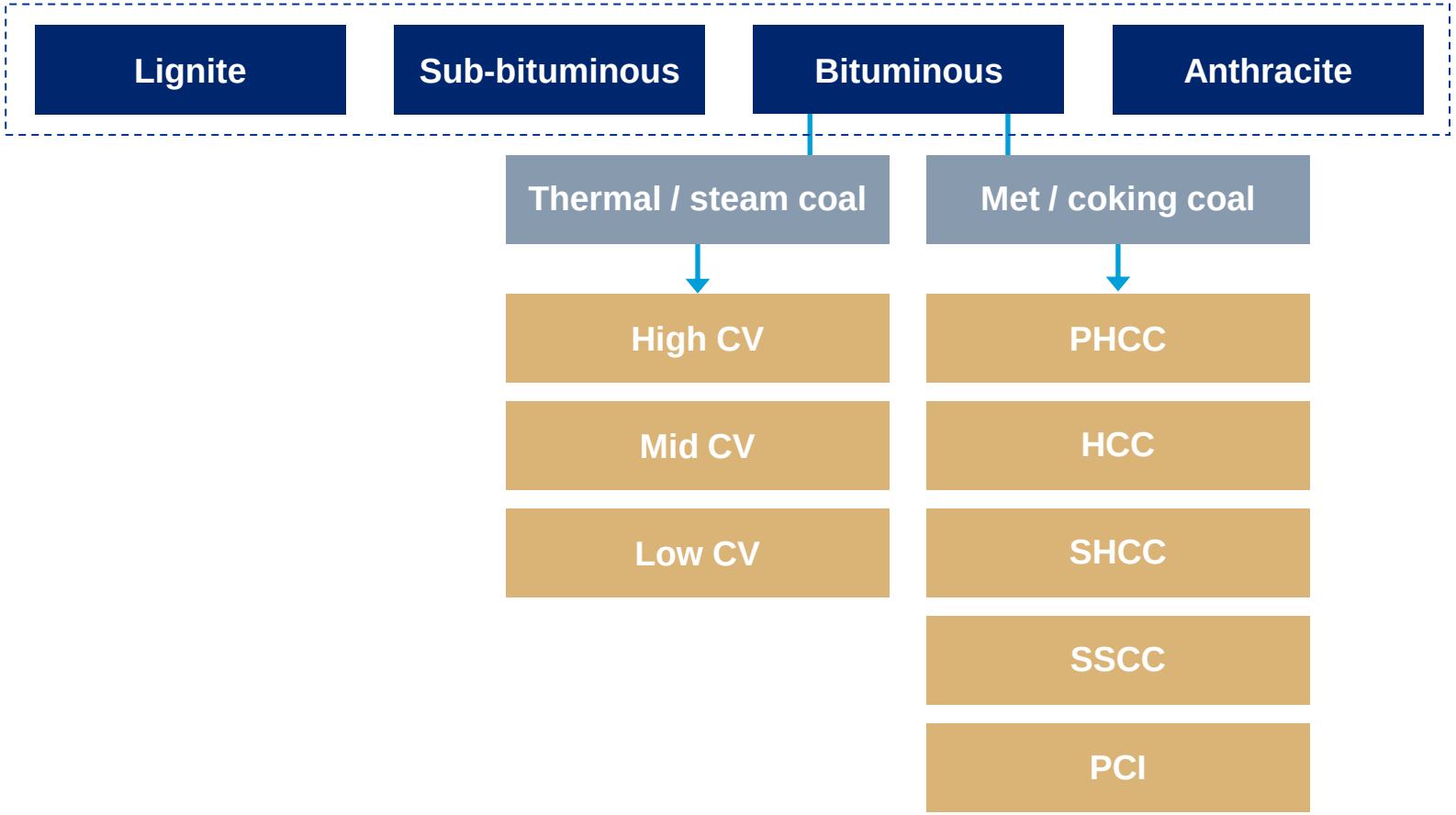
Alternating swamp and burial phases leads to the formation of coal measure

Coal rank

Rank is the degree of transformation of the original plant material – it is not the age of the coal, rather it is the maturity of the coal.



Classification vs. categorisation



Standards exist for coal **classification**

No standards exist for coal **categorisation**

Coal categorisation

There are no formal definitions, these are marketing terms

Material	PHCC	HCC	SHCC	SSCC	PCI	LCV thermal	MCV thermal	HCV thermal
Also known as:	Premium Low Vol, PLV, PMV	Hard Coking, Std Hard	Semi-Hard, 2nd Tier, Qld Rangals	Semi-Soft, Weak, HVSS	Low Vol PCI	SCoTA FOB INDO 3800	HA Aus, RB3 API3	gC Newc, DES ARA RB1
Calorific value	—	—	—	—	>7600GAD	<5600 min 3600 NCV to qualify for 3800 indices	5600-5850 min 5300 NCV to qualify for 5500 indices	>5850 min 5850 NCV to qualify for 6000 indices
CSR	67-74	60-67	35-60	<35	<10	0	0	0
Volatiles	18-24	18-28	18-28	24-38	10-15	22-35	22-35	22-35
CSN	7-9	5-9	3-7	1-5	<1	<3	<3	<3
Ash	9-10.5	8-10	8-10	8-10	8-10	17-30	15-17	8-14
Price relativity	97-100%[1]	90-97%[1]	80-90%[1]	65-80%[1]	75-85%[1]	50-85%[2]	60-95%[2]	100-110%[2]

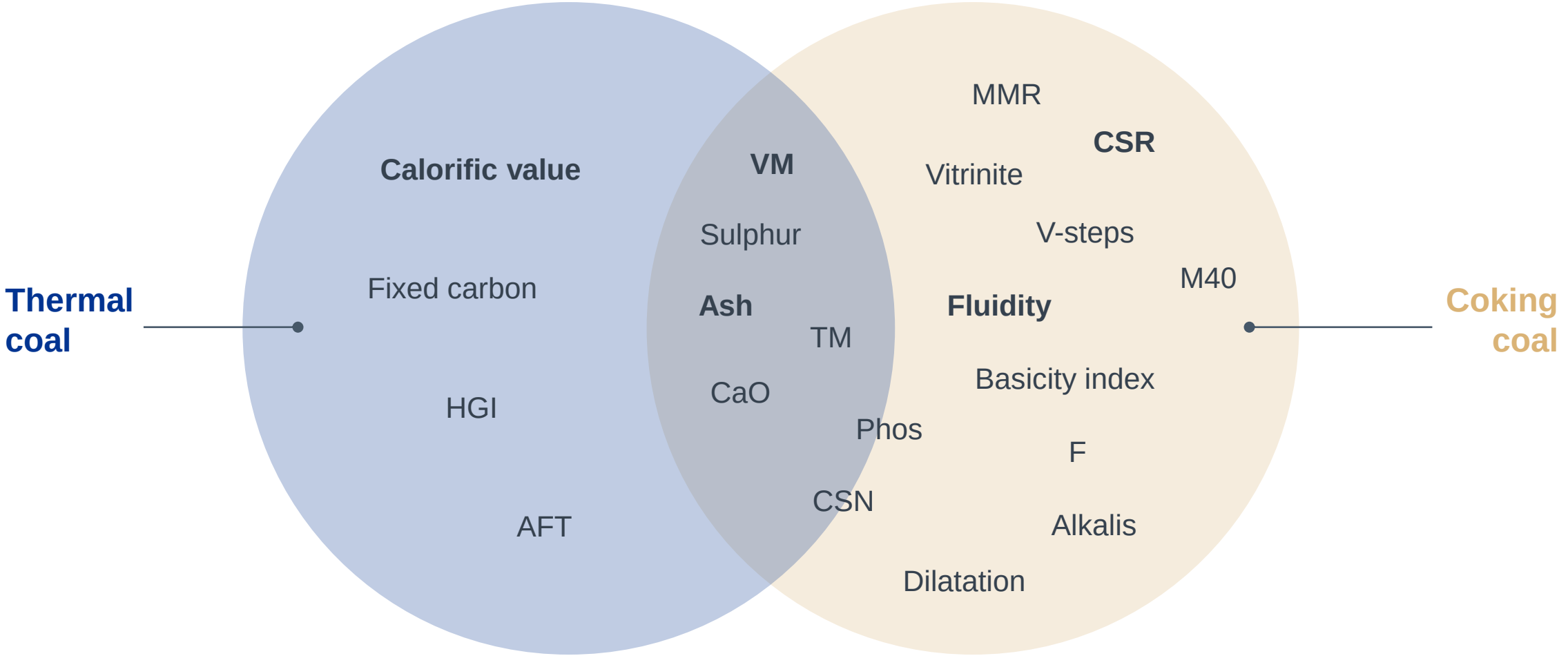
1. Relative to the Platts PLV HCC Index
2. Relative to gC NEWC Index. Indicative, depends on the prevailing market

Coal components

Non-coal: **Useless** bits	Coal: **Useful** bits
Water (moisture) Free (surface) and Air-dried (inherent)	**Fixed carbon** Carbon (most)
Mineral matter Ash and Mineral volatiles (Si, Al, Ca, Mg, Na, K, Hg, As, etc.)	
Organic matter Organic sulphur, Nitrogen	**Volatile matter** Oxygen, Hydrogen and Carbon (some)

Important qualities for thermal vs. coking coals

Some mutual interests, but steel and power plants focus on different parameters



2

Coal sampling and testing

Coal sampling

Why do we sample?

- A coal sample is a representative subsample of the whole coal
- Analysis of a sample provides accurate information about the material from which it was obtained
- Has the potential to carry significant financial weight

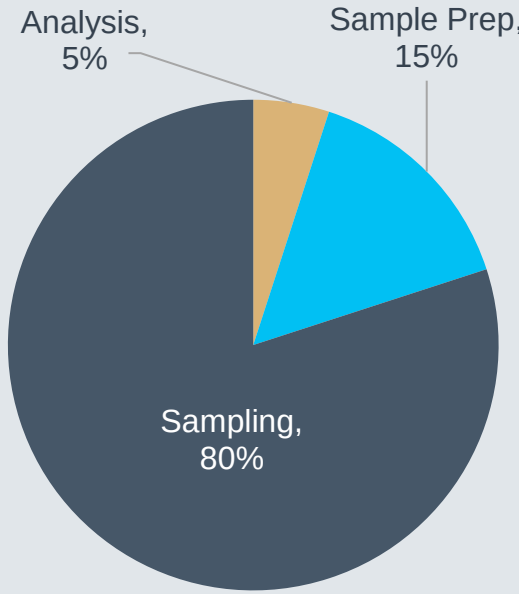
What determines the coal sample size?

- Coal top size
- Quantity
- Testing method
- Desired accuracy

What are the types of sampling?

- Mechanical/automatic
- Manual

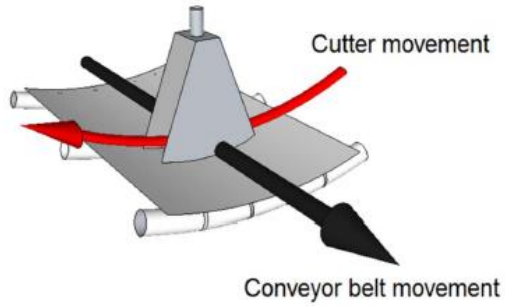
Estimated distribution of errors in coal testing

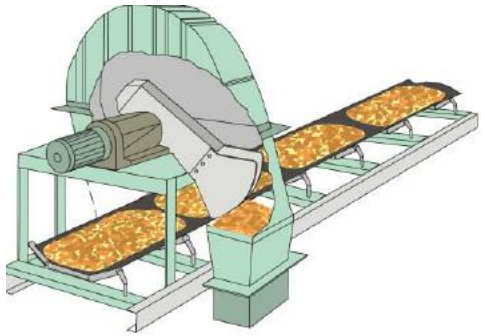


Sampling methods

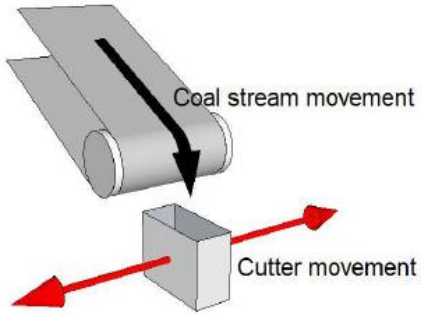
Site and port

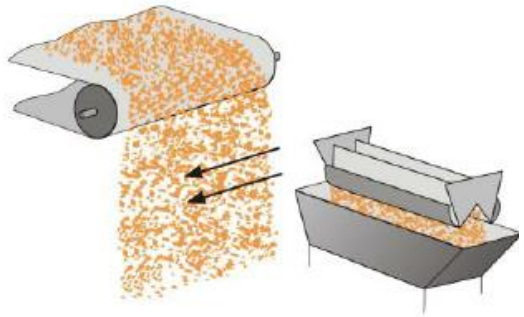
Cross belt



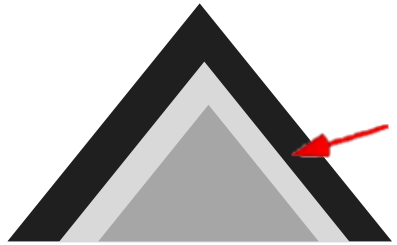


Falling stream

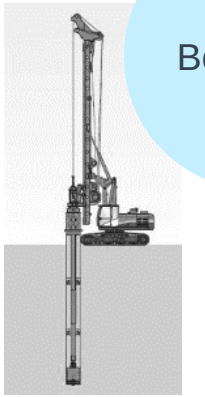




Stockpile sampling



Coal sampling



Bore core

Production sampling

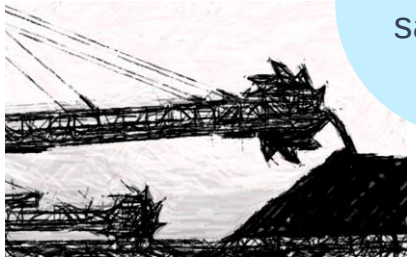
Coal mining

CHPP output sampling
Train load out sampling

CHPP and mine stockpile

Rail to Port

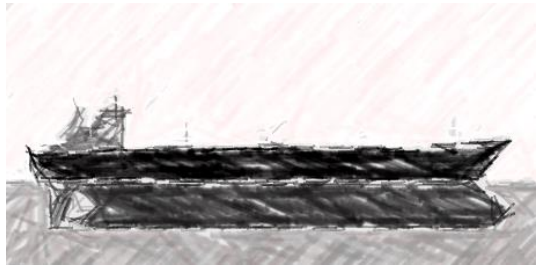
Train discharge sampling (ISO)



Port stockpile

Vessel sampling (ISO)

Vessel loading



Ship to customer

Sampling a vessel

Inbound

- Sample taken as train unloads
- Lab collect, analyse and certify
- Typically not a full cargo
- Invoiced and quality adjustment based on these results

Outbound

- Sample taken as vessel loads
- Lab collect, analyse and certify
- Additional moisture added due to rain and dust management +TM ~1% = reduction in NCV of ~75kcal/kg
- Typically a full cargo or hold
- Invoiced and quality adjustment based on these results

Port

50 mm topsize

Primary sample
1,300 tonnes per cape size vessel

Sub sample
93 tonnes per cape size vessel

Crush to 11.2 mm

Sub sample
4,600 kg per cape size vessel

Sub sample
465-840 kg per cape size vessel

12-14 samples sent to the lab 11.2 mm

Lab

12-14 samples received 11.2 mm

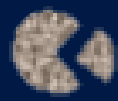
Sub sample
6 kg

Crush to 4 mm

Sub sample
0.3 kg

Mill to 212 µm (ISO) 250 µm (ASTM

Sub sample
60 g



Testing and Analysis

Why?

