JINDAL STEEL & POWER

Jindal Steel and Power Ltd

Seminar on "Opportunities in Alternative Usage of Coal"

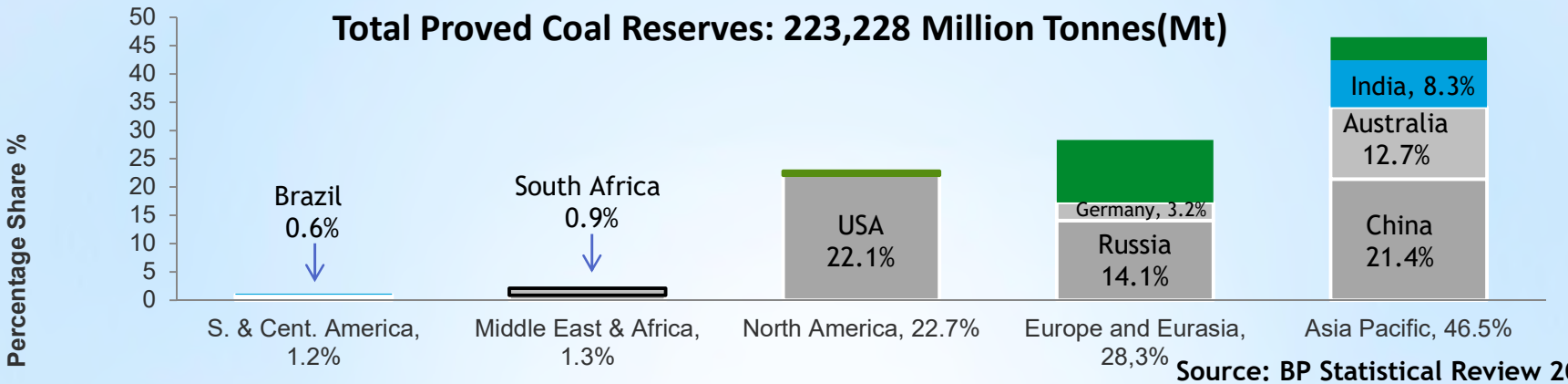
Dated-February 8, 2019

COAL GASIFICATION

Presented to: Lovraj Kumar Memorial Trust

Contents

Global & Domestic Coal Reserve



Source: BP Statistical Review 2016

- India has 5th largest coal reserve in World: **315,148.81 Million tonnes(Mt)** on 1st April 2017

Category Wise Coal reserve
Measured
45.4%
Indicated
44.2%
Inferred
10.4%

Non Coking 279,027 Mt
Superior
13.4%
Inferior
75.8%
Ungraded
10.8%

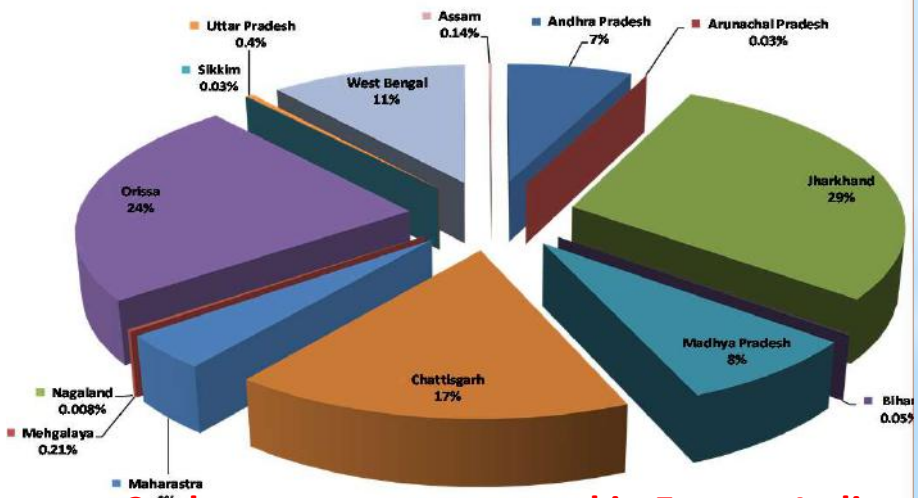
Coal Extracted from Coalfields
2016-17:
644.31 Mt

Since 1950 up to 2016-17:
14438.22 Mt

Source: GSI, NERM 2017

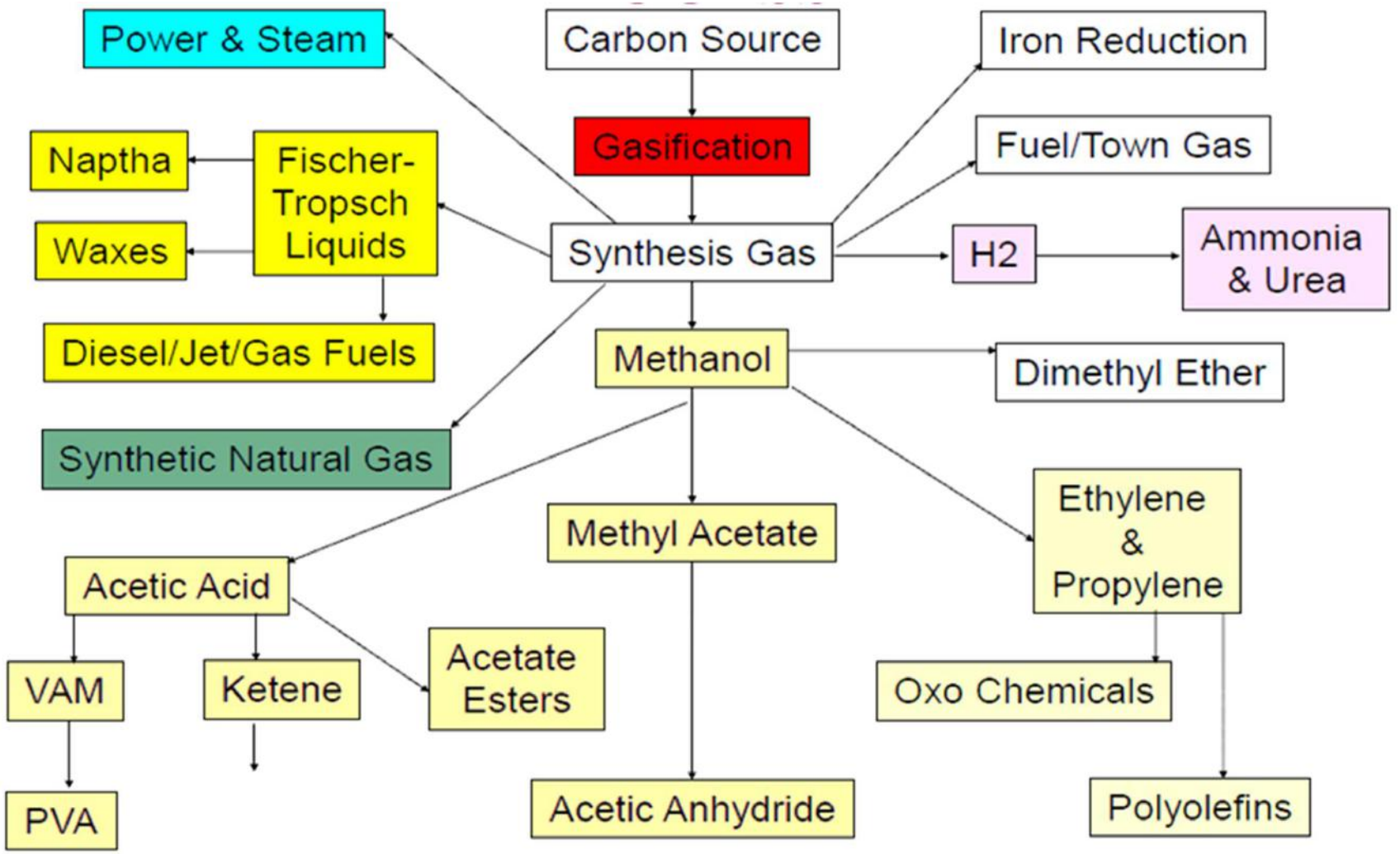
Of the total coal reserves 77% is either Inferior Grade or Ungraded coal Non-Coking Coal

- **Proven/Measured Coal reserves (India):** Coal for more than 236 years



Coal reserves concentrated in Eastern India, Hence CG project based in Angul, Orissa

Applications of Gasification Process



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WHAT IS GASIFICATION?

- Conversion of any carbonaceous fuel to a gaseous product with a useable heating value.

- The feed for Gasification can be
  - Gas (e.g., Natural gas)
  - Liquid (e.g., Light or Heavy oils)
  - Solid (e.g., Coal, Petroleum Coke, Lignite or Biomass)

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GASIFICATION Vs. COMBUSTION

- Partial oxidation
- Higher temperature, often high pressure
- Purpose - Get Fuel-rich gas & not High temperature gas
- Product gases (CO, H_2, CH_4, CO_2, H_2O) have fuel value
- Oxygen as feed instead of air
- Intermediate scrubbing of gas
- Char reaction rate is slower

Coal Gasification Theory Contd..

GENERAL REACTIONS

$$CH + O_2 + H_2O \rightarrow CO + H_2 + CO_2 + H_2O + CH_4$$

$$H_2 + S = H_2S$$

$$C + \tfrac{1}{2} H_2 + \tfrac{1}{2} N_2 = HCN$$

$$\tfrac{1}{2} N_2 + \tfrac{3}{2} H_2 = NH_3$$

$$C + S + \tfrac{1}{2} O_2 = COS$$

$$\tfrac{1}{2} H_2 + \tfrac{1}{2} Cl_2 = HCl$$

$$ASH \rightarrow SLAG + FLY\ ASH$$

Coal Gasification Theory Contd..

GENERAL REACTIONS

		ΔH (+ Endothermic / - Exothermic)
Combustion reactions		
$C + ½ O_2$	$= CO$	- 111 MJ/kmol
$CO + ½ O_2$	$= CO_2$	- 283 MJ/kmol
$C + O_2$	$= CO_2$	- 394 MJ/kmol
$H_2 + ½ O_2$	$= H_2O$	- 242 MJ/kmol
Boudouard reaction		
$C + CO_2$	$\leftrightarrows 2\ CO$	+ 172 MJ/kmol
Water gas reaction		
$C + H_2O$	$\leftrightarrows CO + H_2$	+ 131 MJ/kmol

Coal Gasification Theory Contd..