- **Customers** have different **quality requirements** depending on the intended use
- **Premiums**, **penalties**, or rejection limits can be based on certain parameters
- **Contract relies on** accuracy of the analysis to achieve a **fair result** for the buyer and seller
- Mine **exploration** and **production** coal quality analysis is essential to **value resource**/reserve or for **production planning**

How?

- Each test has a **standard that sets out the method** to be followed (ISO, ASTM, BS and AS). Whitehaven contracts typically follow ISO standards
- There are **hundreds of different tests** only a selection of the thermal coal tests will be discussed in this presentation
- **Testing** undertaken at **independent** laboratories

What?

Physical

- Total Moisture ISO 589
- Fixed Carbon ISO 17246
- Ash ISO 1171
- Ash Analysis
- Ash Fusion Temperature ISO 540
- Volatile Matter ISO 561 / ASTM D3175
- Hardgrove Grindability Index
- Sizing
- Crucible Swelling Numbers

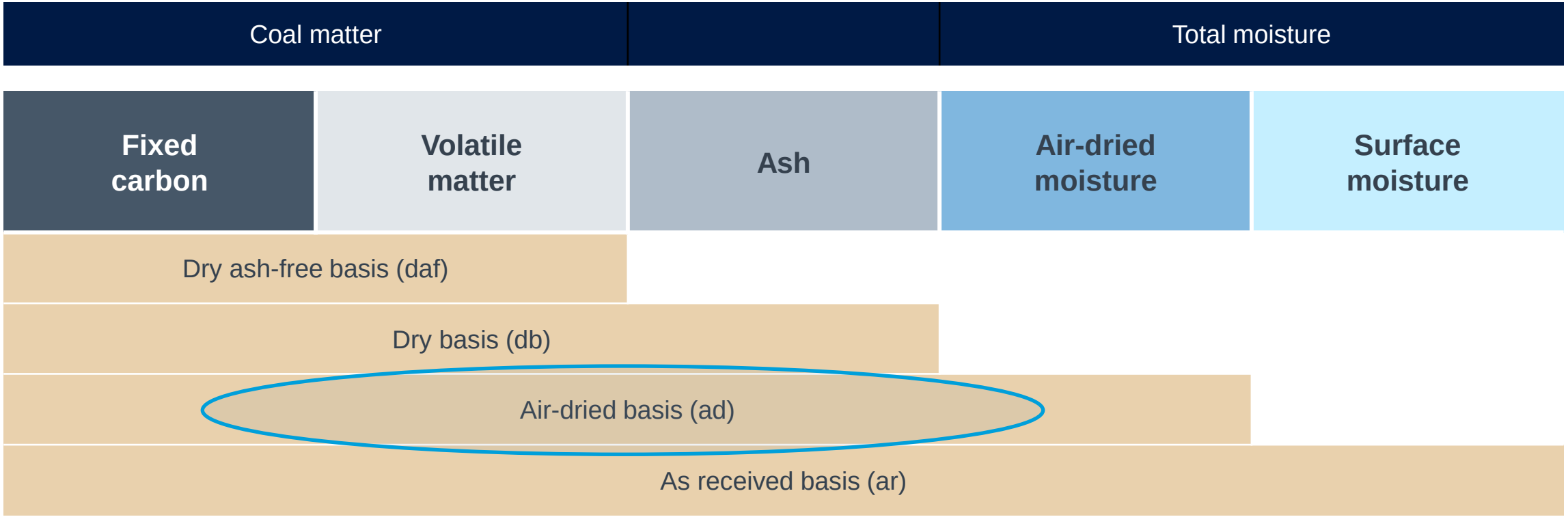
Chemical

- Proximate Analysis Inherent Moisture ISO 11722
- Calorific Value
- Ultimate Analysis
- Elements in Coal

Non-destructive

- XRD
- Apparent Relative Density
- Lithotypes
- Petrographic tests

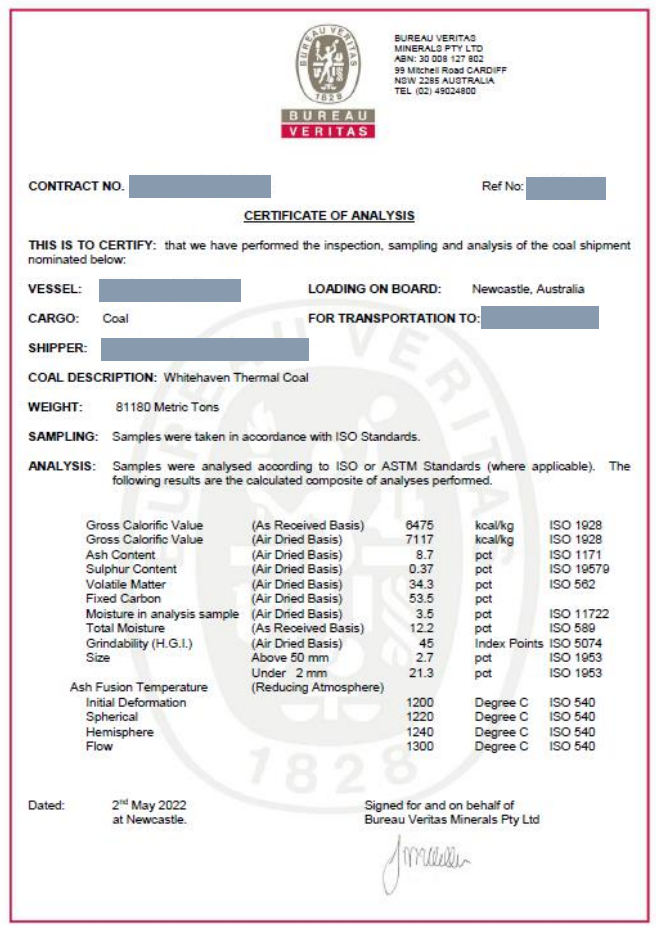
Different bases



In the lab and at Whitehaven most analysis is done on air dried basis.
Power stations fire coal on an as received basis only.

Quality

Certificates



BUREAU VERITAS
MINERALS PTY LTD
ABN: 30 008 127 802
99 Mitchell Road CARDIFF
NSW 2285 AUSTRALIA
TEL (02) 49024800

CONTRACT NO. [redacted] Ref No: [redacted]

CERTIFICATE OF ANALYSIS

THIS IS TO CERTIFY: that we have performed the inspection, sampling and analysis of the coal shipment nominated below:

VESSEL: [redacted] **LOADING ON BOARD:** Newcastle, Australia

CARGO: Coal **FOR TRANSPORTATION TO:** [redacted]

SHIPPER: [redacted]

COAL DESCRIPTION: Whitehaven Thermal Coal

WEIGHT: 81180 Metric Tons

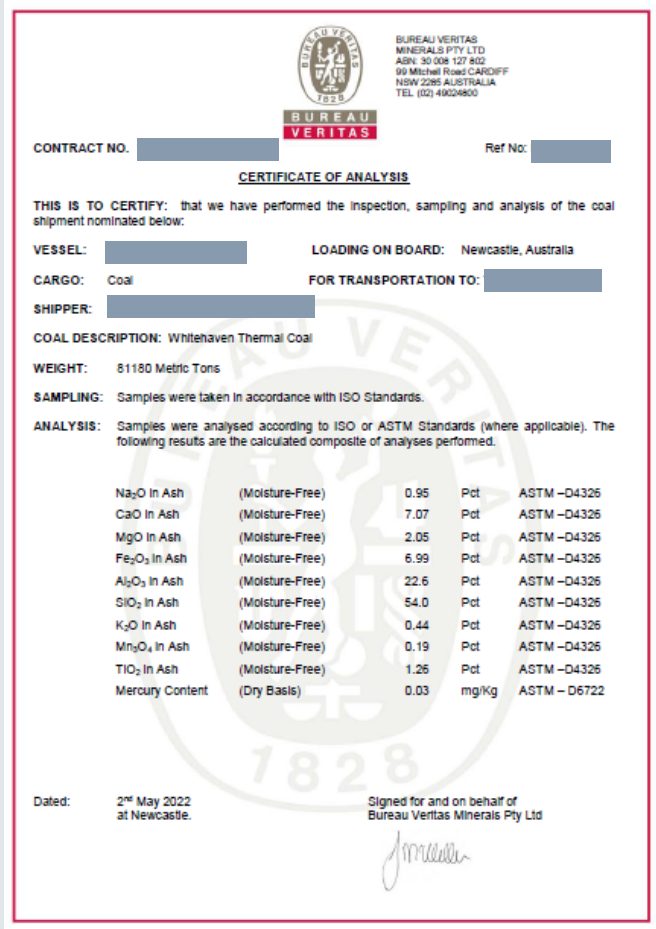
SAMPLING: Samples were taken in accordance with ISO Standards.

ANALYSIS: Samples were analysed according to ISO or ASTM Standards (where applicable). The following results are the calculated composite of analyses performed.

Gross Calorific Value	(As Received Basis)	6475	kcal/kg	ISO 1928
Gross Calorific Value	(Air Dried Basis)	7117	kcal/kg	ISO 1928
Ash Content	(Air Dried Basis)	8.7	pct	ISO 1171
Sulphur Content	(Air Dried Basis)	0.37	pct	ISO 19579
Volatile Matter	(Air Dried Basis)	34.3	pct	ISO 562
Fixed Carbon	(Air Dried Basis)	53.5	pct	
Moisture in analysis sample	(Air Dried Basis)	3.5	pct	ISO 11722
Total Moisture	(As Received Basis)	12.2	pct	ISO 589
Grindability (H.G.I.)	(Air Dried Basis)	45	Index Points	ISO 5074
Size	Above 50 mm	2.7	pct	ISO 1953
	Under 2 mm	21.3	pct	ISO 1953
Ash Fusion Temperature	(Reducing Atmosphere)			
Initial Deformation		1200	Degree C	ISO 540
Spherical		1220	Degree C	ISO 540
Hemisphere		1240	Degree C	ISO 540
Flow		1300	Degree C	ISO 540

Dated: 2nd May 2022 at Newcastle.

Signed for and on behalf of Bureau Veritas Minerals Pty Ltd



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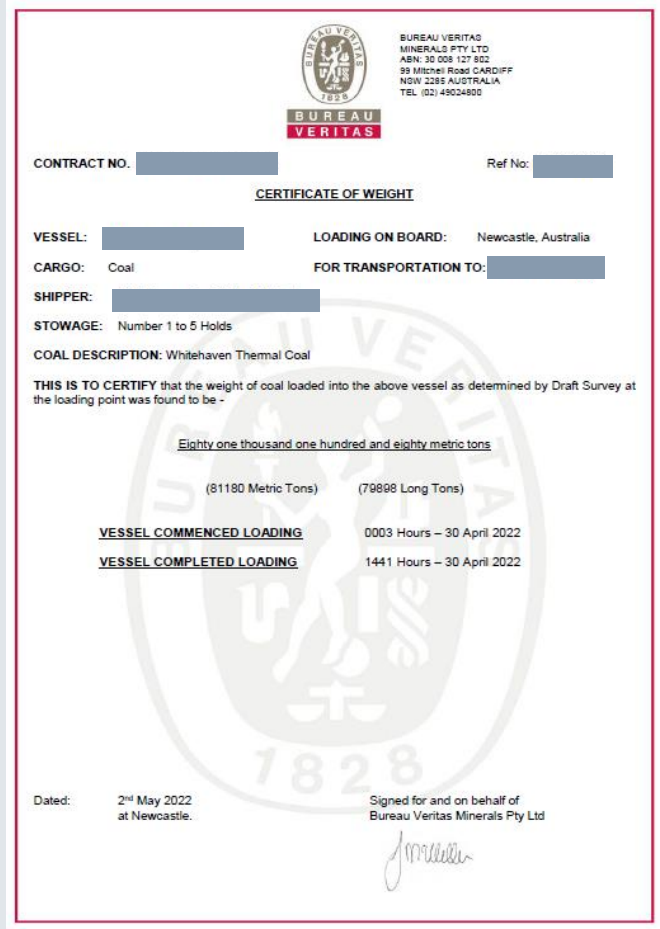
Na_2O in Ash	(Moisture-Free)	0.95	Pct	ASTM –D4326
CaO in Ash	(Moisture-Free)	7.07	Pct	ASTM –D4326
MgO in Ash	(Moisture-Free)	2.05	Pct	ASTM –D4326
Fe_2O_3 in Ash	(Moisture-Free)	6.99	Pct	ASTM –D4326
Al_2O_3 in Ash	(Moisture-Free)	22.6	Pct	ASTM –D4326
SiO_2 in Ash	(Moisture-Free)	54.0	Pct	ASTM –D4326
K_2O in Ash	(Moisture-Free)	0.44	Pct	ASTM –D4326
Mn_3O_4 in Ash	(Moisture-Free)	0.19	Pct	ASTM –D4326
TiO_2 in Ash	(Moisture-Free)	1.26	Pct	ASTM –D4326
Mercury Content	(Dry Basis)	0.03	mg/Kg	ASTM – D6722

Dated: 2nd May 2022 at Newcastle.

Signed for and on behalf of Bureau Veritas Minerals Pty Ltd



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NSW 2285 AUSTRALIA
TEL (02) 49024800

CONTRACT NO. [redacted] Ref No: [redacted]

CERTIFICATE OF WEIGHT

VESSEL: [redacted] **LOADING ON BOARD:** Newcastle, Australia

CARGO: Coal **FOR TRANSPORTATION TO:** [redacted]

SHIPPER: [redacted]

STOWAGE: Number 1 to 5 Holds

COAL DESCRIPTION: Whitehaven Thermal Coal

THIS IS TO CERTIFY that the weight of coal loaded into the above vessel as determined by Draft Survey at the loading point was found to be -

Eighty one thousand one hundred and eighty metric tons

(81180 Metric Tons) (79898 Long Tons)

VESSEL COMMENCED LOADING 0003 Hours – 30 April 2022

VESSEL COMPLETED LOADING 1441 Hours – 30 April 2022

Dated: 2nd May 2022 at Newcastle.

Signed for and on behalf of Bureau Veritas Minerals Pty Ltd

Repeatability and reproducibility

Maximum acceptable difference between results

Repeatability

Analysis is performed:

- Within a single laboratory
- On the same sample
- Using the same apparatus

Reproducibility

Analysis is performed:

- Between laboratories
- On a representative sample taken after the last stage of the reduction process.

Quality		AS	Repeatability (r)	Reproducibility (R)	Reporting
Gross CV (MJ/kg a.d.)		1038.5	0.13	0.3	0.01
Chlorine (% a.d.)		1038.8.1	0.01	0.02	0.01
CSN		1038.12.1	—	1	1/2
Ash composition (% Na_2O)		1038.14.1	0.05	0.2	0.01
Ash fusion (Def. °C)	**<1,300°C** **≥1.300°C**	1038.15	30 50	80 150	10
Abrasion index	**≤20** **>20**	1038.19	2 10% of mean	— —	1 1
HGI		1038.20	2	5	1
Size (mm)		3881			

0.13 MJ/kg = 31 kcal/kg

0.3 MJ/kg = 71.6 kcal/kg

Total moisture – ISO 589

Physical analyses

Total Moisture (TM) is the amount of moisture present in coal, including both surface moisture and inherent moisture.

Testing

- Visibly wet samples are air-dried (≤40°C) first to determine free moisture
- Drying in air oven at 105-110°C. Lower-rank coals are dried under nitrogen
- The sample is weighed after 1.5 hours and each subsequent ½ hour until steady state, gravimetric loss from a sample at 105-110°C assumed to be water

Why do we do this test?

TM of coal affects its combustion and pulverising temperature, boiler design size for thermal application & coking time and bulk density for coke making. Also affects handling characteristics.

IM sample:	Size	Weight	Time
	-11.2 mm	1 kg	Until dry 1.5 hrs +

Ash – ISO 1171

Coal does not contain ash, the ash in coal refers to the inorganic residue left behind after coal is burned. It consists of minerals, metals, and other incombustible materials present in the coal.

Testing

- Fully combusting sample at 815°C in air
- Weighed once cooled and the mass loss is referred to as Ash %

Ash sample:

Size	Weight	Time
-212 um	1 gram	4 hrs

Why do we do this test?

In a power station ash affects combustion efficiency, high ash content can lead to reduced combustion efficiency, lower heat output, and increased particulate emissions.

For coking coal impacts slag volumes and coke reactivity (dependent on ash chemistry)

Ash crucible and oven

Volatile matter – ISO 562 / ASTM D3175

Volatile matter in coal refers to the combustible gases and hydrocarbons that are released as vapors when coal is heated in the absence of oxygen.

Testing

- (ISO) A silica crucible with lose lid heated to 900°C in oxygen-free atmosphere for 7 minutes
- (ASTM) 950°C in Pt or Ni-Cr crucible with a close-fitting lid
- The loss in mass after heating less the IM (ad) equals the VM%, determines inorganic and organic volatiles together

VM sample:

Size	Weight	Time
-212 um	1 gram	25 mins

Why do we do this test?

In a power station, Volatile Matter provides an indication of the ease of combustibility of coal. The presence of volatile matter influences the ignition, flame stability, and burnout characteristics of coal.

For coking coal Volatile Matter impacts coke yield, coke oven gas production.

Volatile Matter is an integral part of coal classification systems and can be used to determine the rank.

ASTM D3175 vs ISO 562

The ASTM test generally produces higher Volatile Matter numbers by 1-2% (decreasing difference with increasing rank). The prime reason for this is higher temperature achieved by the ASTM test. Also, the ASTM test has significantly inferior repeatability limits:

ASTM = 0.5%, ISO = 0.3%.

Calorific Value

Chemical analyses

Calorific Value or Specific Energy is the amount of heat that will be liberated per unit mass of coal, when the coal is burnt.

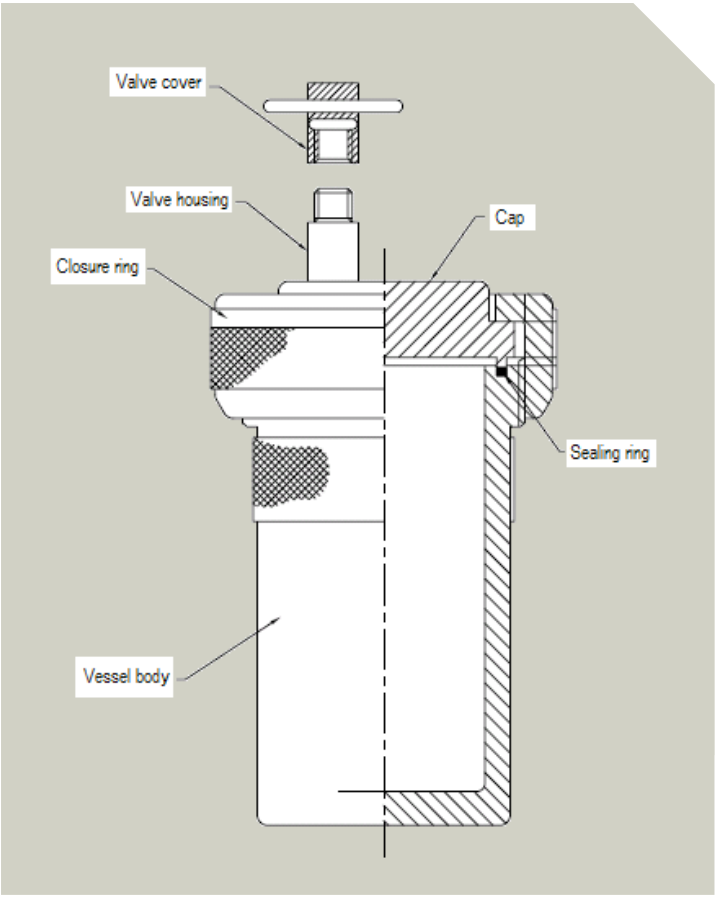
Testing

- The heat energy released from coal combustion can be determined by burning a weighed sample in pressurised oxygen atmosphere in a pressure vessel “bomb calorimeter”, while observing the change in temperature of the surrounding water jacket
- Measures gross calorific value at constant volume which can be converted to different basis. GCV (ar), GCV (ad), GCV (db), GCV (daf) and NCV (ar)
- Calorific value can be reported as either MJ/kg, kcal/kg or Btu/lb

CV sample:

Size	Weight	Time
-212 um	1 gram	15 mins

	MJ/kg	kcal/kg	Btu/lb
MJ/kg	—	238.846	429.923
kcal/kg	0.004187	—	1.8
Btu/lb	0.002326	0.5555	—



Crucible Swelling Number (CSN) – ISO 501

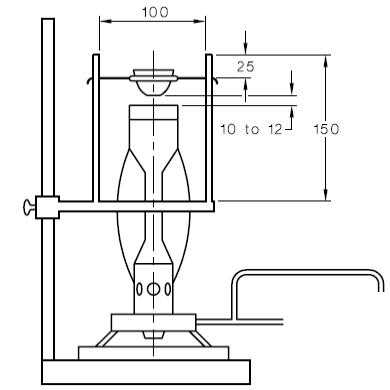
Empirical determination of the coking properties of coal.

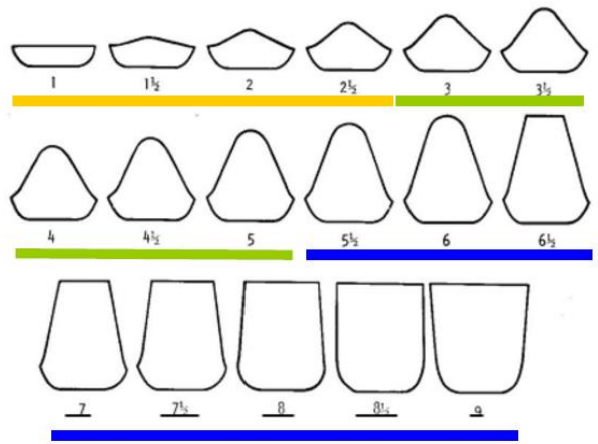
Testing

- Coal sample heated by flame to 820°C in a covered crucible under standard conditions for 2.5 min
- Coke button is compared to a series of standard profiles and given a number between 0 and 9

CSN sample:

Size	Weight	Time
-212 um	1 gram	2.5 mins





Potential Coke Quality

PCI/Thermal Coal

Weak Coking Coal

Coking Coal

Properties of interest for coking coal users

Chemical properties

- **Moisture Content** affects cargo pro-rata weight; coke oven packing density; efficiency /productivity; indicative of handling (slumps, hang-ups); dust issues; linked to TML
- **Volatile Matter** indicative of coke quality (low-vol has potential to make strongest coke); affects yield and coke ovens gas; suggestive of oven wall pressure risks.
- **Ash Content** affects slag volume (15% of BF slag from coal) and coke reactivity.
- **Ash Chemistry** usually discussed by Alkali content (Na + K) and/or Basicity index (Fe +Ca +Mg +Na +K) / (Si + Al). Affects reactivity, slag composition (flux requirements), refractory degradation.
- **Impurities** of Sulphur & Phosphorous, which make steel weak and must be removed; affects productivity and cost. About 90% of S in hot metal comes from coal, rest comes from iron ore. Most P in hot metal comes from iron ore, ~20% comes from coal.

Plastic properties

Petrographic properties

Properties of interest for coking coal users

Chemical properties

Plastic properties

- **CSN** (Crucible Swell Number) or FSI (Free Swelling Index). Indicator of coking potential: CSN <3 indicates PCI or thermal coal; 3-5 indicates weak coking coal; 5½-9 potential to be a HCC.
- **Maximum Fluidity** how viscous coal is when molten. Measured in dial divisions per minute (ddpm) – how many times the stirrer inside the formed coal bed spins under constant torque load. Interpretation of results depends on coal rank.
- **Dilatation** measures expansion of a coal cylinder. On average, weaker coking coals have dilatation ~50%; stronger CCs ~100%.
- **Chinese G** measures ability of a coking coal to "carry" poorer quality coal. A "button" of coke made from coal mixed with 20% of a standard anthracite. Button is tumbled and amount of fines generated measured. Used to calculate G number. Typically range between 20-100, with higher values indicating a better quality.

Petrographic properties

Properties of interest for coking coal users

Chemical properties

Plastic properties

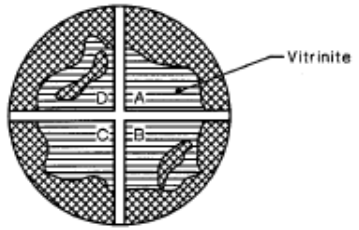
Petrographic properties

- **Vitrinite Reflectance** is most definitive measure of coal rank – measures light that reflects from vitrinite component of coal. Measured under microscope using calibrated light source. Either measured as “Maximum” or “Random”. Normally refer to “Mean Maximum Reflectance of Vitrinite (in oil)” or MMR, typically +0.07 points above Random reflectance value. Coking coals MMR 0.65 – 1.90% (high-vol to low-vol).
- **Vitrinite Distribution** or “V-Steps” describes range of vitrinite reflectance; not all vitrinite in a coal has exactly the same MMR. Multiple peaks or ‘long tails’ in a vitrinite distribution indicate blending or presence of heat affected material.
- **Maceral Analysis** measures different macerals types (Vitrinite, Inertinite, Liptinite and their many sub-categories). Performed under microscope by taking at least 500 visual observations. Maximum coke strength occurs when coal is 60-70% vitrinite.

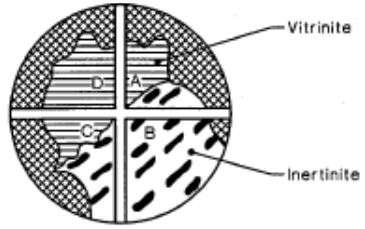
Maceral analysis

ISO 7404-3, ASTM D2799

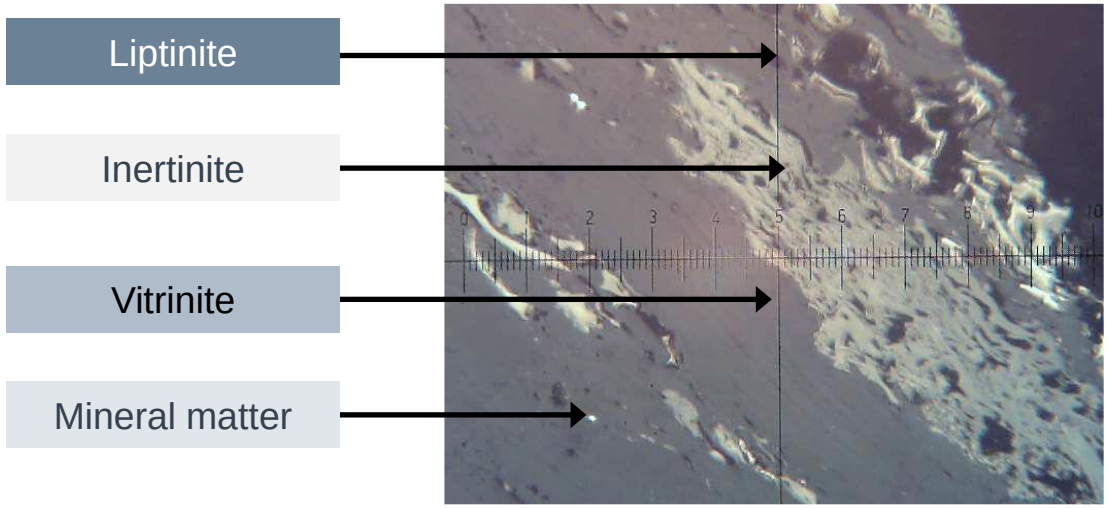
- Coal samples crushed to -850µm and set in an epoxy and resin mixture and ground to a polished surface
- The petrographic block is placed under a microscope on a moving stage arranged to step across the surface of the block in a rasta pattern.
- The coal material under the cross-lines of the microscope are identified by a trained petrographer.
- Once a sufficient number of points are identified (min 500 to be statistically valid), a volume percent concentration can be determined.



(a) Normal case—Count point A (vitrinite)



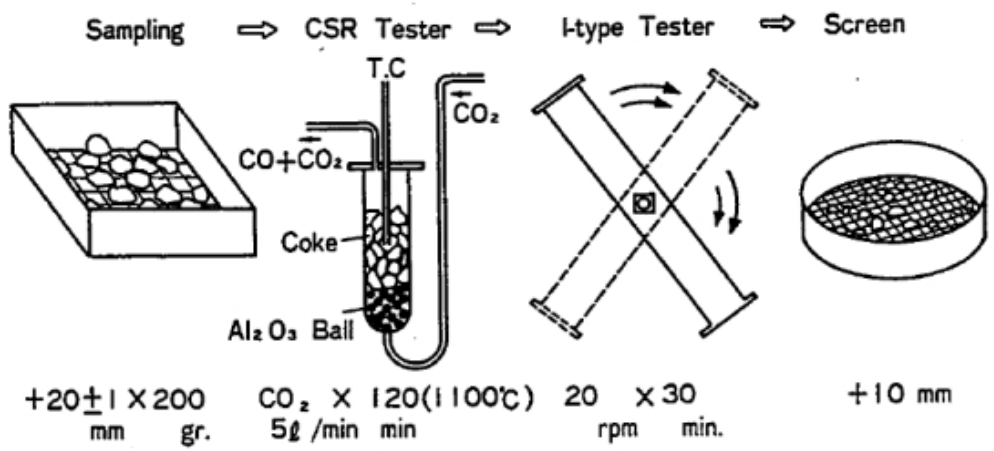
(b) Boundary case—Count point B (inertinite)



“CSR” – Coke Strength after Reaction

One of the popular coke strength tests that is linked to Blast Furnace productivity

200g sample of 20mm coke is heated at 1100°C under carbon dioxide for 2 hours.