GENERAL REACTIONS

		ΔH (+ Endothermic / - Exothermic)
Methanation reaction		
$C + 2\,H_2$	$\leftrightarrows\ CH_4$	- 75 MJ/kmol
$CO + 3\,H_2$	$\leftrightarrows\ CH_4 + H_2O$	- 206 MJ/kmol
$CO_2 + 4\,H_2$	$\leftrightarrows\ CH_4 + 2\,H_2O$	- 165 MJ/kmol

The reverse Steam-reforming reactions are endothermic

CO shift reaction

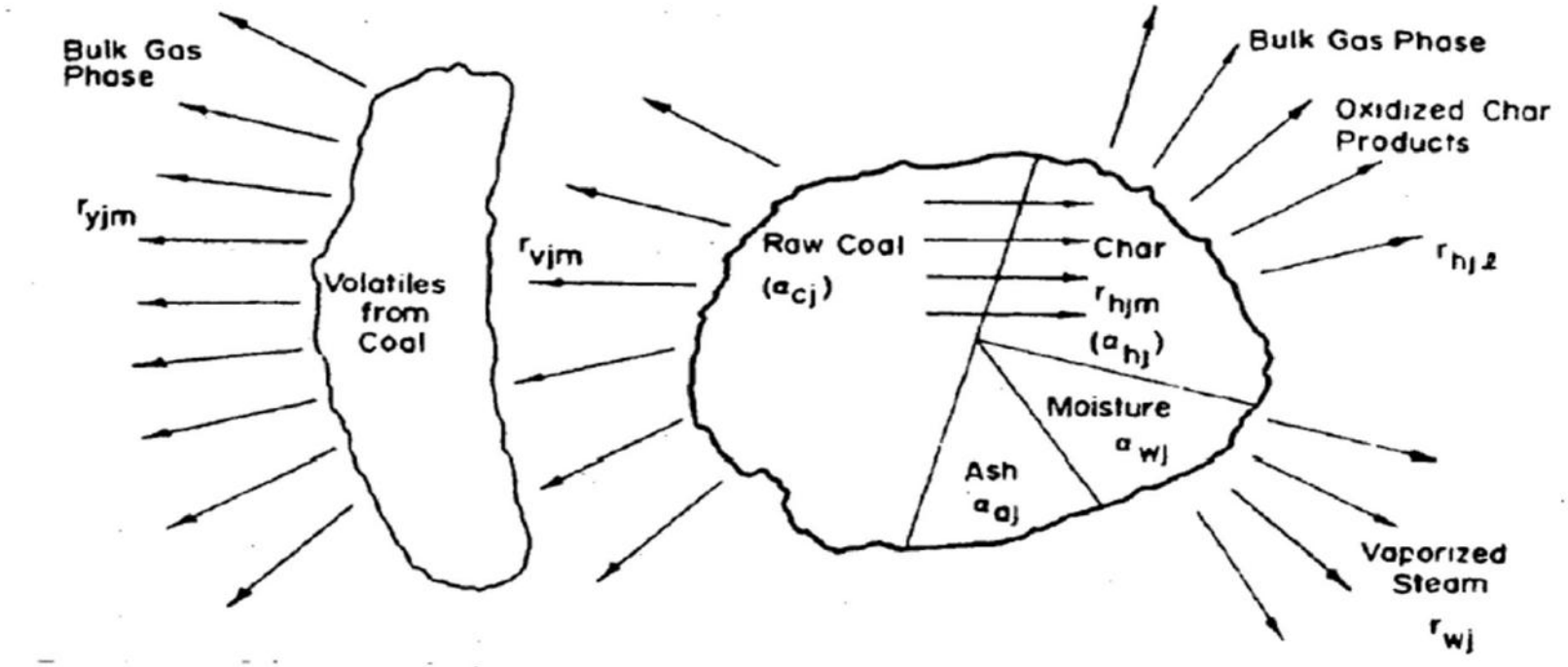
$CO + H_2O$	$\leftrightarrows\ CO_2 + H_2$	- 41 MJ/kmol

Gasification Reaction – Summary

$$CH + O_2 + H_2O \rightarrow CO + H_2 + CO_2 + H_2O + CH_4$$

Coal Gasification Theory Contd..

What Happens to a Coal Particle?



Coal reactions are generally divided into two distinct components

- **Devolatilization of the raw coal**
- **Oxidation of the residual char**

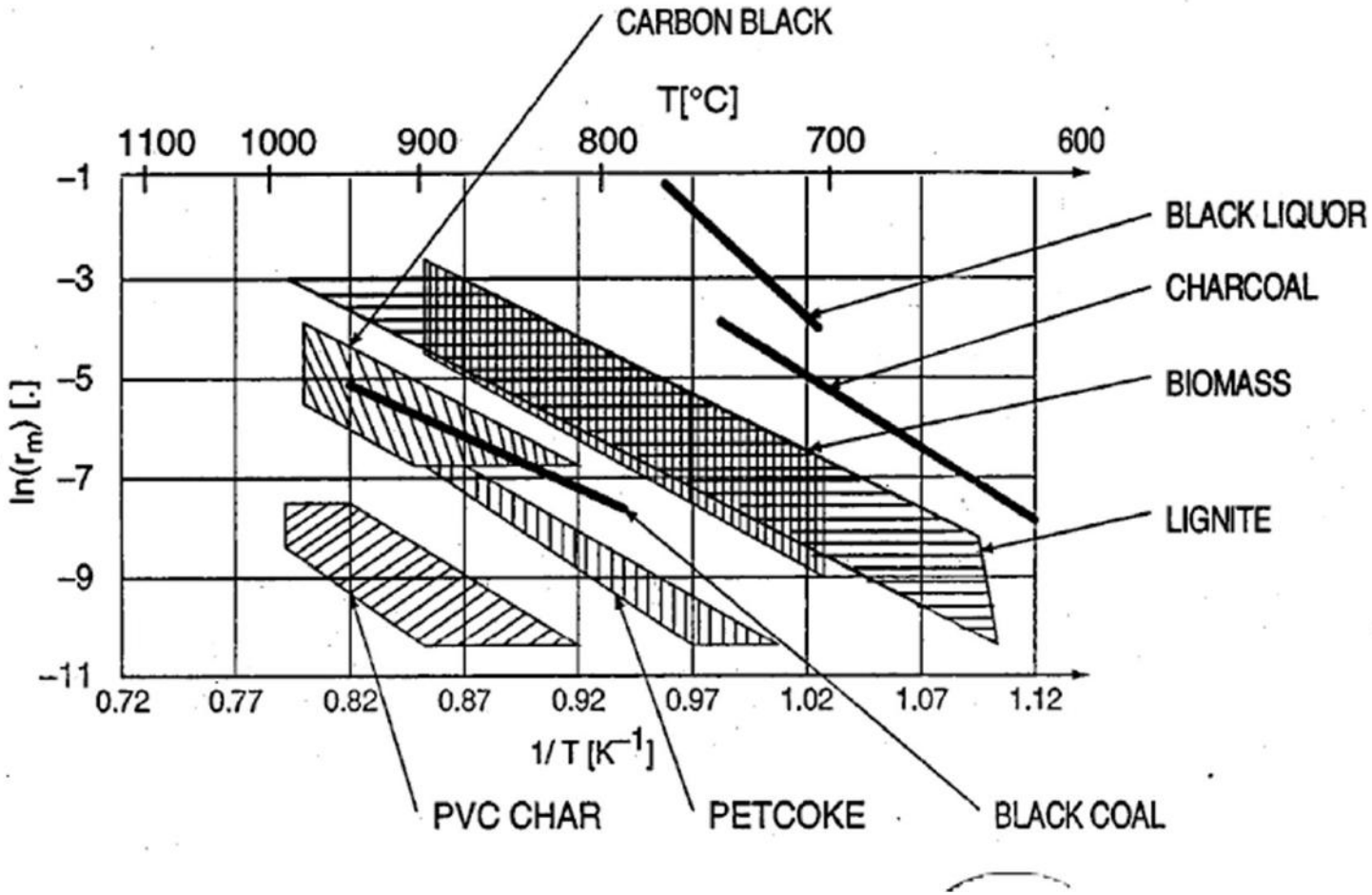
Coal Gasification Theory Contd..

Reactivity : The reactivity of coal and char depends on various factors in particular

- The porosity of coal, that is, its inner structure, surface and active sites
- The crystal structure of the fixed carbon
- Catalytic effects of ash component in the coal
- Young (Low rank) coal such as brown coal has high specific surface and thus a high reactivity
- Older coal have lower reactivity
- Reactivity is enhanced by alkalies , particularly potassium

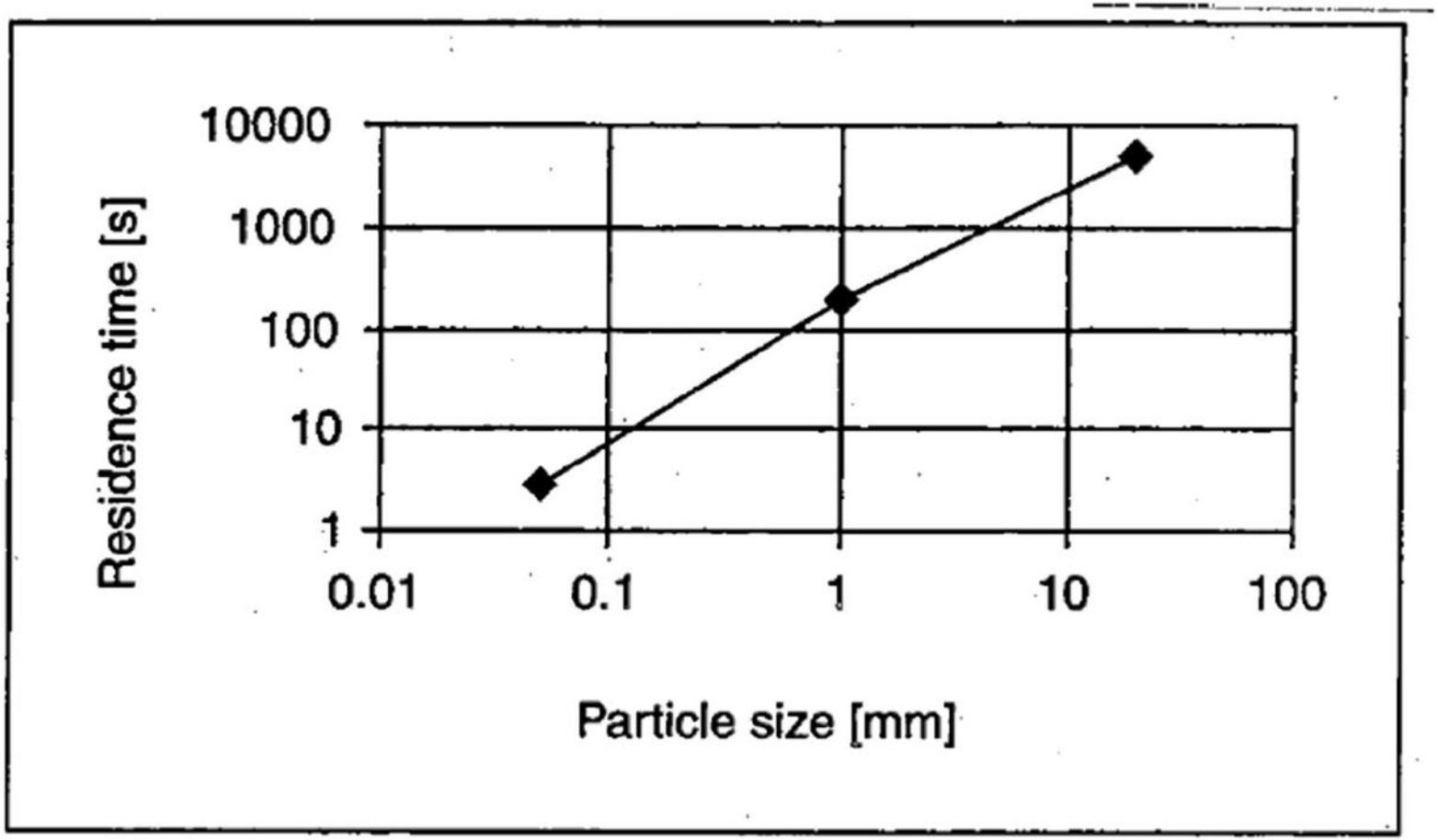
Coal Gasification Theory Contd..