CRI = percent weight loss after reaction
CSR = percent weight of reacted and tumbled coke

WHITEHAVEN COAL

3

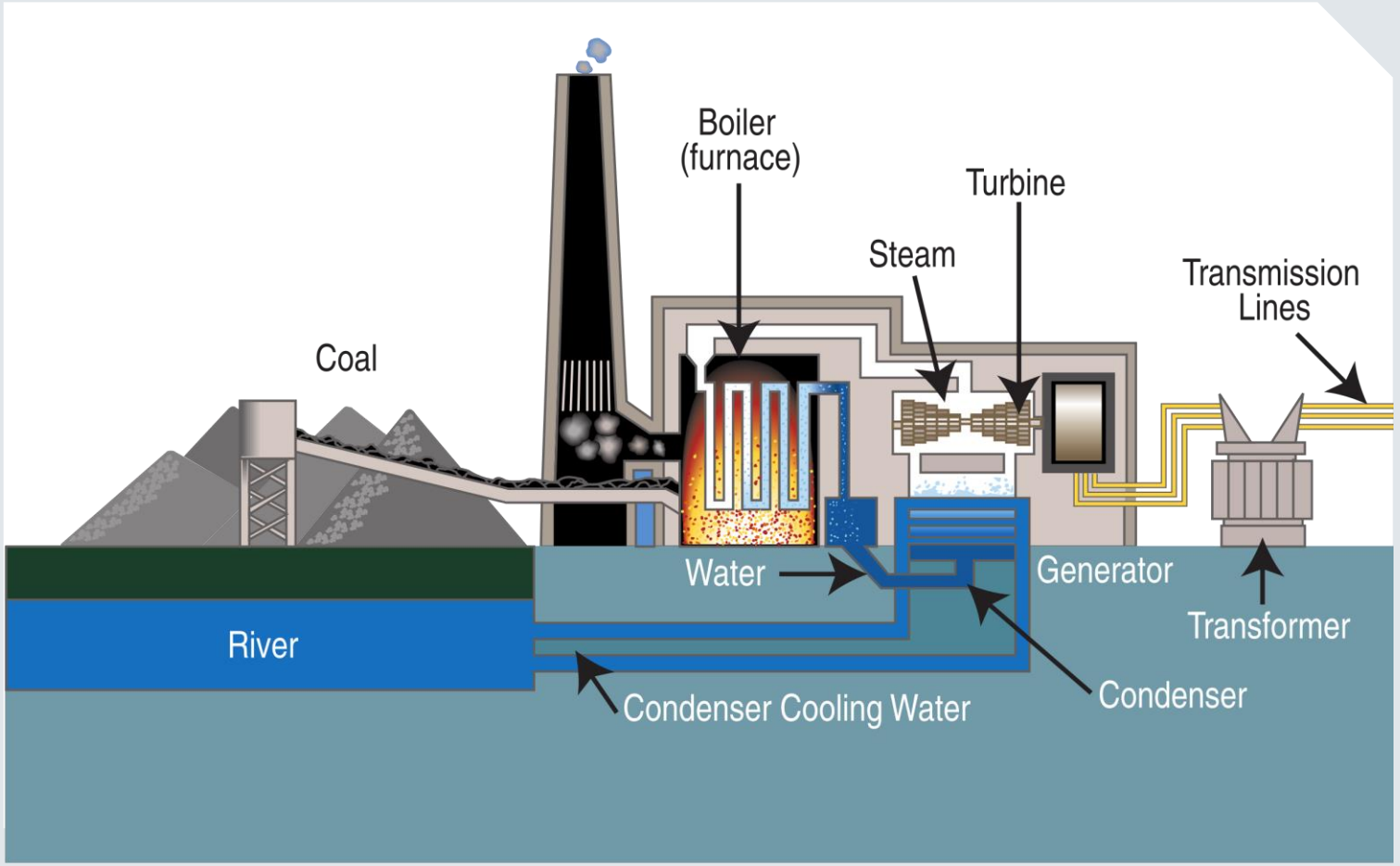
Thermal coal and power generation

Coal fired power station

Key unit operation

- Coal handling plant
- Pulverisers
- Combustion (Boiler)
- Steam circuit (Boiler + Turbine + Condenser)
- Emissions control
- Ash disposal system

Steam Circuit and Combustion circuits never come into physical contact contact.

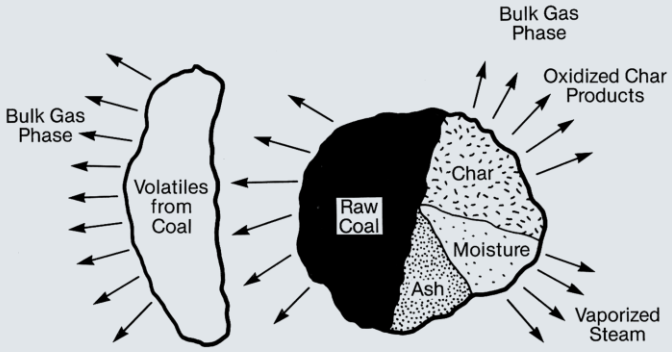


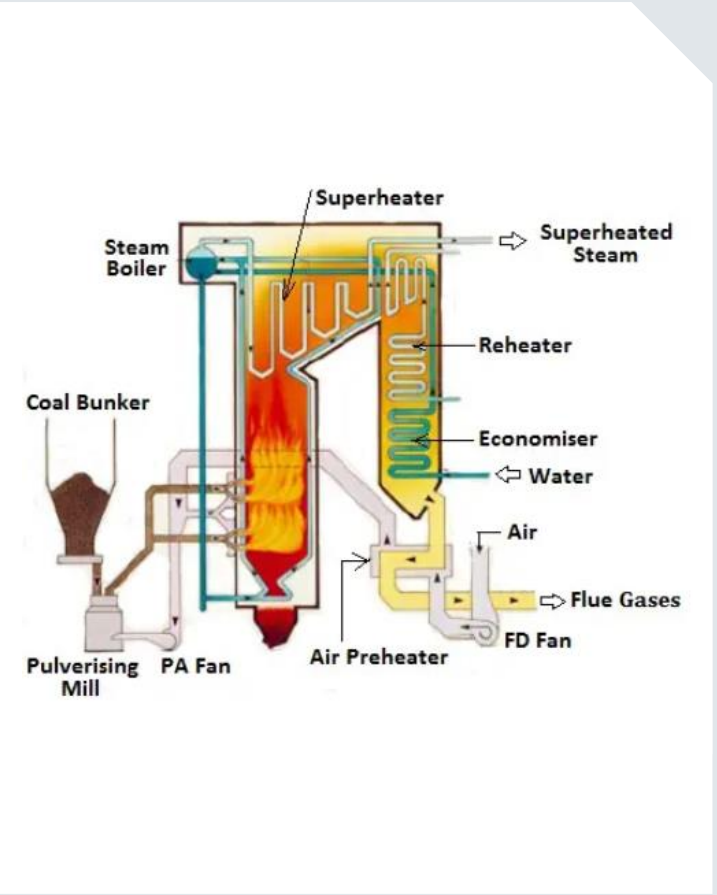
The boiler

- The boiler converts thermal energy in the coal to steam energy
- The boiler is fully enclosed with water-filled tubes or water walls
- The combustion zone contains the burning coal which transfers heat (radiant heat) and turns the water into superheated steam
- There are 4 main types of designs for boiler firing systems
- Temperature in radiative zone in the boiler ~1500°C
- Higher NCV = less coal required to produce the same quantity of steam

Combustion – coal particle

- VM burns off first, left with char and ash particle
- The finer the particle the quicker it burns
- 4-5 seconds in the radiant section





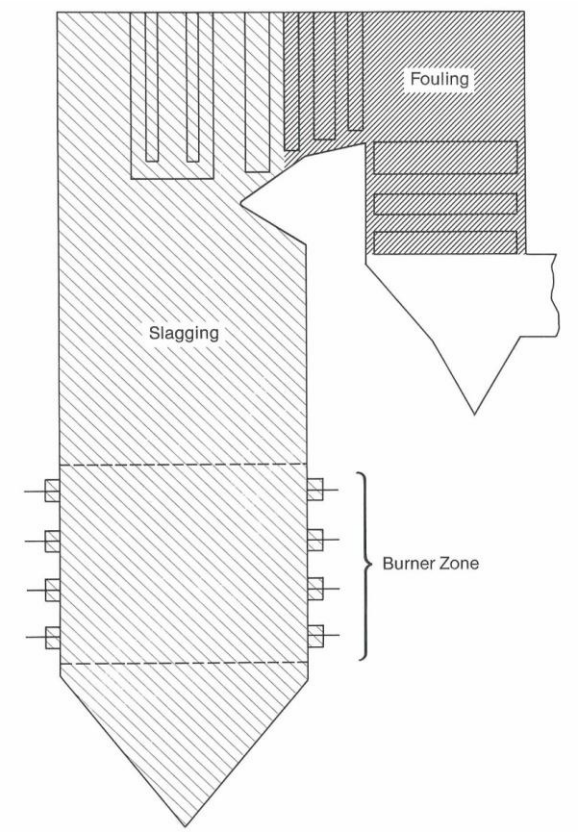
Slagging and fouling

Slagging and fouling occurs due to coal properties, boiler design, and boiler operation. High levels of Fe_2O_3, CaO, MgO, Na_2O, K_2O in Ash.

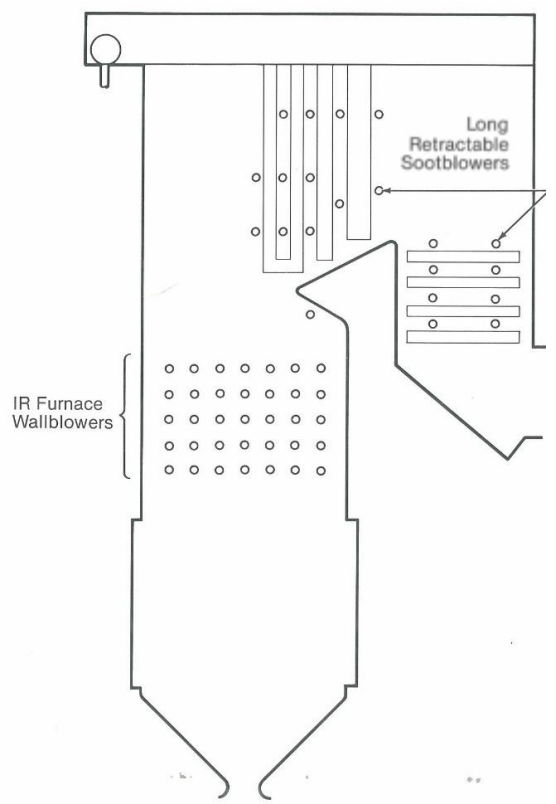
- Impacts heat transfer process in the radiant section
- Creates lumps in the bottom of the furnace causing damage and blockages
- Interference with burner flow patterns
- Excessive soot-blowing

- Low steam temperature
- Excessive soot-blowing
- Poor gas flow distribution (erosion)
- Compromised air-heater performance (blockages, poor heat transfer)

Slagging and fouling

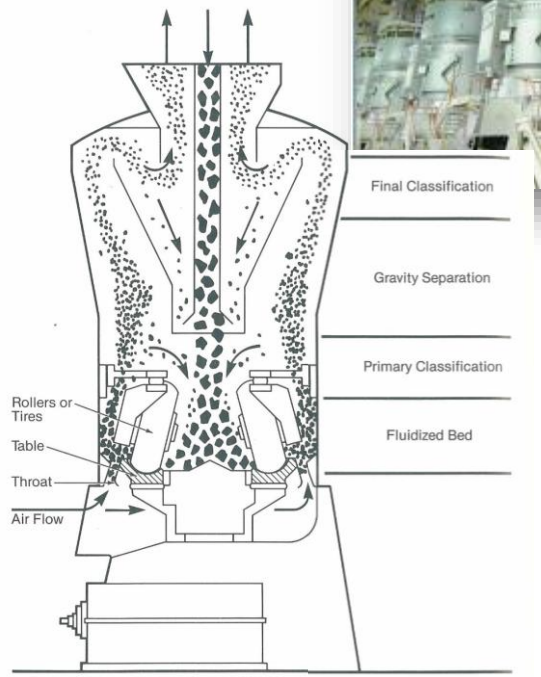


Sootblower arrangement

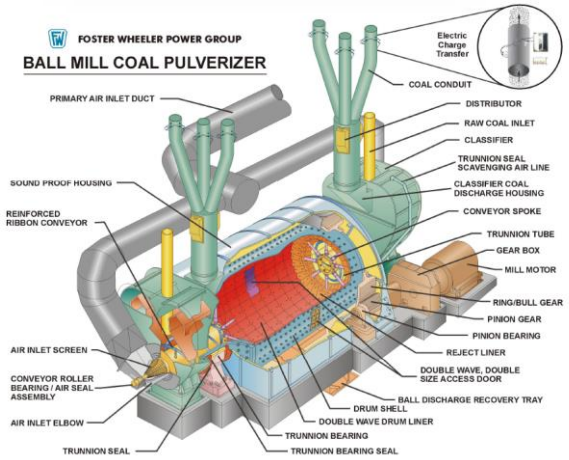


Pulverisers (Mills)

Vertical Spindle Mill



Ball Mill



There are 2 main types of pulverizes:

- Vertical Spindle Mill – most common and economical
- Ball Mill

The coal mill/pulveriser prepares the coal to facilitate combustion.

- Dry (Primary Air)
- Classify
- Transport

Typically 4-5 mills in a power station.