REACTIVITY OF FUELS AS FUNCTION OF TEMPERATURE



Coal Gasification Theory Contd..

RESIDENCE TIME AS FUNCTION OF PARTICLE SIZE



Coal Gasification Theory Contd..

ASH BEHAVIOR

- The relationship between ash-melting characteristics and composition is a complicated one and is dependent largely on the quaternary SiO_2-Al_2O_3-CaO-FeO.

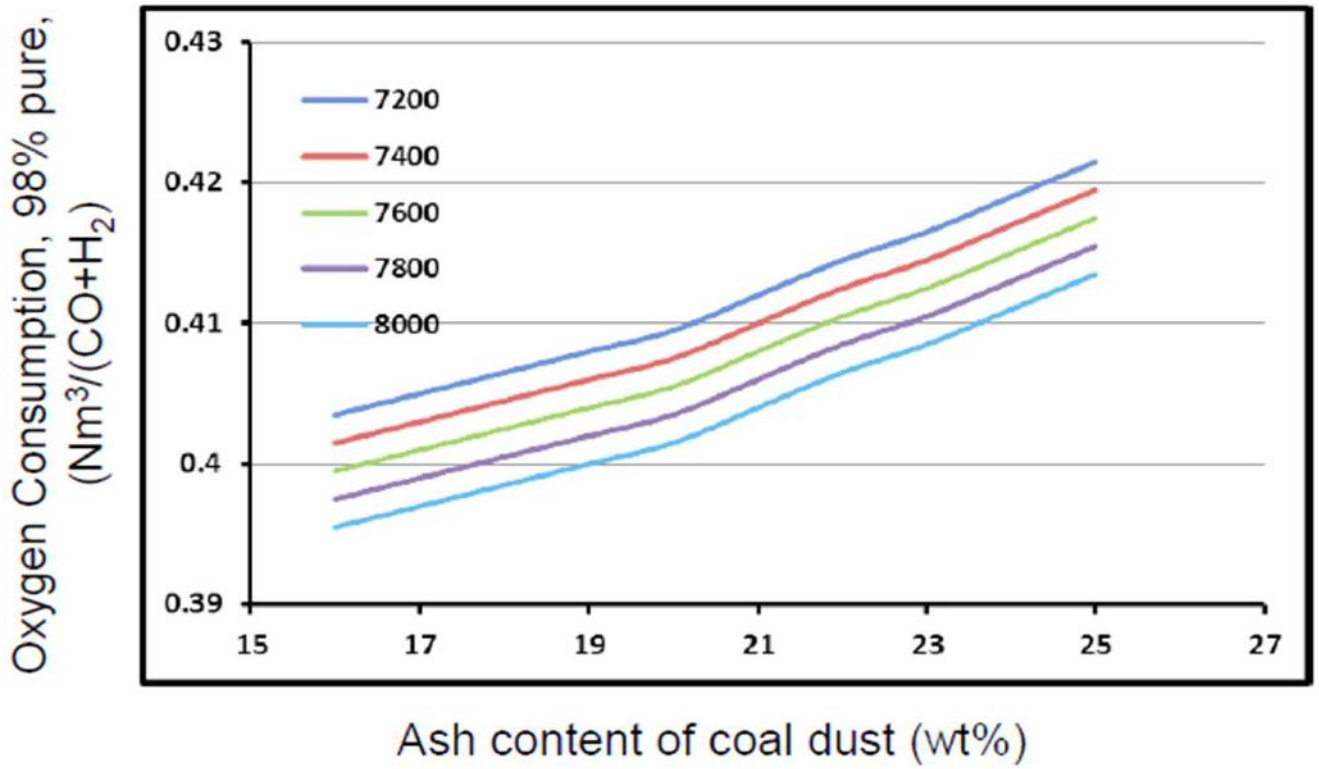
- In general, slags that are high in SiO_2 and/or Al_2O_3 will have high ash melting points, but this is reduced by the presence of both CaO and FeO.

- The SiO_2/Al_2O_3 ratio is also important – where the Calcium content is already high, SiO_2 addition can lower the ash melting point.

- Slag is very different from ash as it has been molten and is in fact a fusion-cast material similar to glass.

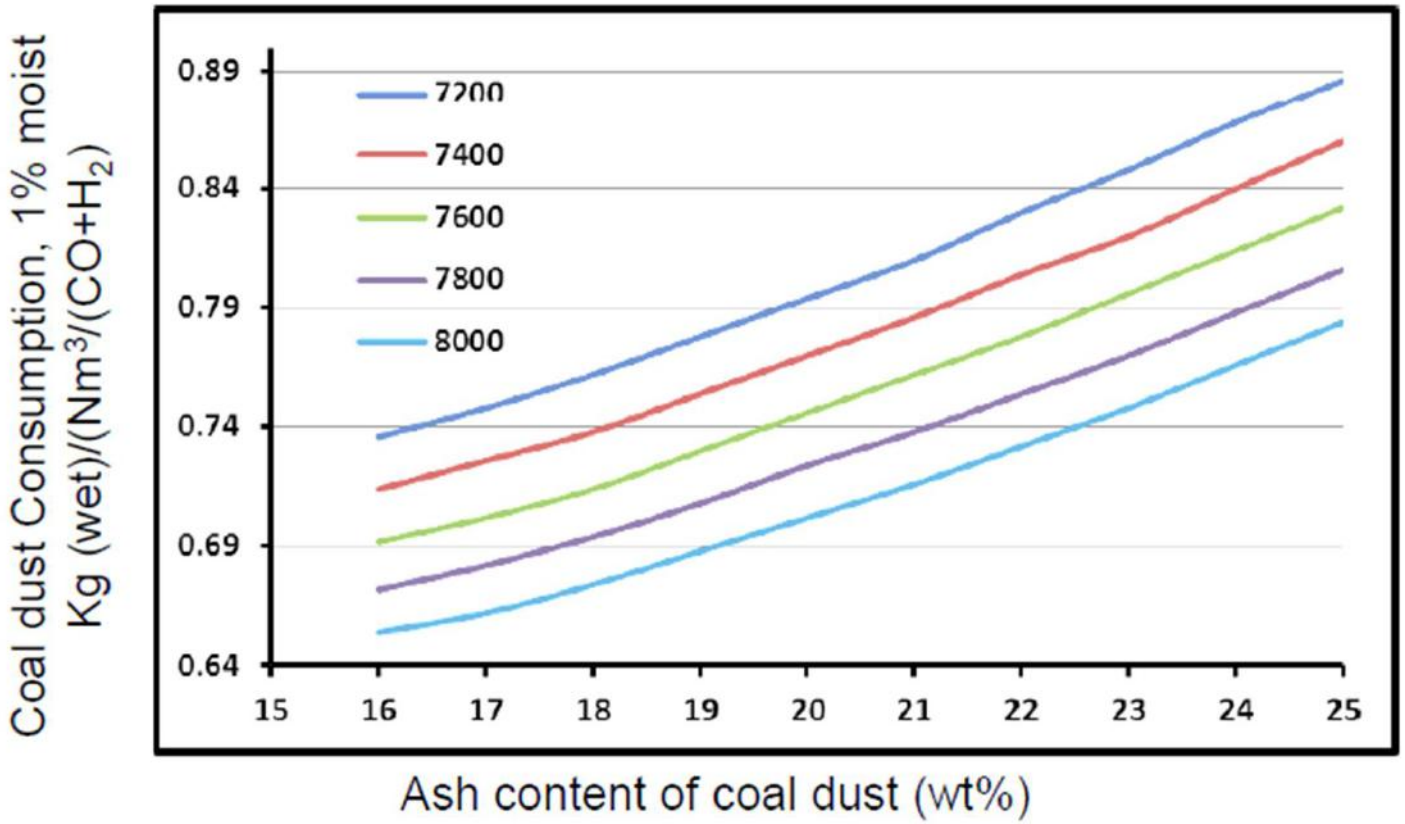
Coal Gasification Theory Contd..

O2 consumption depending on Ash content and CV



Coal Gasification Theory Contd..

Coal dust consumption depending on Ash content and CV



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EFFECT OF PRESSURE

Synthesis gas composition changes with pressure

- Methane and CO2 content go up with increasing pressure
- H2 and CO content go down
- However, at high temperatures (1500^{o}C) the change in gas composition with pressure is negligible.

Coal Gasification Theory Contd..

EFFECT OF TEMPERATURE

- Below the ash softening point for fluidized bed and dry ash moving bed Gasifiers
- Above the ash melting point for slagging (entrained bed) Gasifiers
- Flux may be required to be added for coal/coke having very high ash melting point
- CO content goes up while H_2 content goes down with increasing temperature
- CO + H_2 yield goes through a mild maximum between 1200 and 1300 deg C
- Methane content goes down with increasing temperature
- Oxygen demand is more at high temperatures

Coal Gasification Theory Contd..

TYPES OF GASIFIERS

1) **Moving/Fixed bed** — **Lurgi/BGL**

   Counter-current
   Co-current

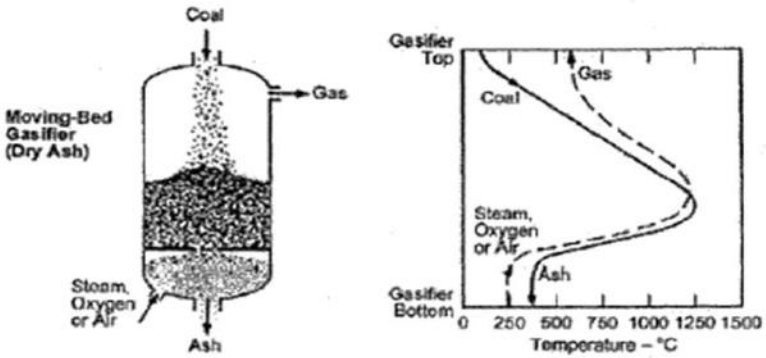
2) **Fluidized bed** — **Winkler/KBR etc**

3) **Entrained flow** — **GE/Shell/Conoco/Siemens/Uhde**

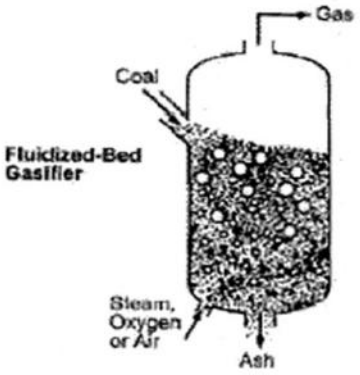
   Dry pulverized solid fuel
   Fuel slurry
   Atomized liquid fuel

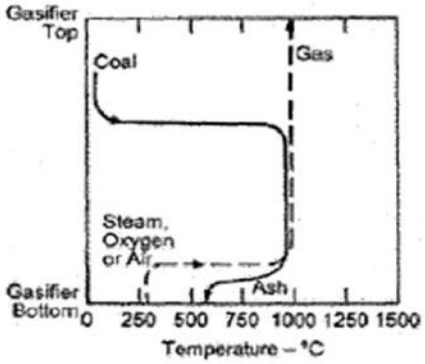
Coal Gasification Theory Contd..

TYPES OF GASIFIERS

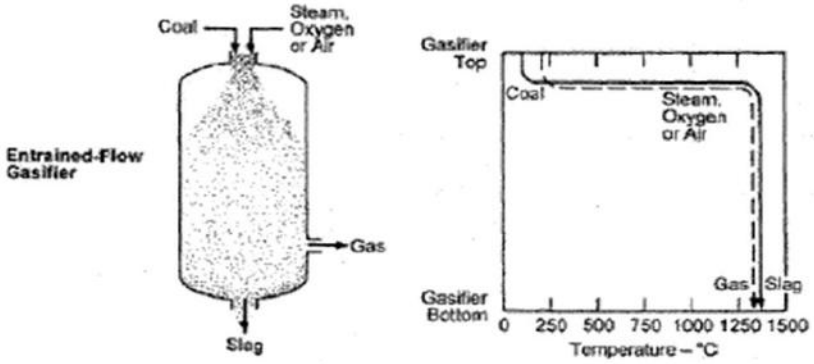


MOVING BED GASIFIER





FLUIDIZED BED GASIFIER



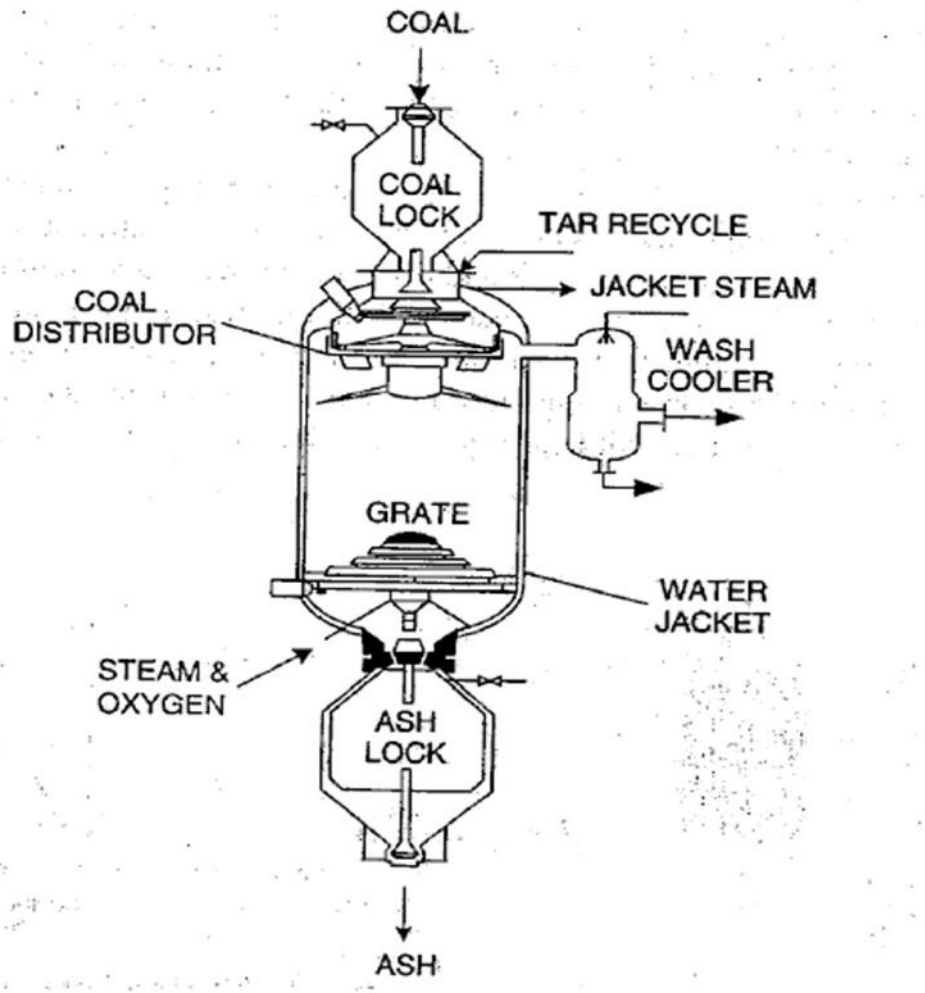
ENTRAINED FLOW GASIFIER

Coal Gasification Theory Contd..

Category	Moving Bed		Fluidized Bed		Entrained flow
Ash Condition	Dry Ash	Slagging	Dry ash	agglomerating	slagging
Typical Processes	Lurgi	BGL	Winkler/HTW /CGB	KRW U-Gas	Shell, Texaco, E-Gas, Noell,KT
Feed Characteristics					
Size	6-50 mm	6-50 mm	6-10 mm	6-10 mm	< 100 µm
Acceptability of fines	Limited	Better than dry ash	Good	Better	Unlimited
Acceptability of caking coal Preferred coal rank	Yes (with stirrer) any	Yes high	Possibly Low	Yes any	Yes any
Operating Characteristics					
Outlet gas temp	Low (425-625^{o})	Low (425-625^{o}C)	Moderate (950-1050^{o}C)	Moderate (950-1050^{o}C)	High (1250-1600^{o}C)
Oxygen demand	Low	Low	Moderate	Moderate	High
Steam Demand	High	low	Moderate	Moderate	low
Other Characteristics	Hydrocarb on in gas	Hydrocarbon in gas	Lower carbon conversion	Lower carbon conversion	Pure gas high carbon conversion

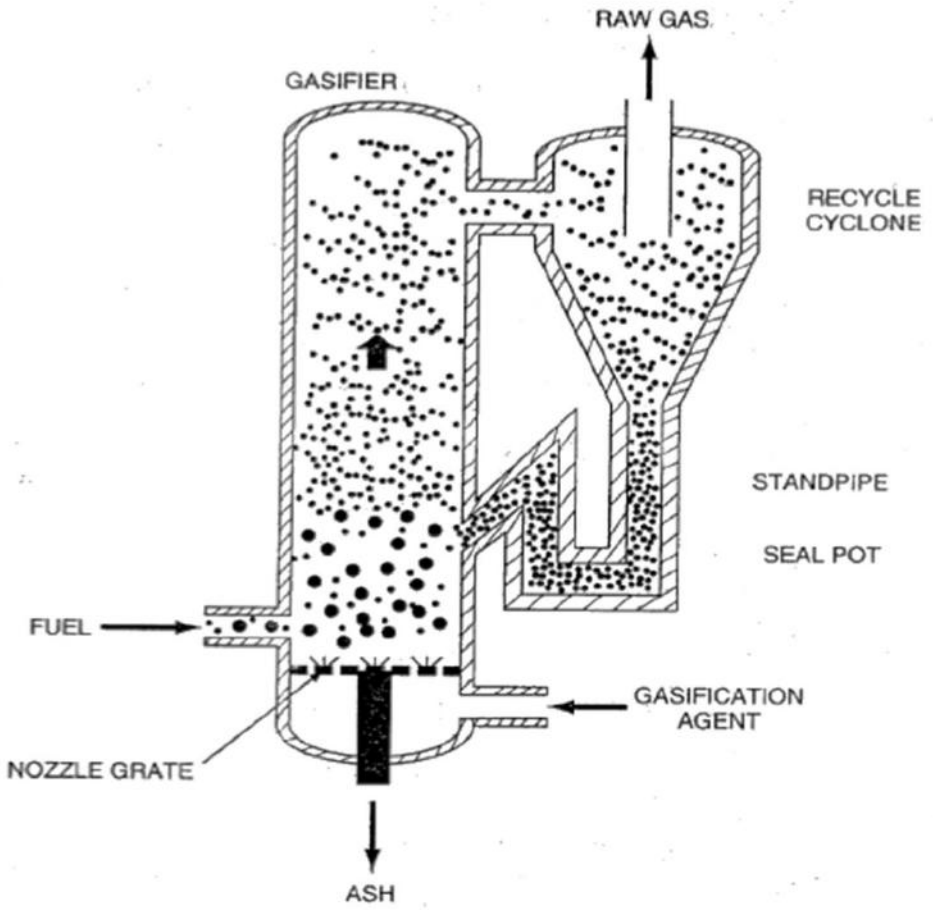
Coal Gasification Theory Contd..