HGI is believed to impact the “grindability”

Steam Circuit

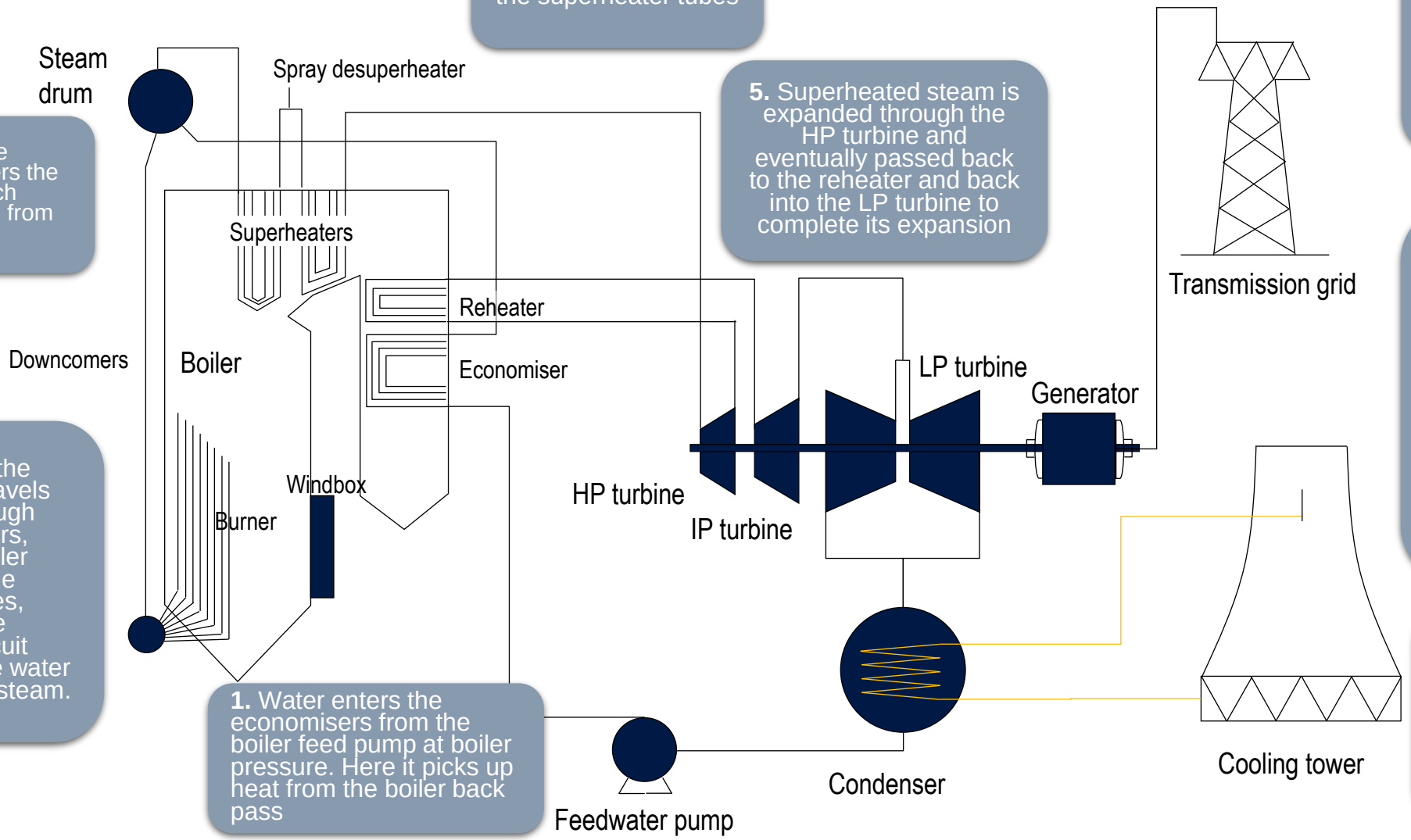
4. Saturated steam is separated from water in the steam drum and superheated in the superheater tubes

5. Superheated steam is expanded through the HP turbine and eventually passed back to the reheater and back into the LP turbine to complete its expansion

2. Water from the economiser enters the steam drum which separates steam from water

3. Water from the steam drum travels circulates through the downcomers, outside the boiler and back up the water wall tubes, returning to the drum. This circuit evaporates the water into saturated steam.

1. Water enters the economisers from the boiler feed pump at boiler pressure. Here it picks up heat from the boiler back pass



Generator

The turbine creates energy which is transferred in the generator and stored for use in the transmission grid.

Cooling Tower

Steam is cooled back to water and sent back to the condenser and into the steam circuit

- Evaporative forced draft
- Evaporative natural draft
- Air forced draft
- Air natural draft
- Sea/river water

Condenser

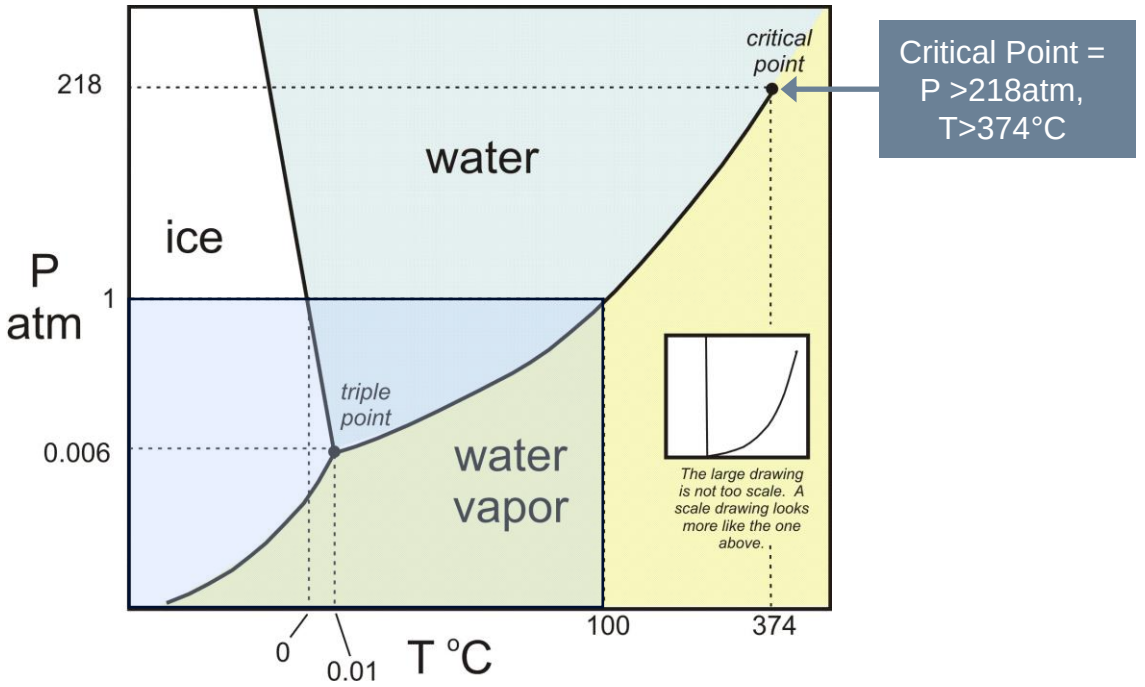
Cools steam from the turbine into water

Subcritical, supercritcal and ultrasupercritical?

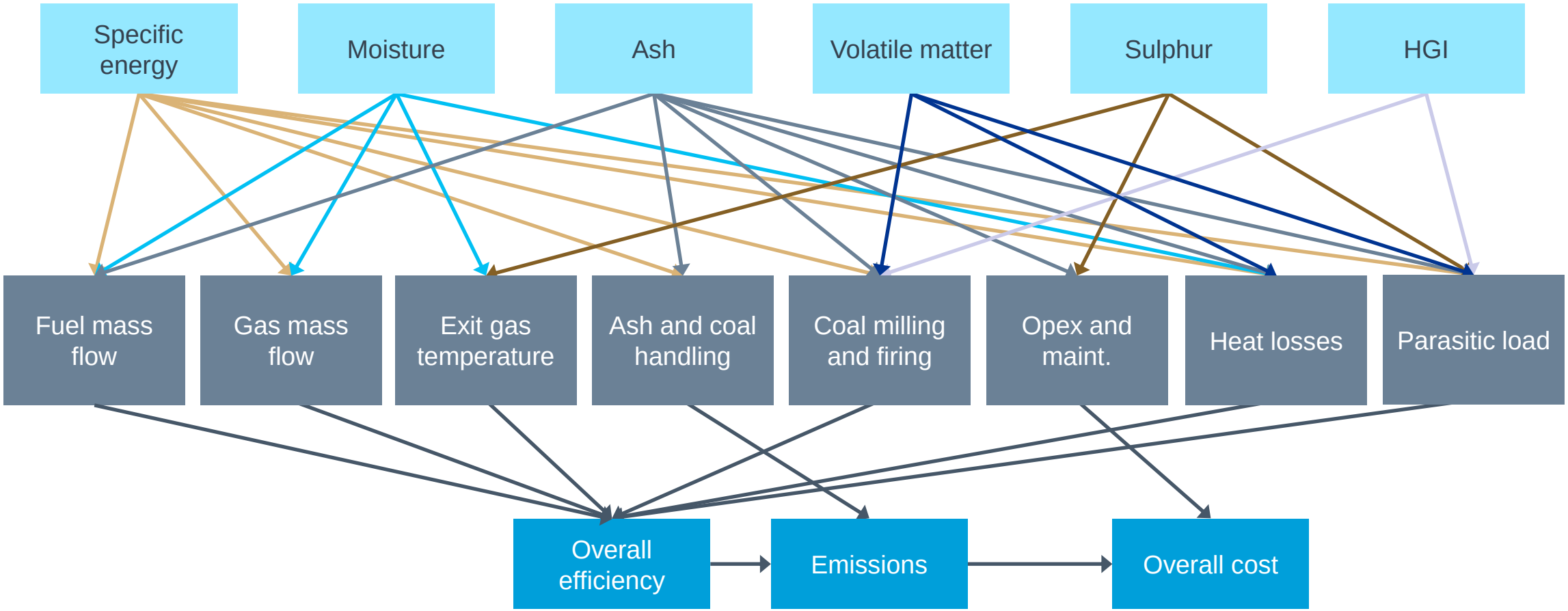
Subcritical: less than critical pressure of 220 bar (218 atm)

Supercritical: greater than the critical temperature and pressure (218 atm, 374°C)

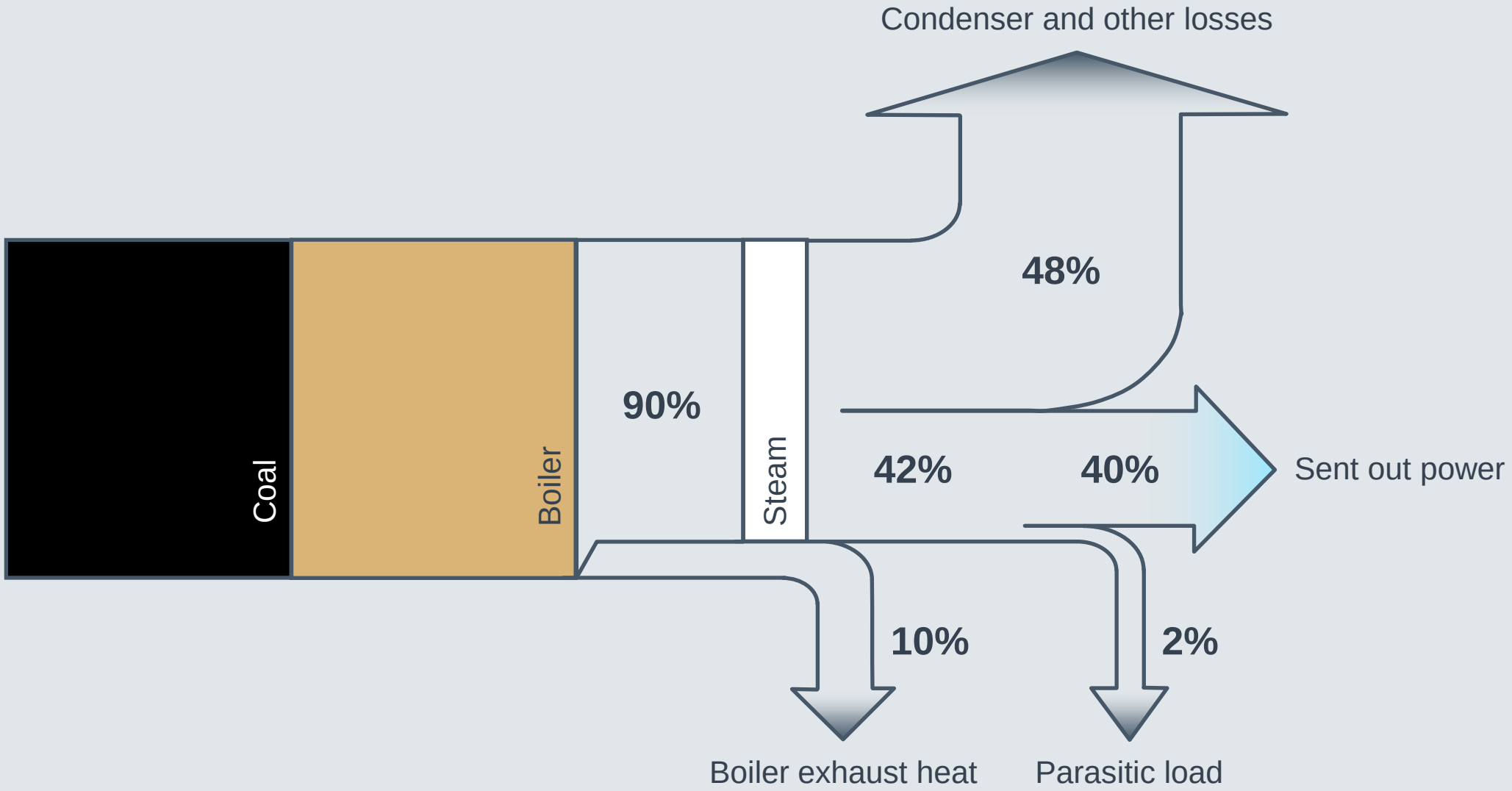
Ultrasupercritical: extra high pressure and temperature (nominally >250 atm, 650°C)