LURGI DRY ASH GASIFIER – MOVING BED



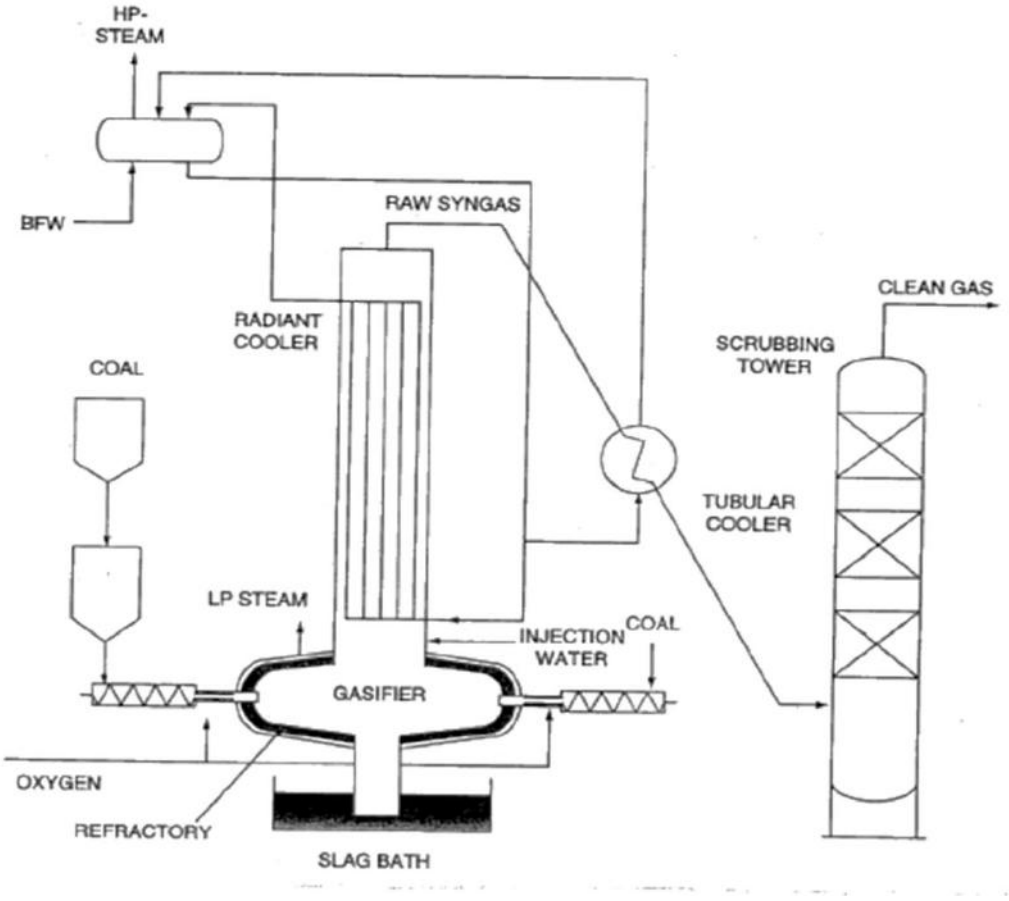
Coal Gasification Theory Contd..

LURGI CIRCULATING GASIFIER – FLUIDIZED BED



Coal Gasification Theory Contd..

KOPPERS-TOTZEK GASIFIER – ENTRAINED BED



History of Gasification

PERIOD	TECHNOLOGY
Before 1700	Major fuels were Wood and Charcoal
1700-1750	Industrial revolution – Coal as fuel
1800-1900	Coal Pyrolysis – Town gas supply Water gas, Producer Gas
1920	Cryogenic air separation – Oxygen replaces air
1926	Winkler Fluidized Bed Gasifier
1931	Lurgi Moving Bed Gasifier
1940	Koppers-Totzek Entrained Flow Gasifier

History of Gasification contd..

PERIOD	TECHNOLOGY
1950s	Texaco and Shell develop Oil Gasification
1970s	Oil crisis
1973	Texaco develops Slurry Process for Coal Gasification
1974	Shell and Koppers-Totzek Pressure Gasification JV
1981	High Temperature Winkler Gasification
1984	Lurgi Slagging Gasifier (together with British Gas)
1999	Shell/Krupp-Uhde develops Pressurised Entrained Flow (PRENFLO) Gasifier

History of Gasification contd..

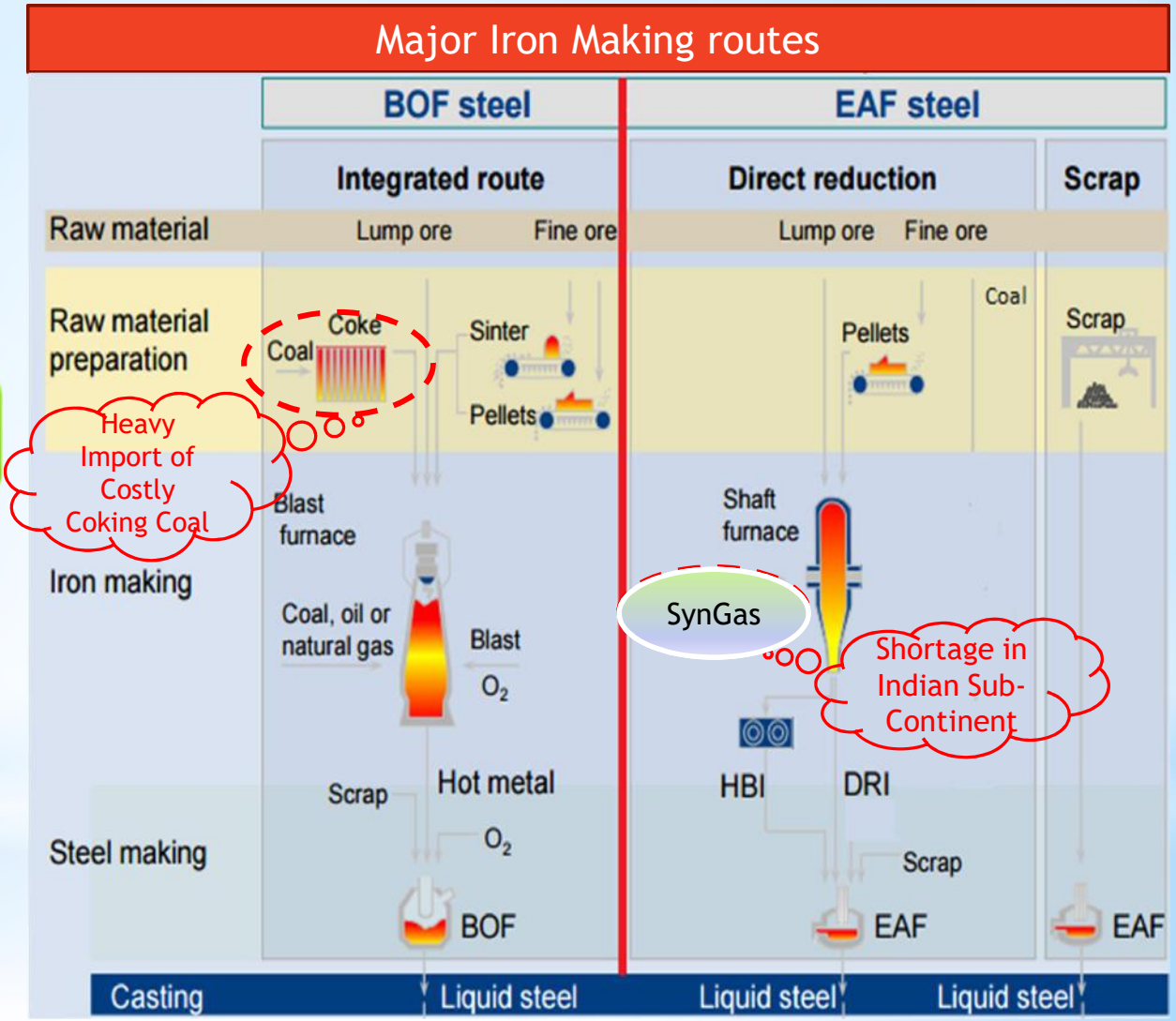
GASIFICATION – INDIAN CONTEXT

PERIOD	TECHNOLOGY	FEED	LOCATION
1940s	Wood Gasification	Wood	FACT - Cochin
1945-1950	Lurgi Fixed Bed	Coal	Sindri
1960s	Winkler Fluidized Bed	Lignite	Neyveli
1960s	Texaco	Naphtha	FACT - Cochin
1970s	Krupp-Koppers Entrained Bed Atm.	Coal	Ramagundam Talcher
1970s	Shell	Fuel oil	Sindri
1980s	Shell	Fuel oil	NFL - Bhatinda, Panipat, Nangal
1980s	Texaco	Fuel oil	GNFC - Bharuch

Selection of Coal Gasification Technology

Selection of Coal Gasification Project

1. Both of the Current Clean Conventional Routes of Iron making are somehow dependent on Imports.
2. However, JSPL also being a supporter of "Make In India" Ideology, tried to use non-coking coal in Clean Steel making.
3. Same is abundantly available in India & can be used effectively.



Selection of Coal Gasification Technology contd..

Blast Furnace Route

1. Centuries old conventional route
2. In India, Metallurgical coal reserves are limited & thus expensive Coking Coal need to be imported

Direct Reduced Iron (DRI)

1. **Abundantly available non-coking coal in country can be used effectively**
2. **Cost of production is low**
3. **Overall Investment is low**

Gas Based

1. Clean Technology
2. Capital cost is comparatively higher
3. Energy Requirement is 20% less than that of rotary kiln based
4. Product suits best steel making qualities
5. DRI fines (-5mm) generated is 5%. Thus, Loss in SMS are less due to low % of fines
6. Sulphur content in DRI is in range of 0.003-0.01%
7. Metallization is 92-94%

Coal Based

1. Prone to pollution
2. Low Capital Cost
3. High Energy Requirement
4. Not suitable for making quality steel (for flat products)
5. DRI fines (-3mm) generated is 30-40%. Thus, Loss in SMS are more due to high % of fines
6. Sulphur in coal is partly attached to DRI & partly goes to atmosphere as SO2 contributing to air pollution
7. Metallization is 86-90%

Selection of Coal Gasification Technology contd..

Blast Furnace Route

Direct Reduced Iron (DRI)

Gas Based

- Reformed Natural Gas
- Coke Oven Gas
- Corex Gas

Coal Based

× *In India Natural Gas availability is limited & not readily available*

× *Coke Oven Gas & Corex Gas are localized & not sufficient*

Syn-Gas from Coal Gasification

India has abundant non-coking coal

Therefore, the only optimum alternate way is Gasification of these coal to produce Syn-Gas for DRI production.