Coal properties and power plant performance

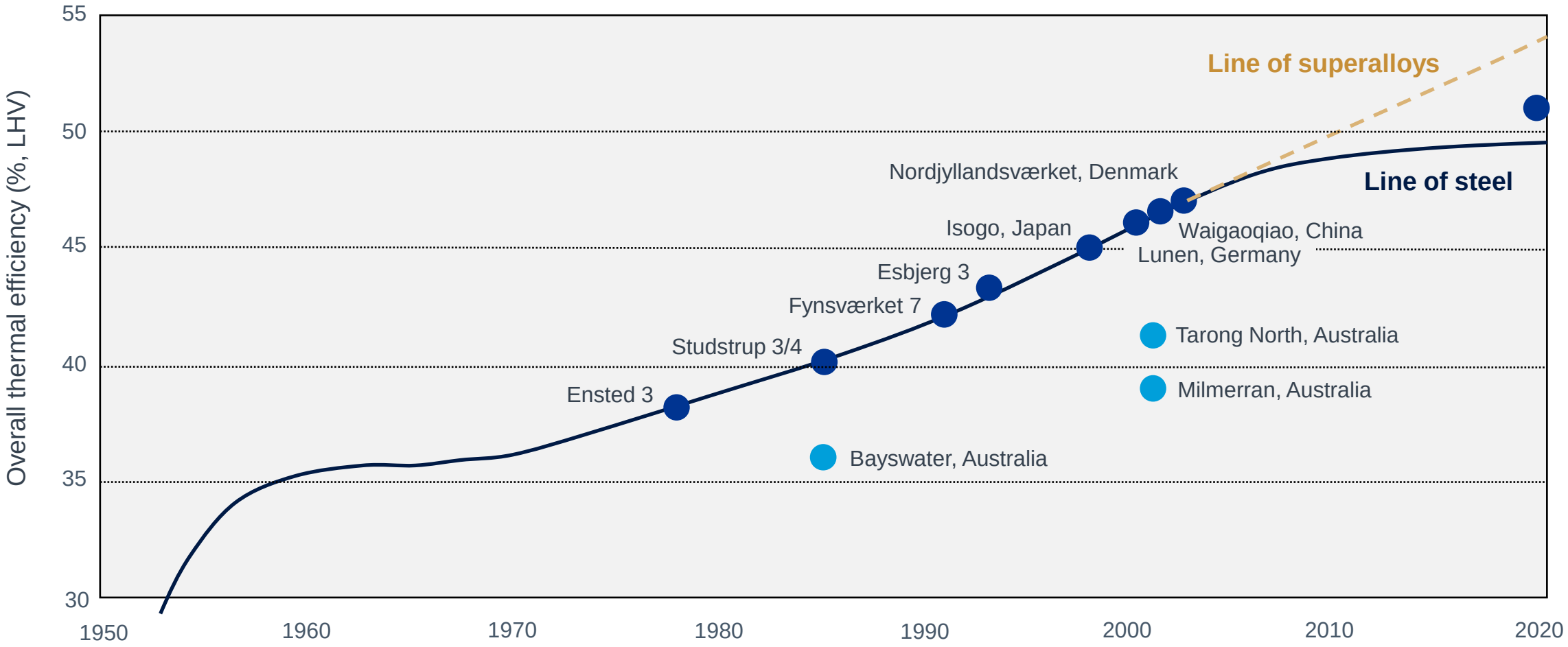


Power plant energy balance



Increase in thermal efficiency over time

Mainly attributable to increase in capability of materials



WHITEHAVEN COAL

4

Met coal and steel making

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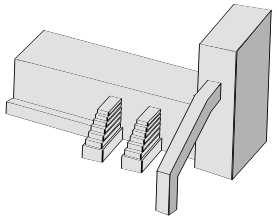
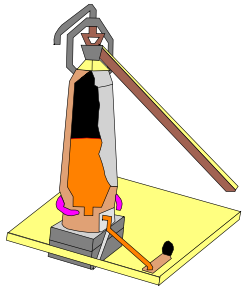
Why do we need coking coal?



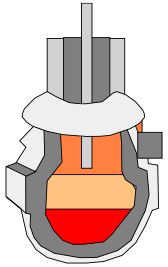
Cokemaking

Coking coal is needed to produce **coke**



Ironmaking

Coke + **iron ore** is used to produce **iron**



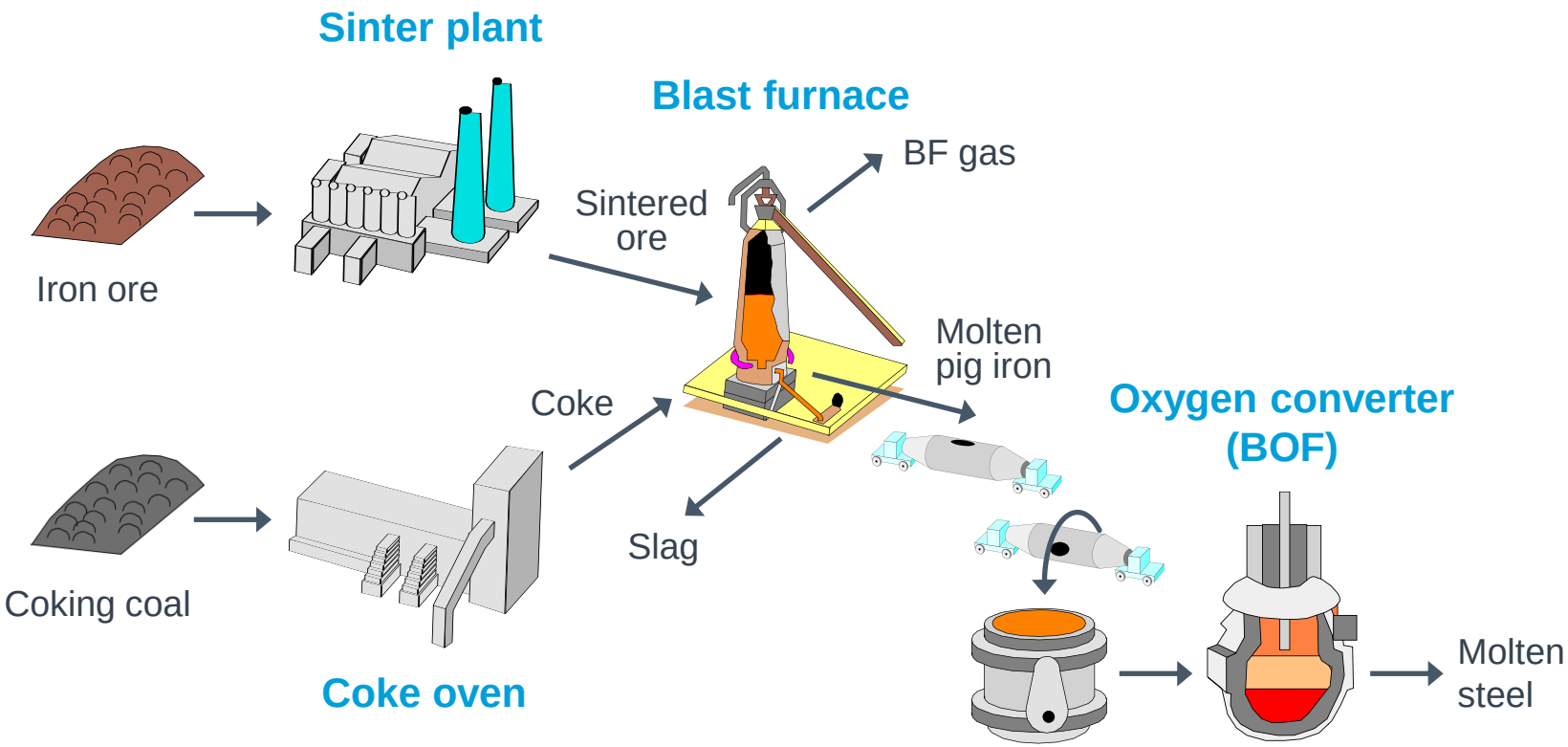
Steelmaking

Iron is needed to produce **steel**

(via the Integrated Steelmaking process)

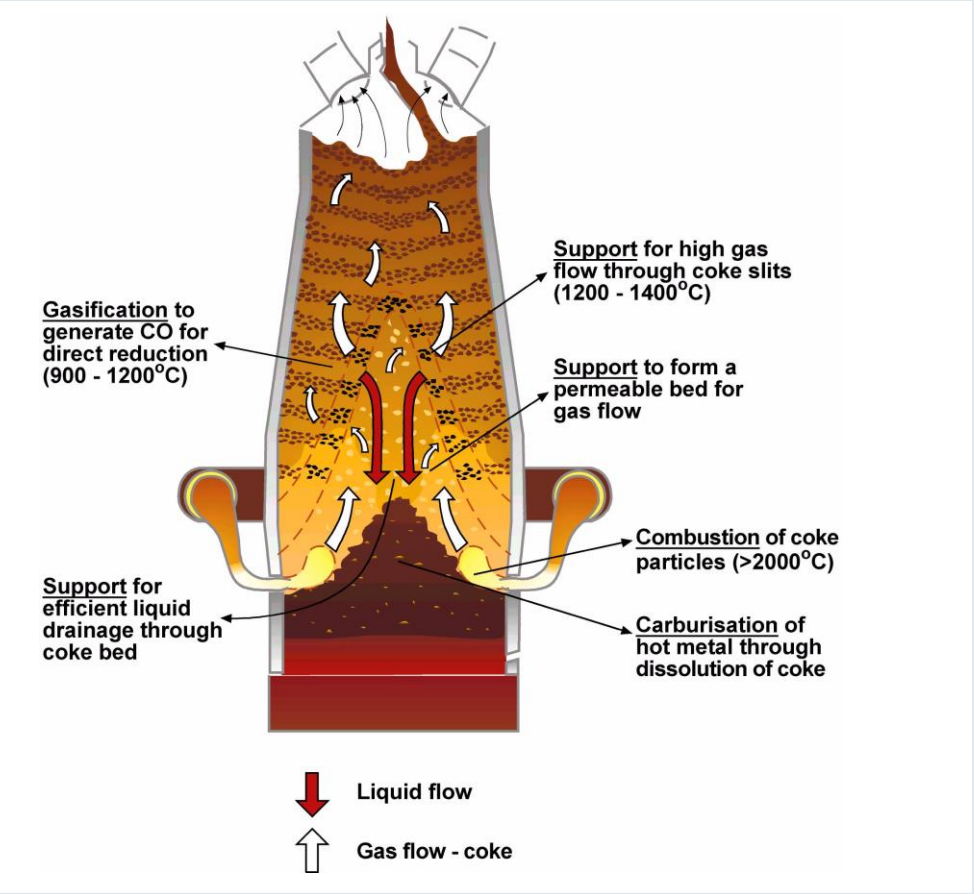
Integrated steel mill

- An integrated steel mill has all the functions for primary steel production: iron making, steelmaking, casting and rolling. Typically has sinter-making and coke-making too, although these can be procured.
- The principal raw materials for an integrated mill are: iron ore, limestone and coking coal (or coke).



Coke in the blast furnace

To a blast furnace, coke quality is more important than ferrous material quality



Four roles of coke

1. Heat source
2. CO reductant source
3. Carburising agent
4. Permeable bed

   Can only be achieved with coke

A good coke is one that:

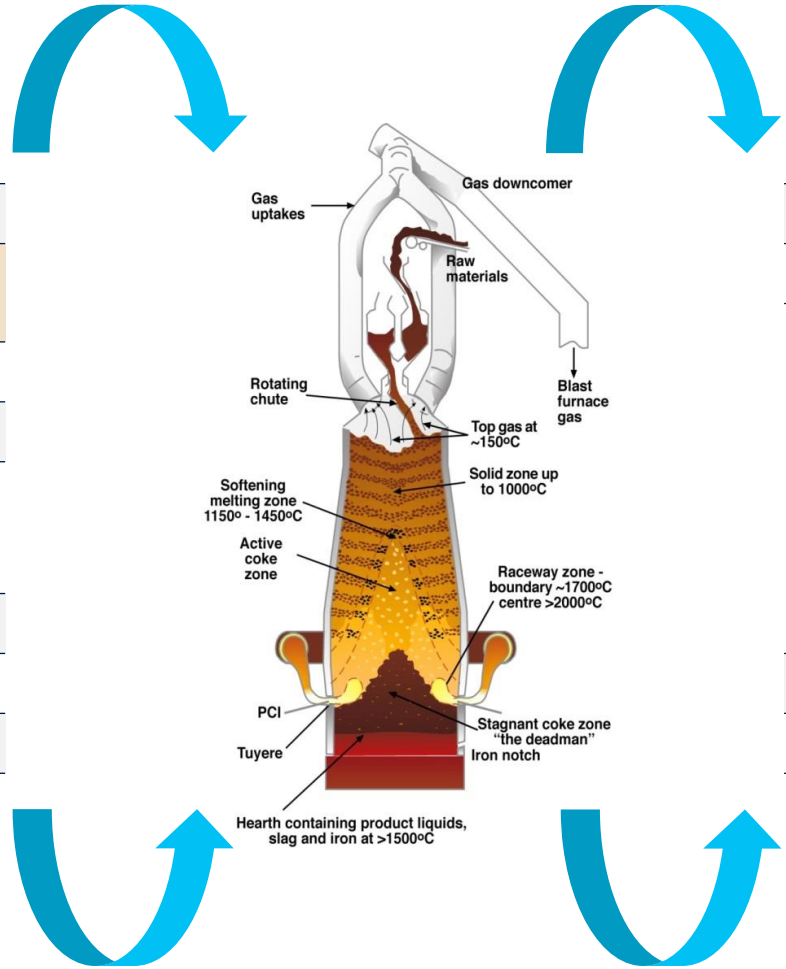
- survives to the lower furnace
- does not generate fine debris

Mass balance of a blast furnace

To produce one ton of hot metal

Inputs (kg)

Ferrous burden	1,600
Coke (Coal equivalent: 490)	350
PCI	150
Flux	100
Blast – air	1,300
– oxygen	40
Natural gas	40



Outputs (kg)

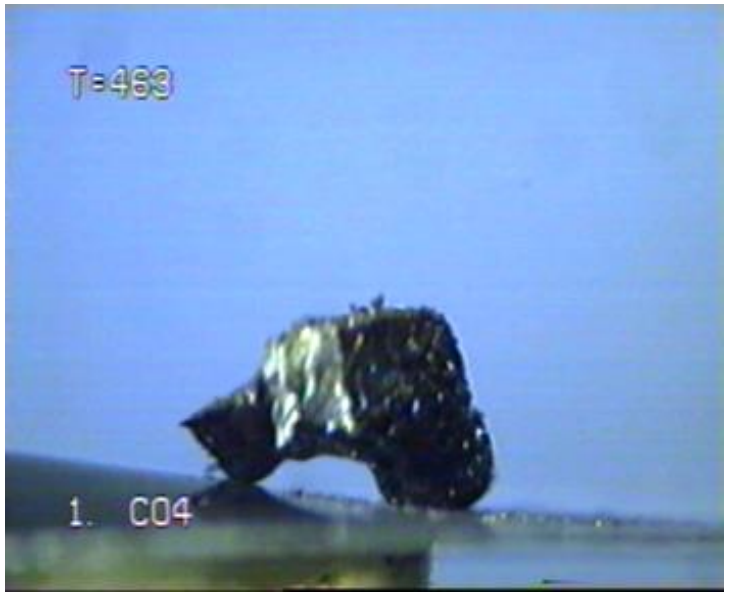
Top gas	2,300
Dust	20
Slag	200–600
Hot metal	1,000

What is different about coking coal?