Types of Gasification Technologies

Technology evaluation & Comparison

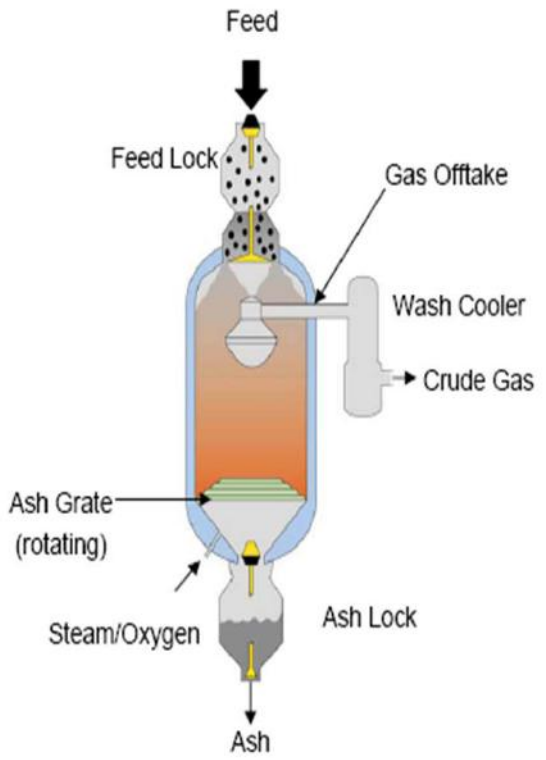
Various Gasification Technologies were considered and evaluated mainly on the basis of Commercial Scale Demonstration, Capital Cost & Operational Cost:

1. Moving/Fixed Bed (Counter- Current, Co-current)
2. Fluidized bed
3. Entrained Flow
   - i) Dry Pulverized solid fuel
   - ii) Fuel Slurry
   - iii) Atomized Liquid Fuel

	FEATURES	Fixed Bed	Fluidized Bed	Entrain Bed
1. a)	Pressure , Kg/cm2	10-30	Atm	30-40
b)	Temperature deg C	1200	1100	1600
c)	Gas-outlet Temp, deg C	675	~850	1370
2	Type of Coal	All ranks	Low rank coal	All types
3	Feed coal size, mm	6 - 50	0 - 9.5	~200 mesh
4	Moisture in feed Coal, wt%	up to 18		<5
5	Maximum ash content, wt%	up to 40	up to 35	up to 25
6	Ash withdrawal	Dry Powder	Dry Powder	Molten Slag
7	Dry gas composition, vol%			
	CO	18-20	34-36	65-66
	H2	39-41	40-42	30-32
	CH4	10-12	3-4	0.4
	CO2	28-30	19-20	1-2
	S ' Compounds	~0.5	~0.5	0.4
	N2 and others	~0.5	1	1
8	H2/CO ratio in gas	2.1	1.25	0.48
9	Calorific value of gas, kcal / Nm3	2600-3400	2640	2980
10	Cold Gas efficiency, %	>85		80-83
11	Carbon Conversion, %	93-99		>93

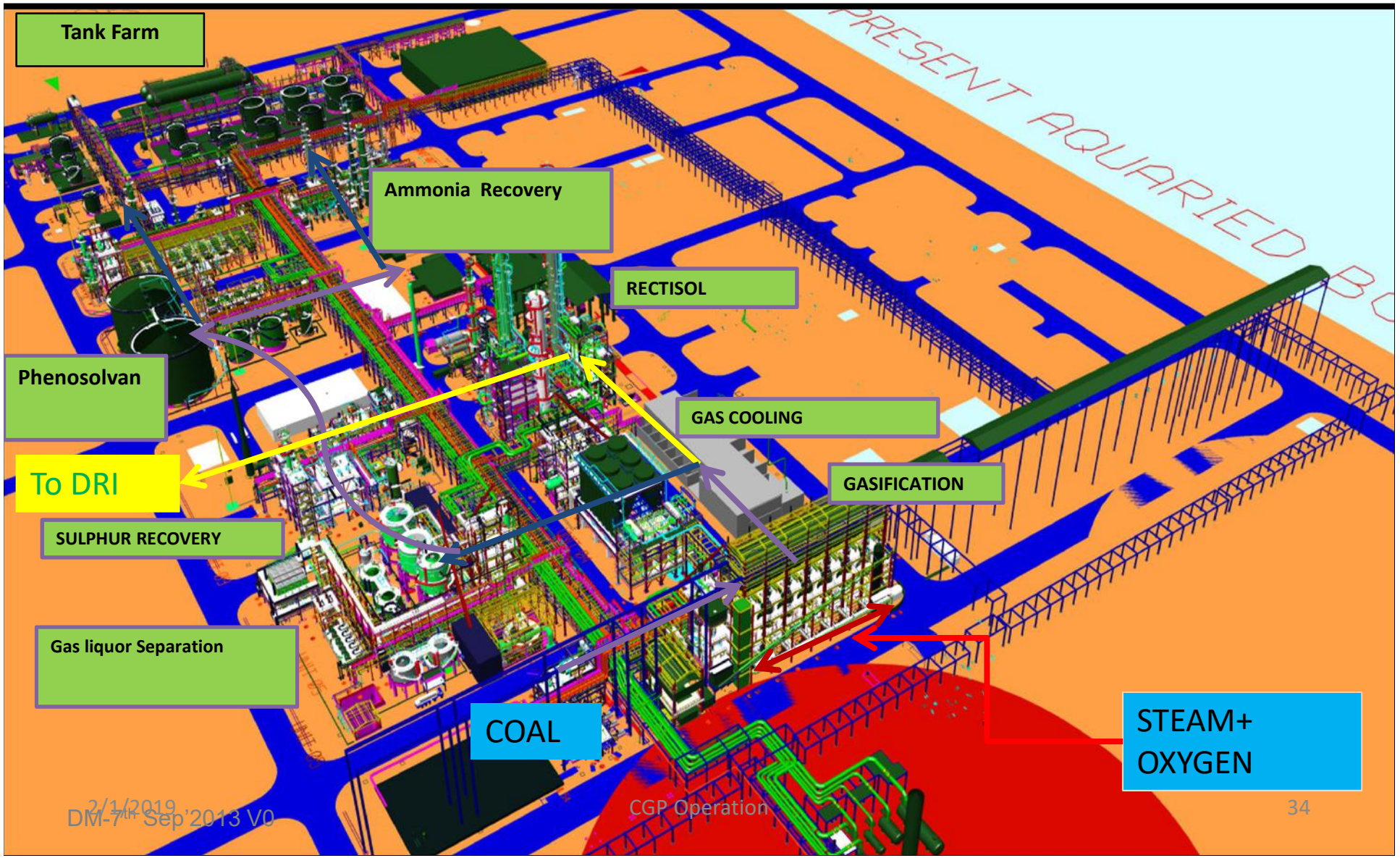
Selection of Fixed Bed Dry Bottom Gasifier at JSPL Angul

- Well demonstrated, mature and Proven Technology with low risk. More than 100 Gasifiers in operation excl. China.
- Suitable for low Rank, high ash content Coal.
- High Carbon conversion efficiency (approx. 95%).
- High Cold Gas efficiency (85%) due to counter-current operation.
- Low Oxygen consumption.
- Gas Composition suitable for steel Industry.
- Ash fusion temperature of Indian Coal is high, therefore, dry bottom type is preferred.
- No Coal drying & grinding required, hence less energy consumption & not hazardous.
- Valuable By-Products like Tar, Oil, Phenol, Ammonia etc.

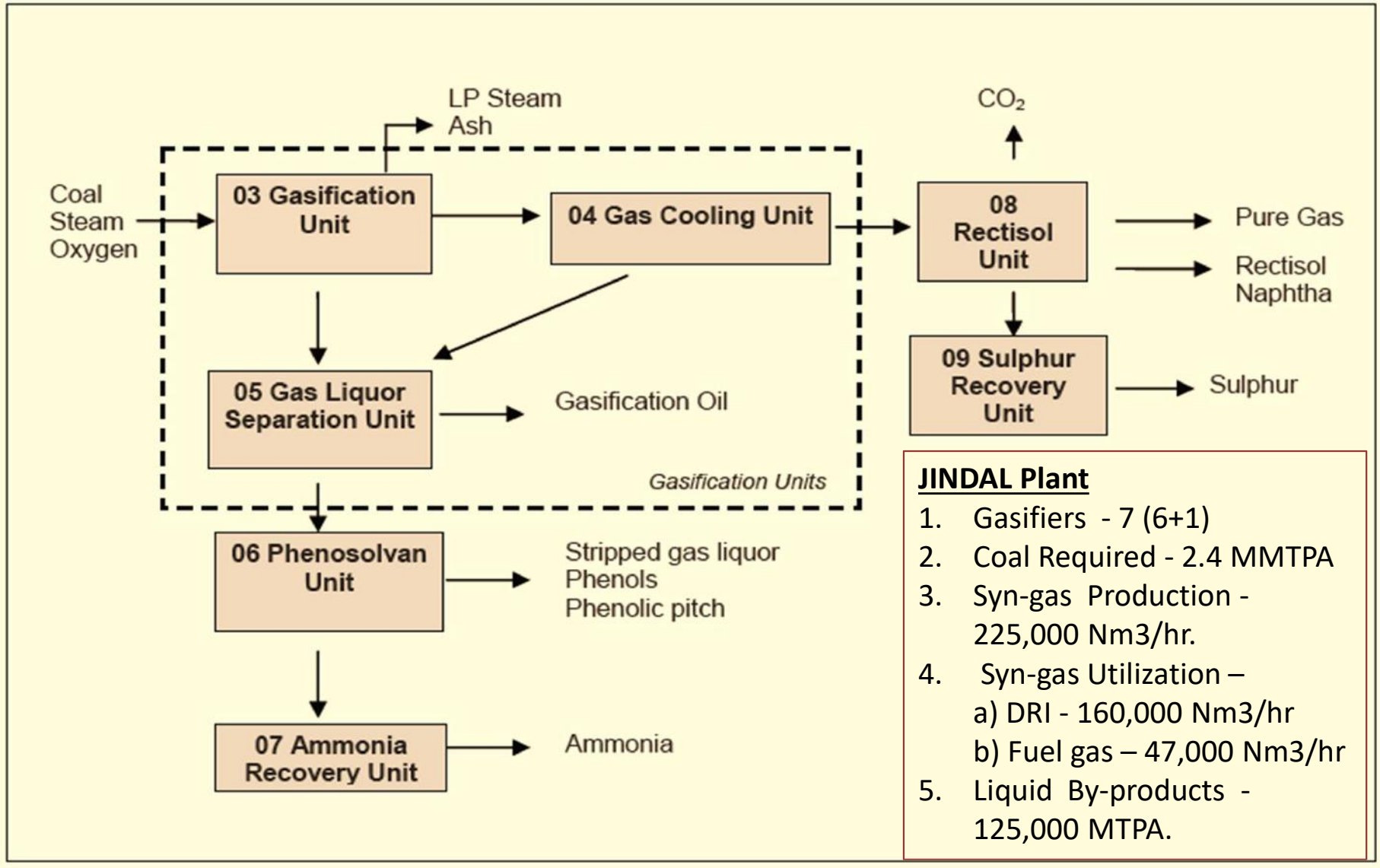


Fixed Bed Dry Bottom Gasifier

Coal Gasification Complex at JSPL Angul at a Glance



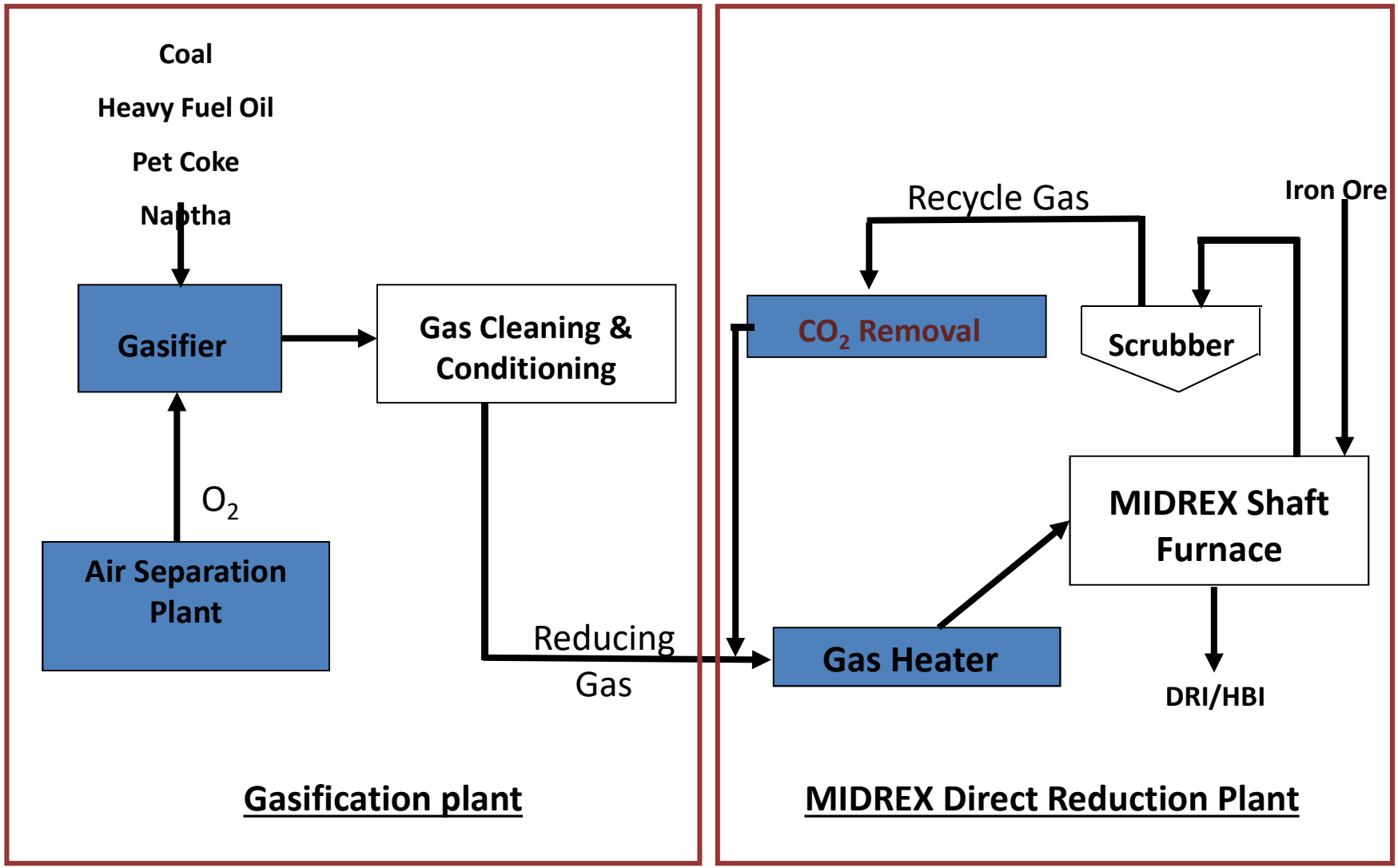
Syn-gas Production route & Units in CGP



JINDAL Plant

1. Gasifiers - 7 (6+1)
2. Coal Required - 2.4 MMTPA
3. Syn-gas Production - 225,000 Nm3/hr.
4. Syn-gas Utilization –
   a) DRI - 160,000 Nm3/hr
   b) Fuel gas – 47,000 Nm3/hr
5. Liquid By-products - 125,000 MTPA.

Syn Gas Integration Route to DRI



CLEAN COAL SPECIFICATION

Coal Analysis (air Dry basis)	Basis	Coal Gasification Plant Angul Unit - Clean Coal Specification (Non-Coking Coal)	Coal Analysis	Basis	Coal Gasification Plant Angul Unit - Clean Coal Specification (Non-Coking Coal)
Proximate Analysis	*%*		**Sizing mm**		
			- 70 to 50	*%*	**>3**
Moisture	*ad*	**7.50**	- 50 to 33	*%*	**16**
Ash	*ad*	**34.3**	- 33 to 22	*%*	**29**
Volatiles	*ad*	**26.3**	- 22 to 15	*%*	**21**
Fixed Carbon	*ad*	**31.9**	- 15 to 10	*%*	**18**
Ultimate Analysis	*%*		- 10 to 7		**7**
Carbon	*daf*	**76.4**	- 7 to 5		**3**
Hydrogen	*daf*	**5.3**	- 5 to 2		**>3**
Nitrogen	*daf*	**1.9**	**Coking Properties**		
Sulphur	*daf*	**0.7**	CO2 Reactivity	*hr-1*	**5.9**
Oxygen	*daf*	**15.7**			
Intial Deformation	℃	**1530**			
Hemispherical	℃	**1590**			
Flowing	℃	**1600+**			

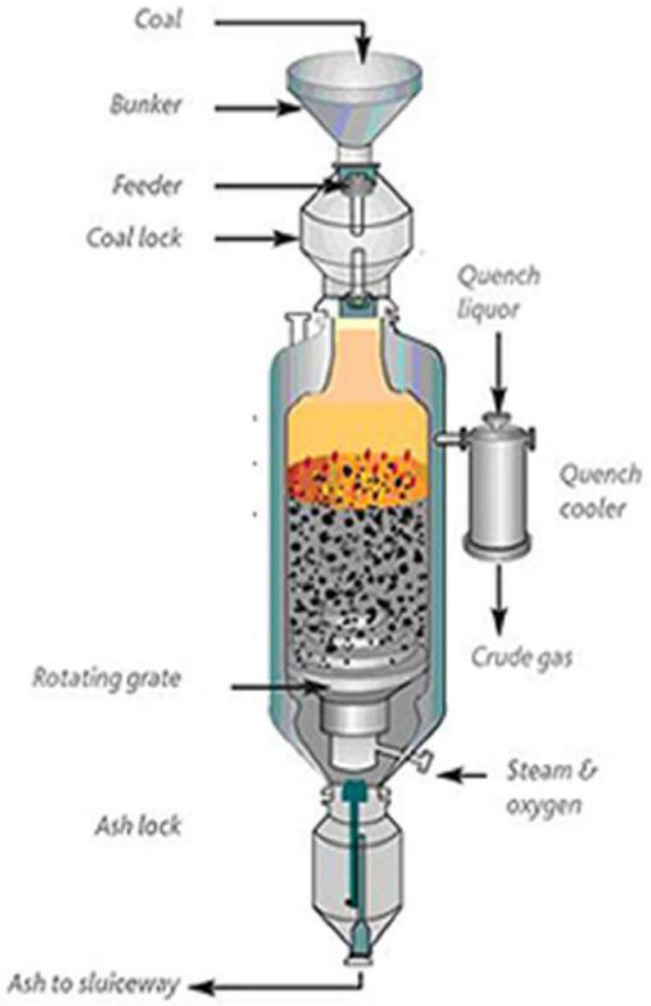
Gasification – Process overview

Gasification Unit

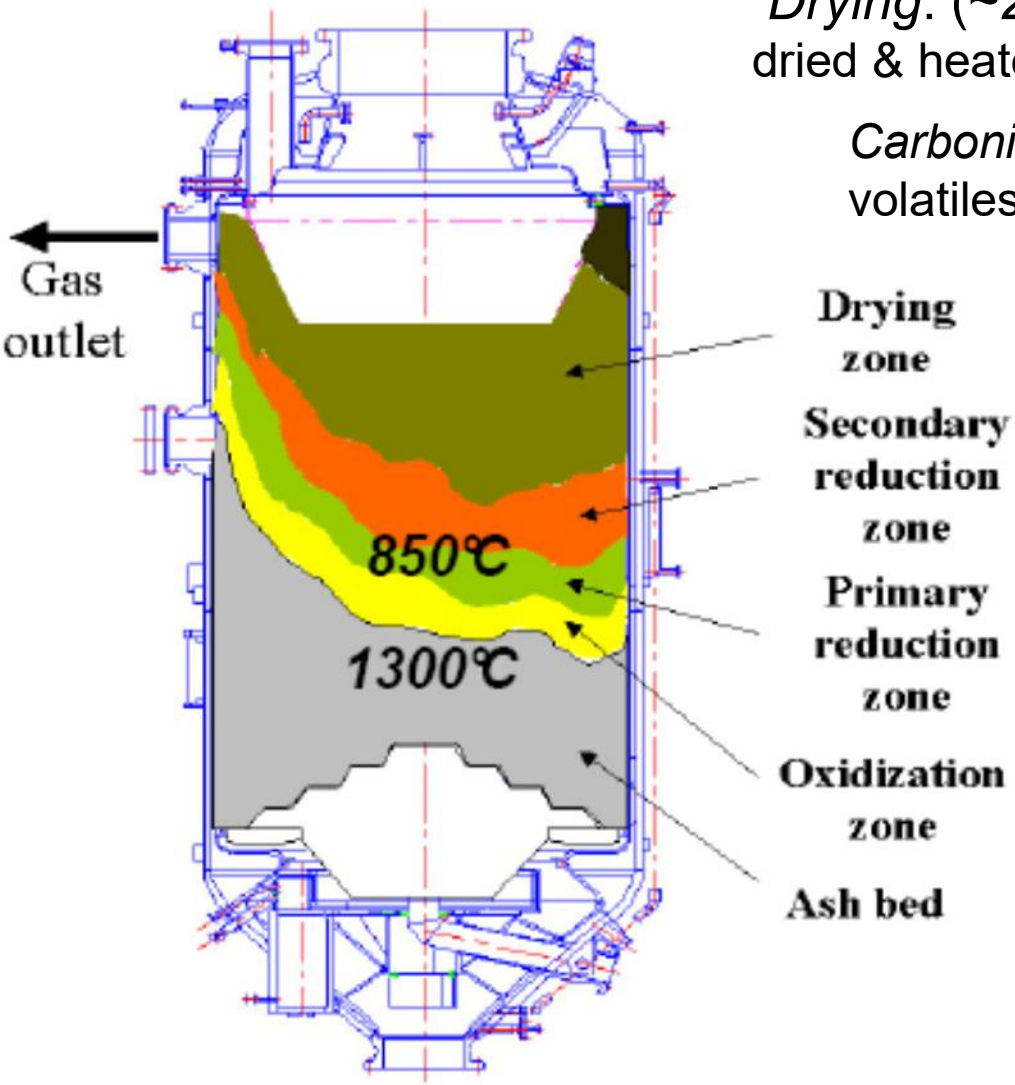
- Sasol-Lurgi gasification is a moderate temperature and pressure process.
- Coal is Gasified typically at a pressure of 29.0 Bar in presence of high pressure steam & pure oxygen to produce syngas for further purification & use.
- Raw Gas (400- 450ºc) immediately quenched with hot gas liquor to approximately 200ºc then it is cooled in Primary Waste Heat Boiler (PWHB) to 190ºC.

Note:- Gasification is the conversion by partial oxidation at elevated temperature of a carbonaceous material into a combustible gas termed as Synthesis gas

The Synthesis gas contains CO, CO2, H2, CH4 and traces of higher hydrocarbons etc.