Behaviour during heating in absence of air (pyrolysis)

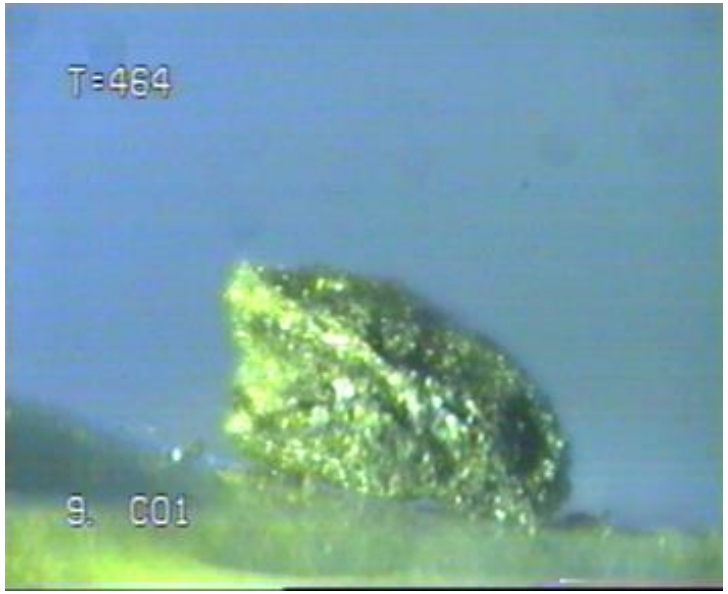
Coking coal

- Becomes “plastic” between 400-500°C
- Swells as volatiles are generated in the plastic coal



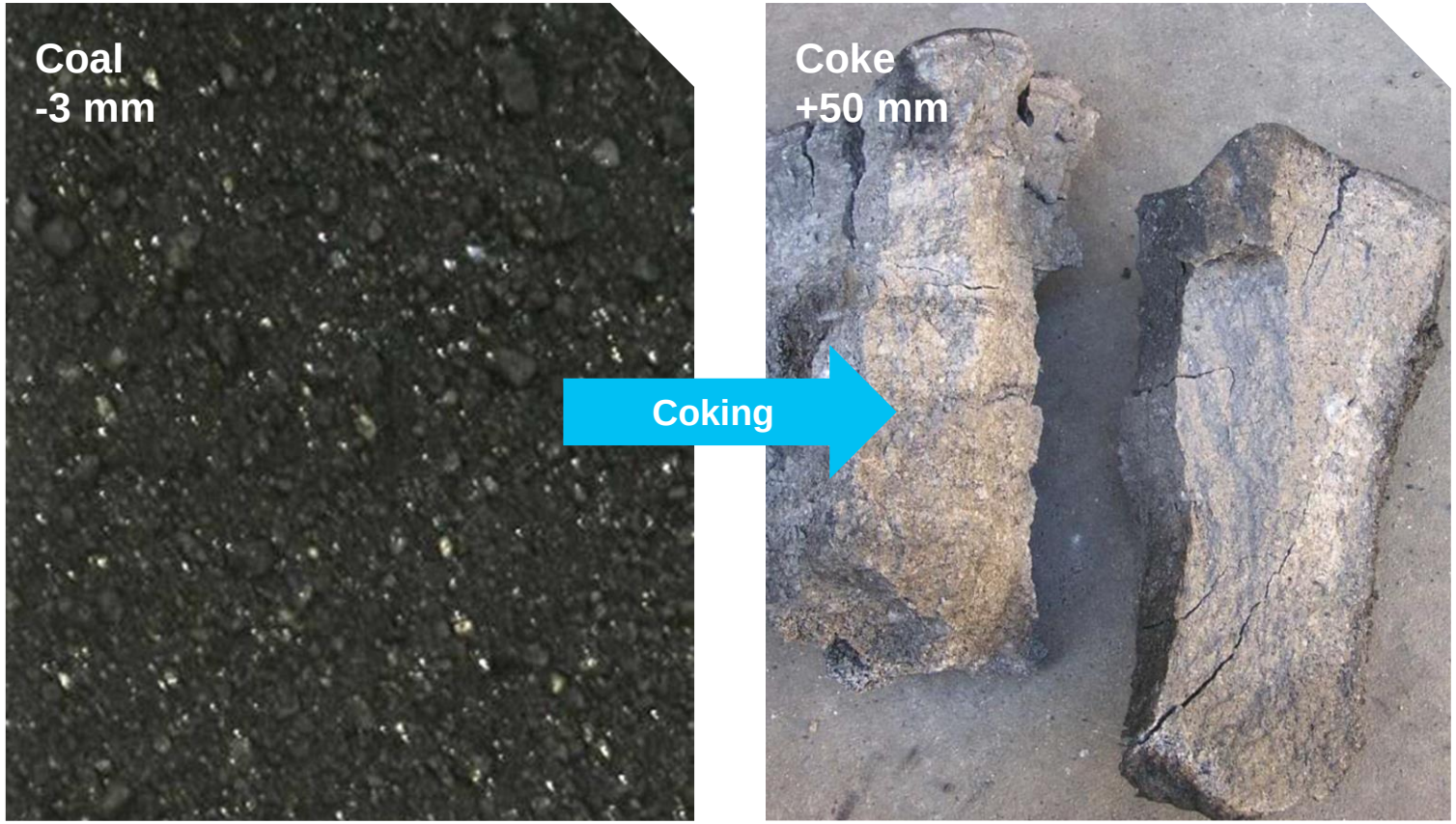
Thermal coal

- Exhibits little plasticity
- Exhibits little or no dilatation



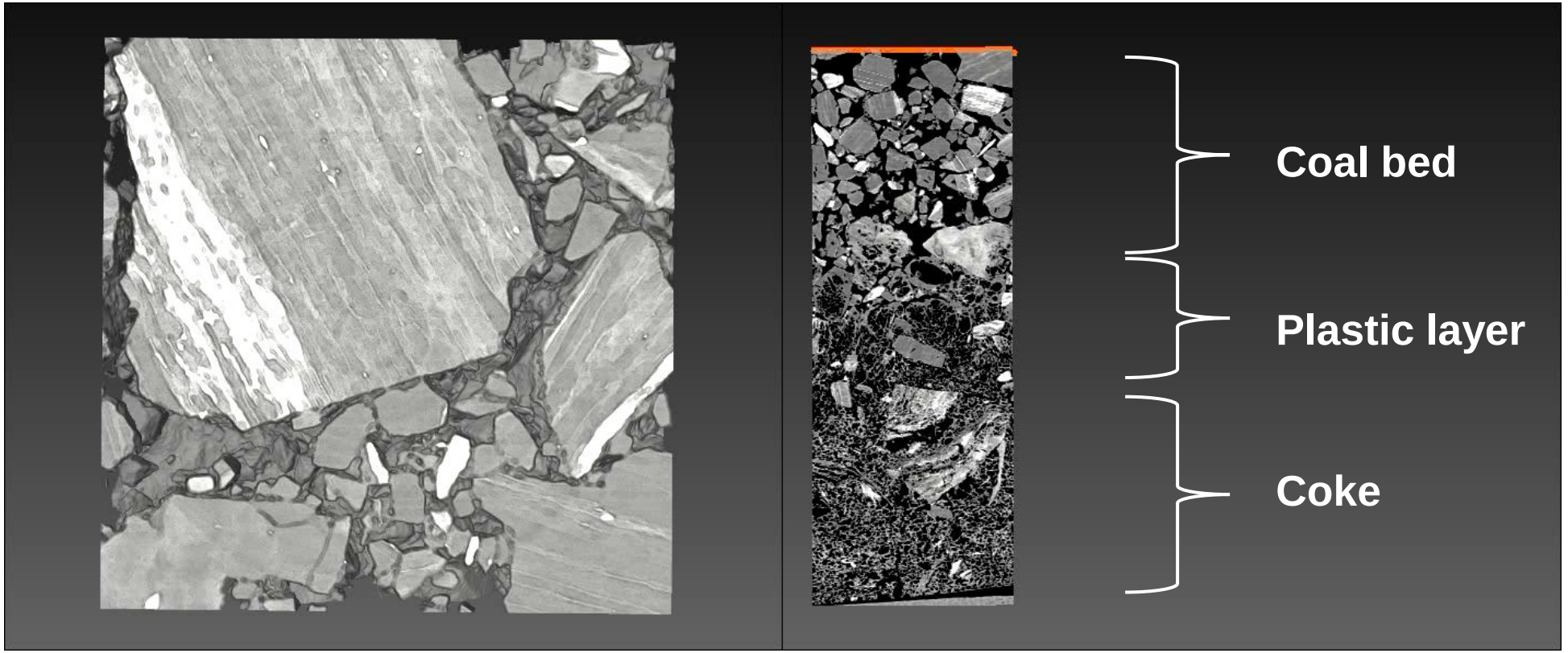
Transforming coking coal to coke

A packed bed of coking coal particles will agglomerate into semi-coke at ~500°C and then fissure and harden into coke lumps as temperatures reach ~1000°C.



Coal pyrolysis of a bed of coal

The plastic layer is the transition zone between coal and coke



Source: ACARP Project Number: C23048; Links Between Microstructure Development in Softening Coal and the Characteristics Controlling Coke Quality; Author: Karen Steel, et al. Published: 01/08/2015

5

Coal blending

Coal blending is an optimisation process

Blending optimisation considers trade-offs between:

- Costs (or value generation)
- Desired qualities
- Yield
- End use optimisation
- Source/supply diversification
- Thermal blending done by producer or customer
- Coke blending usually done by customer

Note: Blending the wrong products often results in a negative outcome for technical reasons

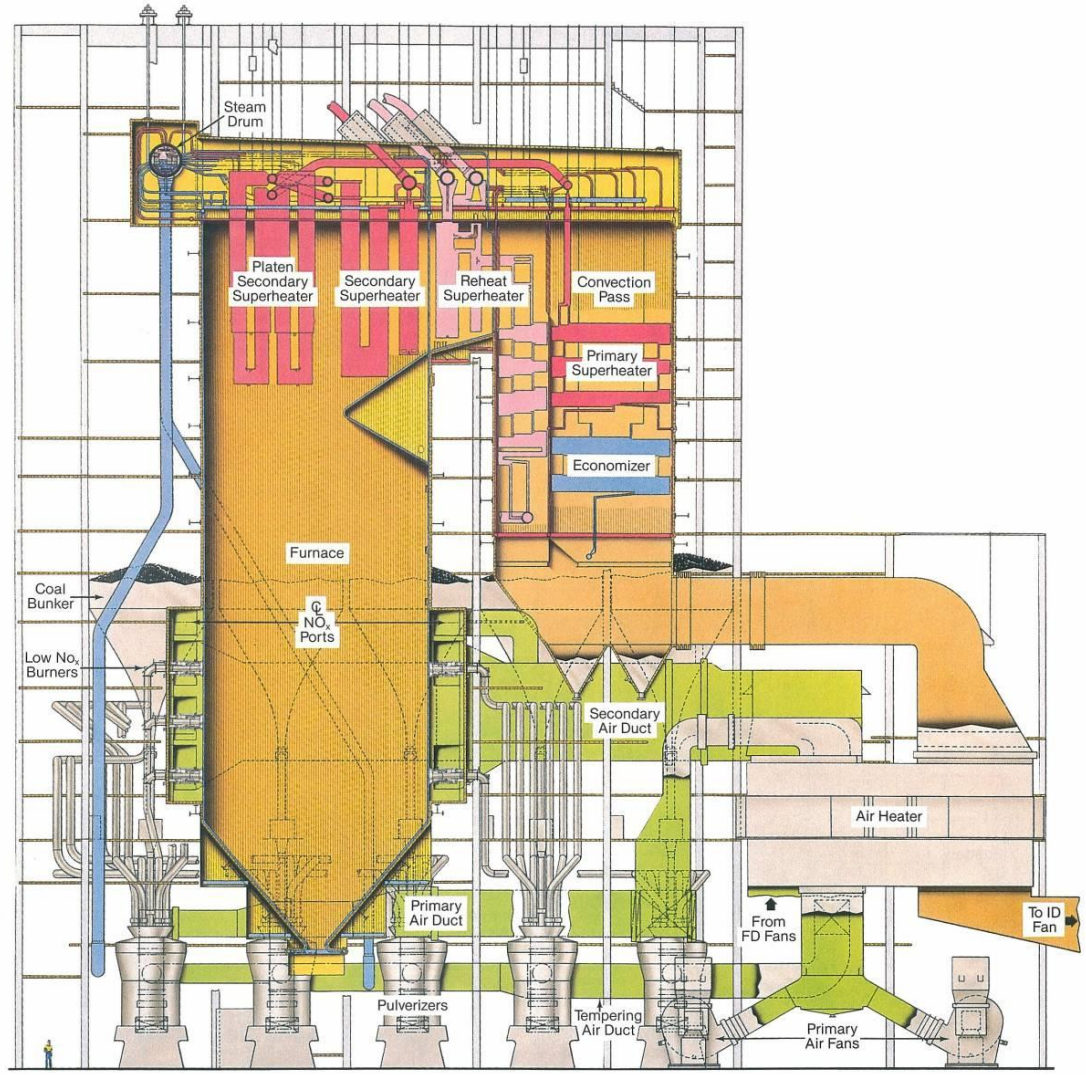
Coal blending in power generation

Blended before the pulveriser

- Differing HGIs → preferential grinding
- Differing VM content will ignite and burn at different rates → heat transfer imbalances
- Differing CSN (swell) → heat transfer imbalances, burner issues
- Ash chemistry can cause problems → Slagging/Fouling, ESP collection efficiency

Blended in boiler will give the operator more control

- Differing ash chemistry → slagging/fouling, ESP
- VM → lower VM can be ground finer in discrete mill to enhance combustion (burnout, flame stability, NOx emissions, heat transfer)
- HGI → lower HGI can be ground finer in discrete mill which avoids preferential grinding



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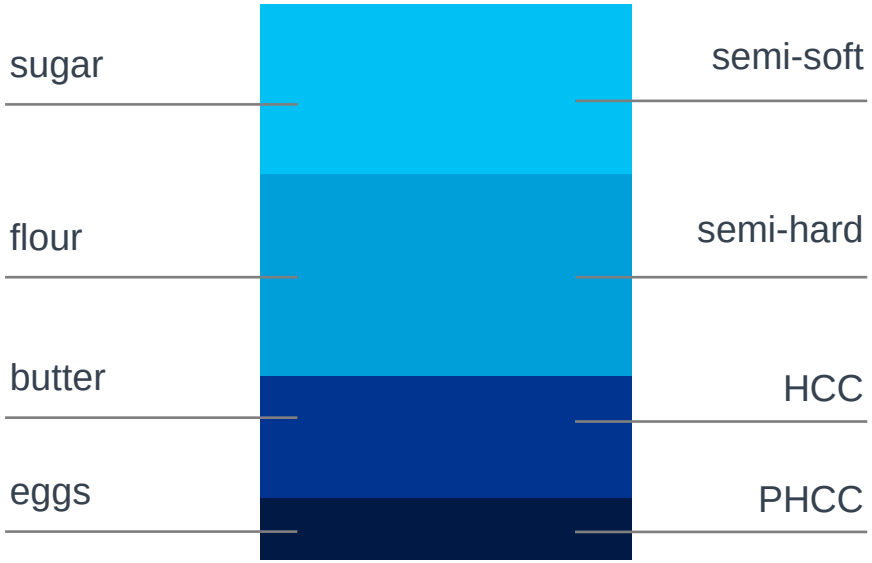
Coking coals are not created equal

A mixture of grades are required in coke-making

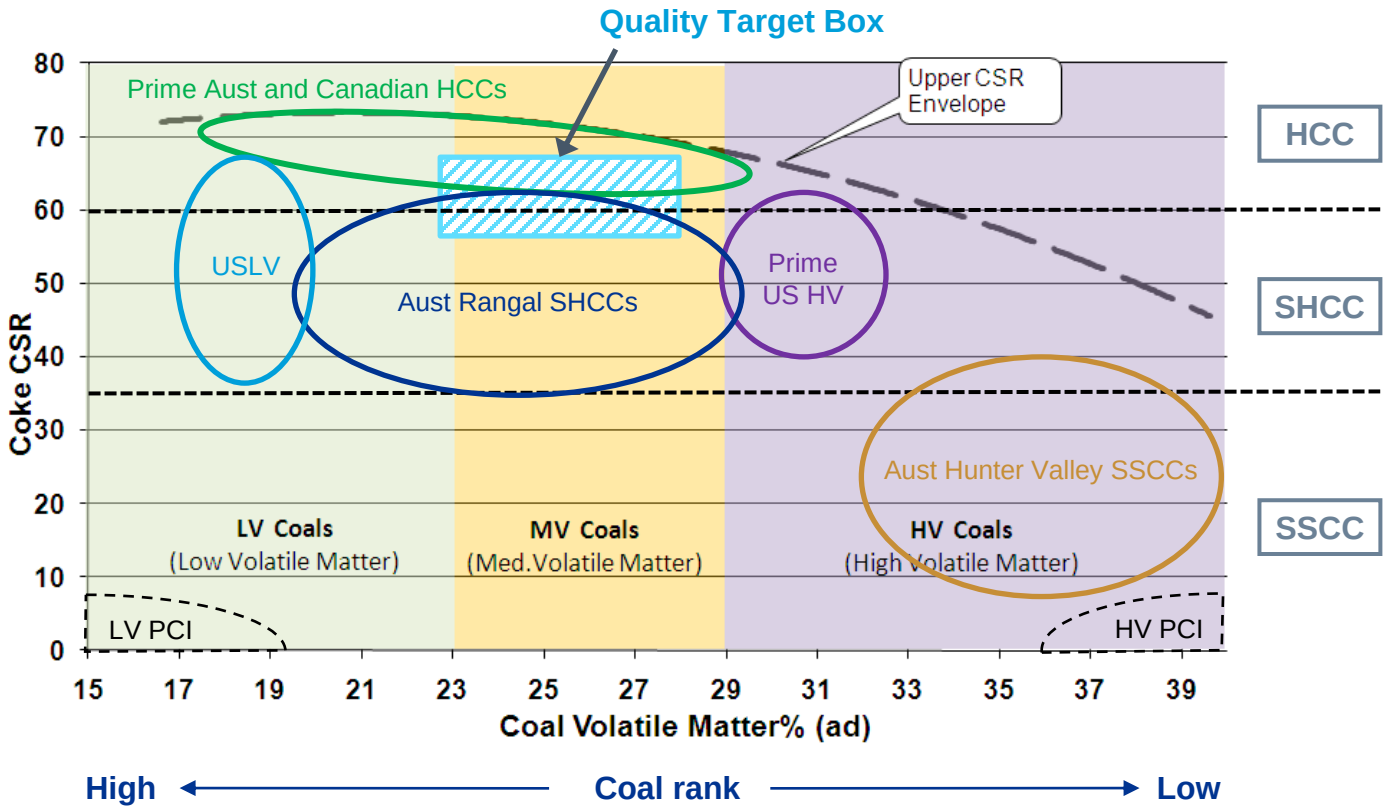
- There are various grades of metallurgical coal (PHCC, HCC, SHCC, SSCC) and each grade has a function in the coke-making blend: strength, caking properties, lowering impurities, cost control
- Coking coals are sold by brands (> 100 brands), each with their own individual quality and supply and demand
- Brands are not necessarily interchangeable and substitutions are seldom 1-for-1
- A coking coal blend is like a cake recipe: you must follow a specific mixture ratio of ingredients or the cake (coke) won't bake. Coke-makers don't like to change their recipe!

Cake vs. Coke blend recipe analogy



Coke blending to a target box – CSR and VM

- Miyazu-Okuyama-Fukuyama defined a blending target box of “sufficient fusibility” based on Gieseler Fluidity and Reflectance values
- Customers source coals so that ‘blend’ lands inside blending box – to achieve required strength without being in a dangerous OWP zone (while balancing other quality parameters: eg. ash, S, P, Vitrinite, ash chemistry, etc.
- Whitehaven’s SS used to reduce costs and increasingly to reduce ash and Sulphur (S in coke is very negative)



WHITEHAVEN COAL

Appendices – additional testing

Proximate analysis

Chemical analyses

Proximate analysis refers to the first set of tests completed and allows characterization of a coal sample. It typically consists of Inherent Moisture, Total Moisture, Ash, Volatile Matter, and Fixed Carbon.

Inherent Moisture – ISO 11722

Inherent moisture (IM) of coal refers to the moisture that is naturally present within the coal itself. IM results are variable, a standard of 3.5% at Whitehaven is used to convert all results to a comparable value.

Testing

- Sample equilibrated to the laboratory temperature and humidity
- Heated at 105-110°C to constant mass under nitrogen

IM sample:	Size	Weight	Time
	-212 um	1 gram	2 hrs

Why do we do this test?

- Ash handling qualities
- Used to convert to different bases

Fixed carbon – ISO 17246

Fixed carbon in coal refers to the solid, non-volatile carbonaceous residue that remains after volatile matter and moisture are driven off during heating or combustion.

- Not analysed → Calculated by difference
- Fixed carbon is also used to calculate fuel ratio

Fixed Carbon = 100% – (Inherent Moisture + Ash + Volatile Matter)

Fuel Ratio = (FC/VM)

Why do we do this test?

Fixed carbon provides an indication of the coal's ability to produce heat when burned. High fixed carbon generally suggests that the coal has a greater potential to generate heat energy.

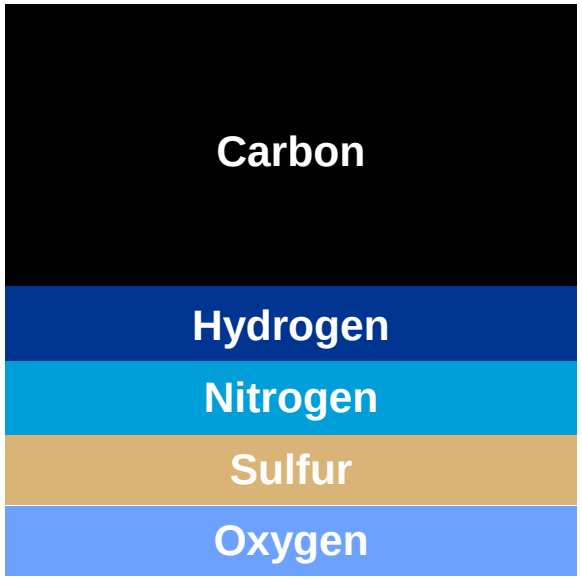
Fuel ratio provides an indication of the coal's behavior during combustion. A high fuel ratio indicates a larger proportion of fixed carbon compared to volatile matter and suggests that the coal will burn with a relatively steady flame and produce less smoke and volatile gases.

Not to be confused with carbon. Carbon refers to the total carbon content present in coal, whereas fixed carbon specifically refers to the carbon content that remains in the coal after volatile matter is driven off during heating.

Ultimate analysis

Chemical analyses

Ultimate Analysis consists of the organically derived components of the coal. Five elements comprise greater than 99% of the organic portion of coal, usually presented such that they sum to 100%.



Carbon Hydrogen and Nitrogen ISO 29541

- Combusted in pure oxygen at 950ºC in a high temperature tube
- Combustion gases produced (CO_2, H_2O, N_2) are drawn through an infra-red detection cells to determine the concentration of C, H and a thermal conductivity cell to determine N.

CHN sample:

Size	Weight	Time
-212 um	80-100 mg	30 mins

Sulphur ISO 19579

- Combustied in oxygen at 1,350°C, the gas stream passes through an infra-red adsorption detection cell that measures the adsorption wavelength of sulfur dioxide
- Determines the total of all 3 forms (sulfate, pyritic and organic)

TS sample:

Size	Weight	Time
-212 um	0.3 g	10 mins

Oxygen

- Calculated by difference

Why do we do this test?

Combustion characteristics, NO_x emissions, SO_x emissions

Ash analysis / Ash fusion temperature – ISO 540

Physical analyses

Ash analysis

Determines all inorganic compounds in the ash as oxides

Two common instrumental methods:

- X-ray Fluorescence Spectrometry (XRF)
- Atomic absorption spectrometry (AAS)

AA sample:	Size	Weight	Time
	-212 um	1 gram	3-4 hrs

Why do we do this test?

- Results can indicate the potential for slagging and fouling
- Ash disposal and utilisation ESP and FGD performance

Ash fusion temperature

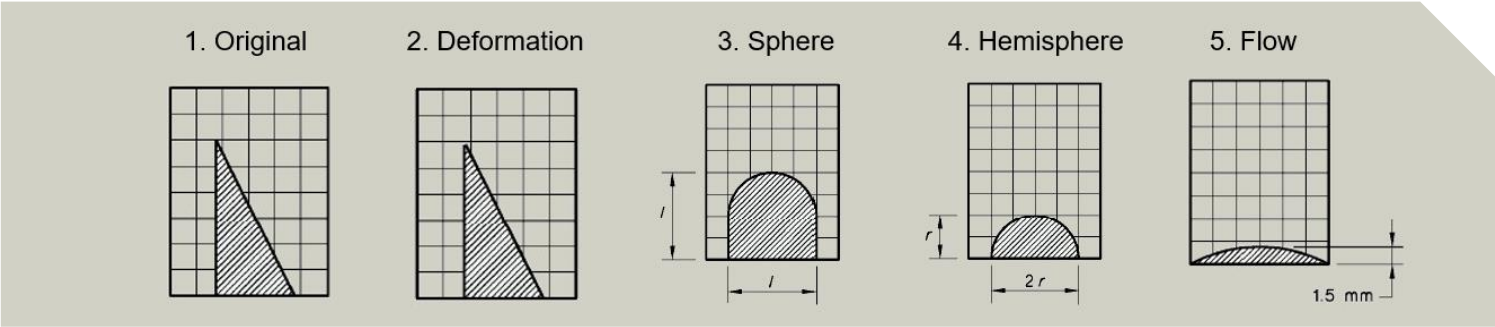
Is it sticky when hot?

- Moulded pyramids or cubes from coal ash subjected to steady temperature increase from 900° to 1,600°C
- Reducing atmosphere (H_2 50% CO_2 50%) or oxidising atmosphere (Air or CO_2)

AFT sample:	Size	Weight	Time
	-63 um	1 gram	2-3 hrs

Why do we do this test?

The ash fusion temperature provides insights into the ash's behavior in the furnace and its potential for causing operational issues, such as slagging and fouling.



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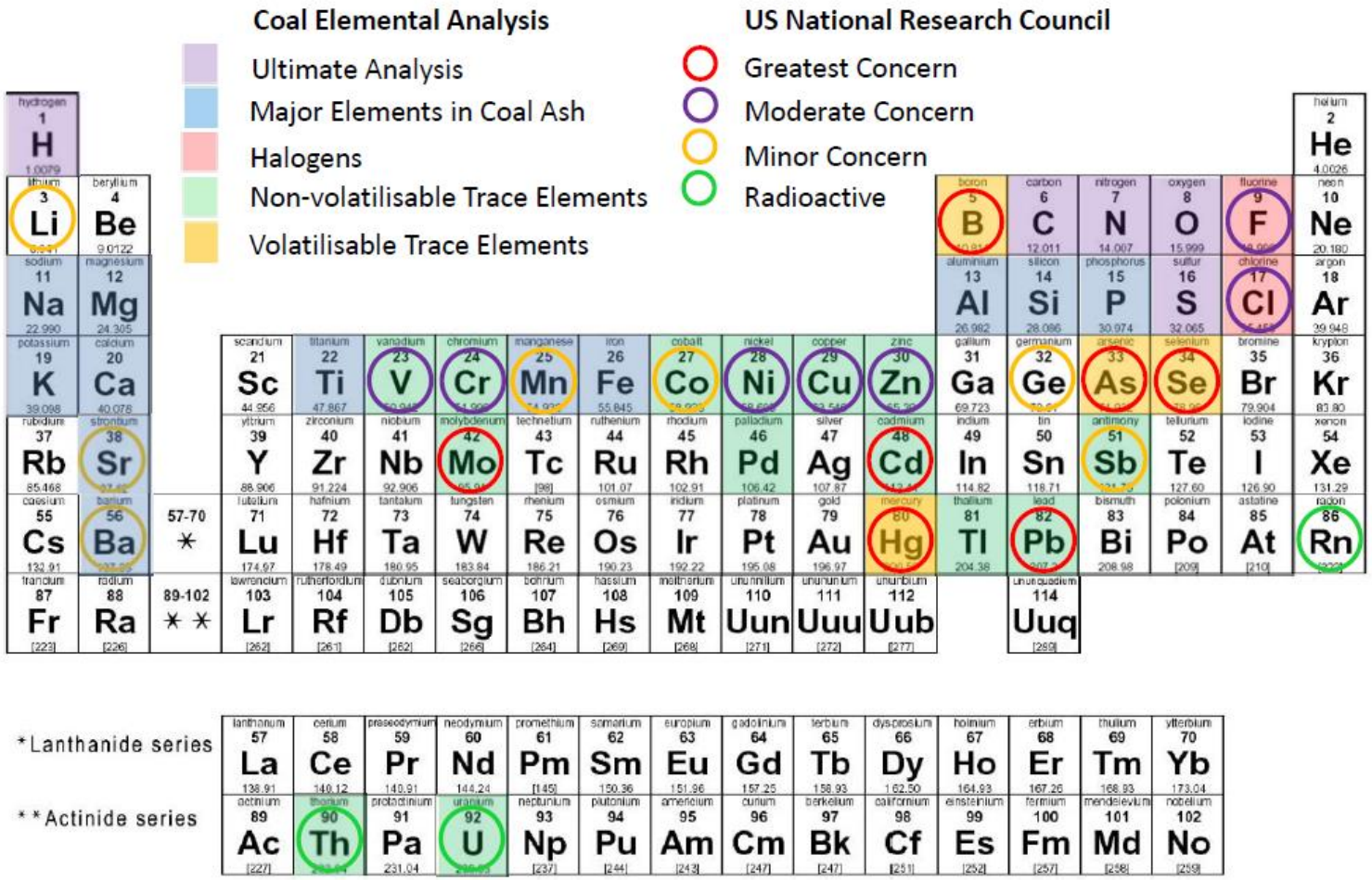
Elements in coal

Why do we do this test?

- Government restrictions, China have restrictions on F, Cl, Hg, As and Phos
- SCoTA rejection parameter on Se
- Trace elements may be emitted from the stack to the atmosphere as vapours or on fine ash particles
- Many coal trace elements are toxic if occurring in high quantities



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