Gasification – Process overview contd..



Drying: (~200°C)The wet screened coal is dried & heated up

Carbonization Zone: (500~600°C The volatiles contains in coal are driven out

Gasification Zone: (~800°C)

$C + H_2O = CO + H_2$ -118.5 kJ/mol

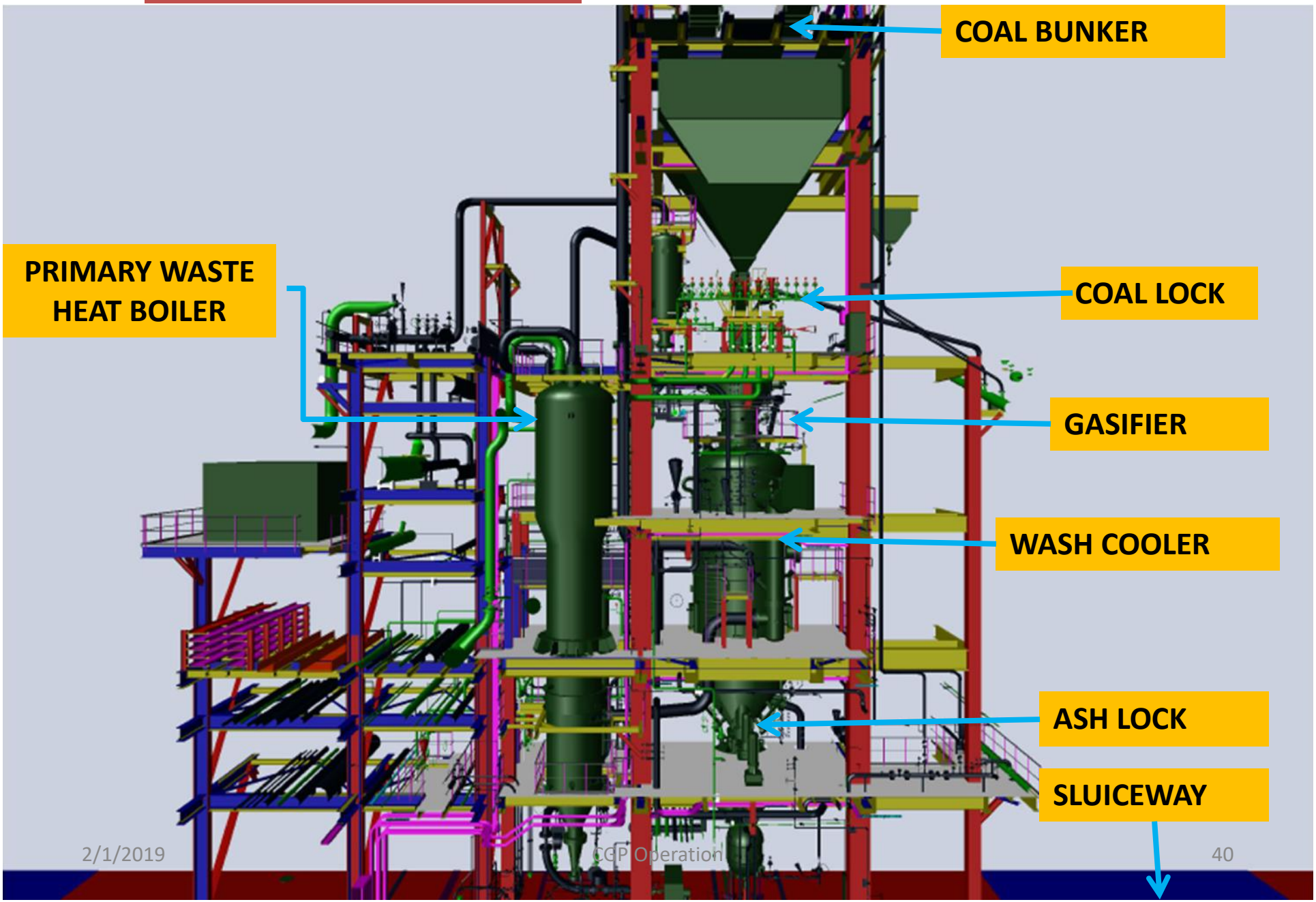
Combustion Zone: (~1200°C)

$C + O_2 = CO_2 + 405.5$ kJ/mol

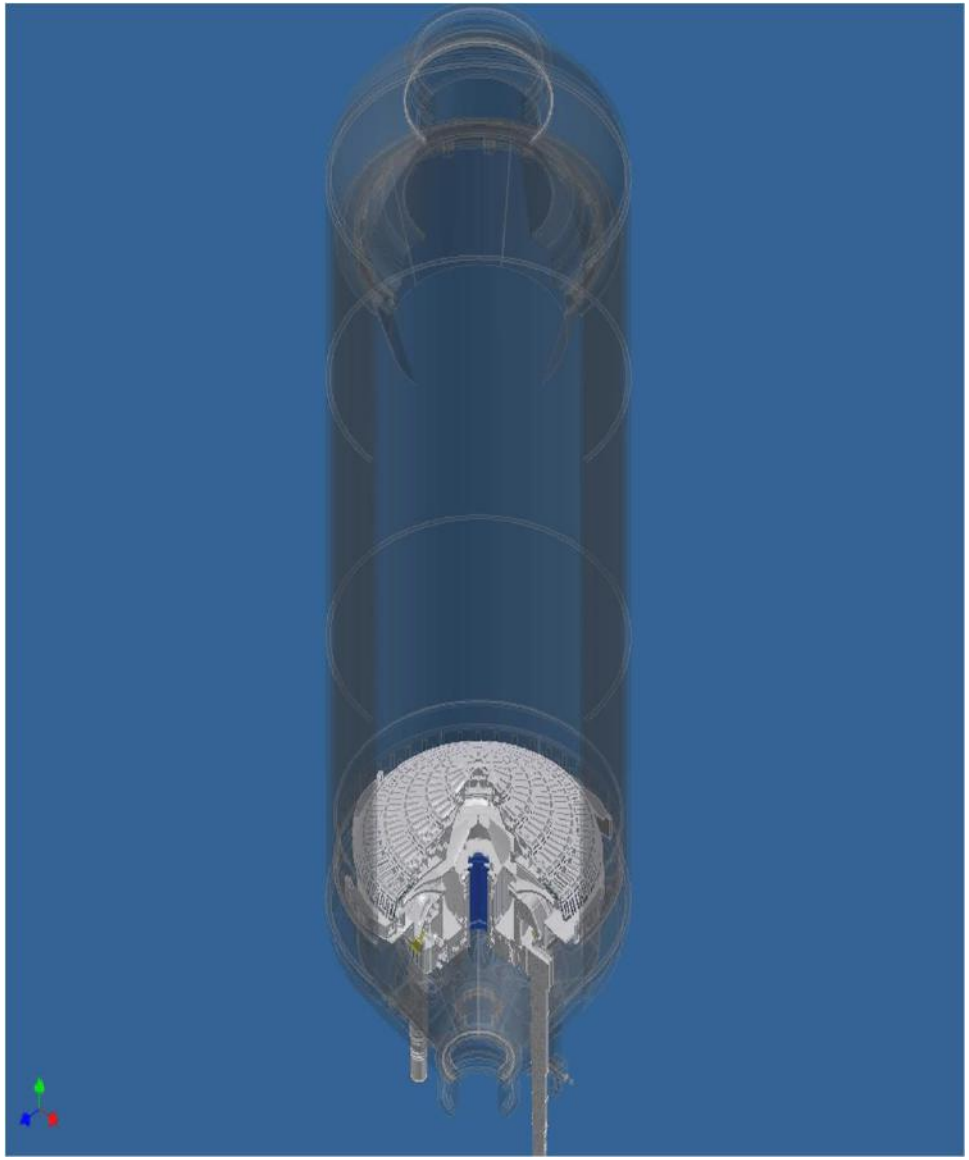
$C + ½ O_2 = CO + 122.9$ kJ/mol

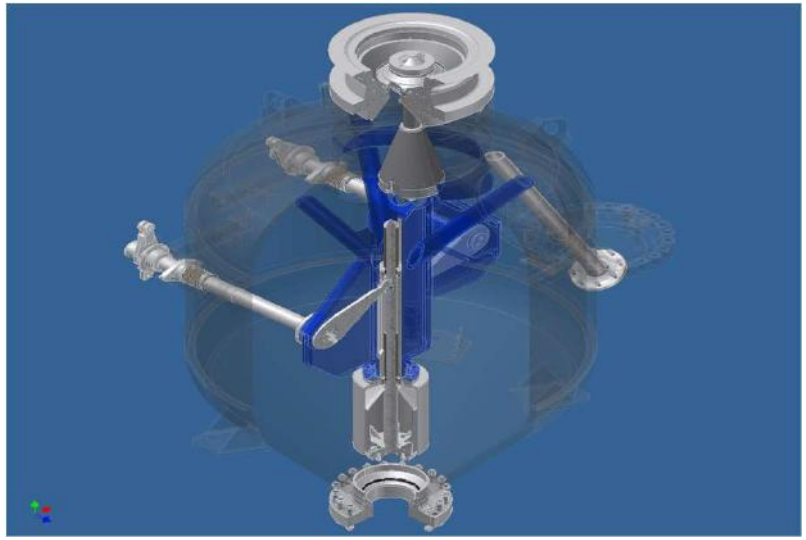
Ash Bed: Ash is cooled and agent is heated

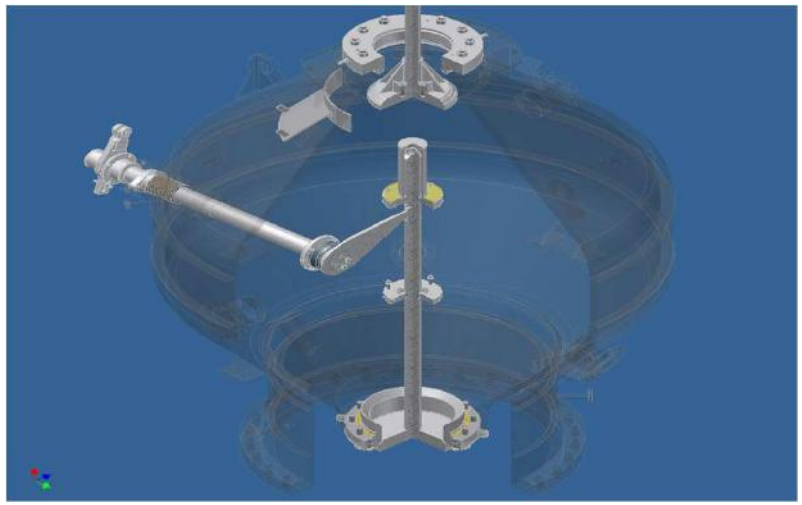
GASIFICATION FRONT VIEW



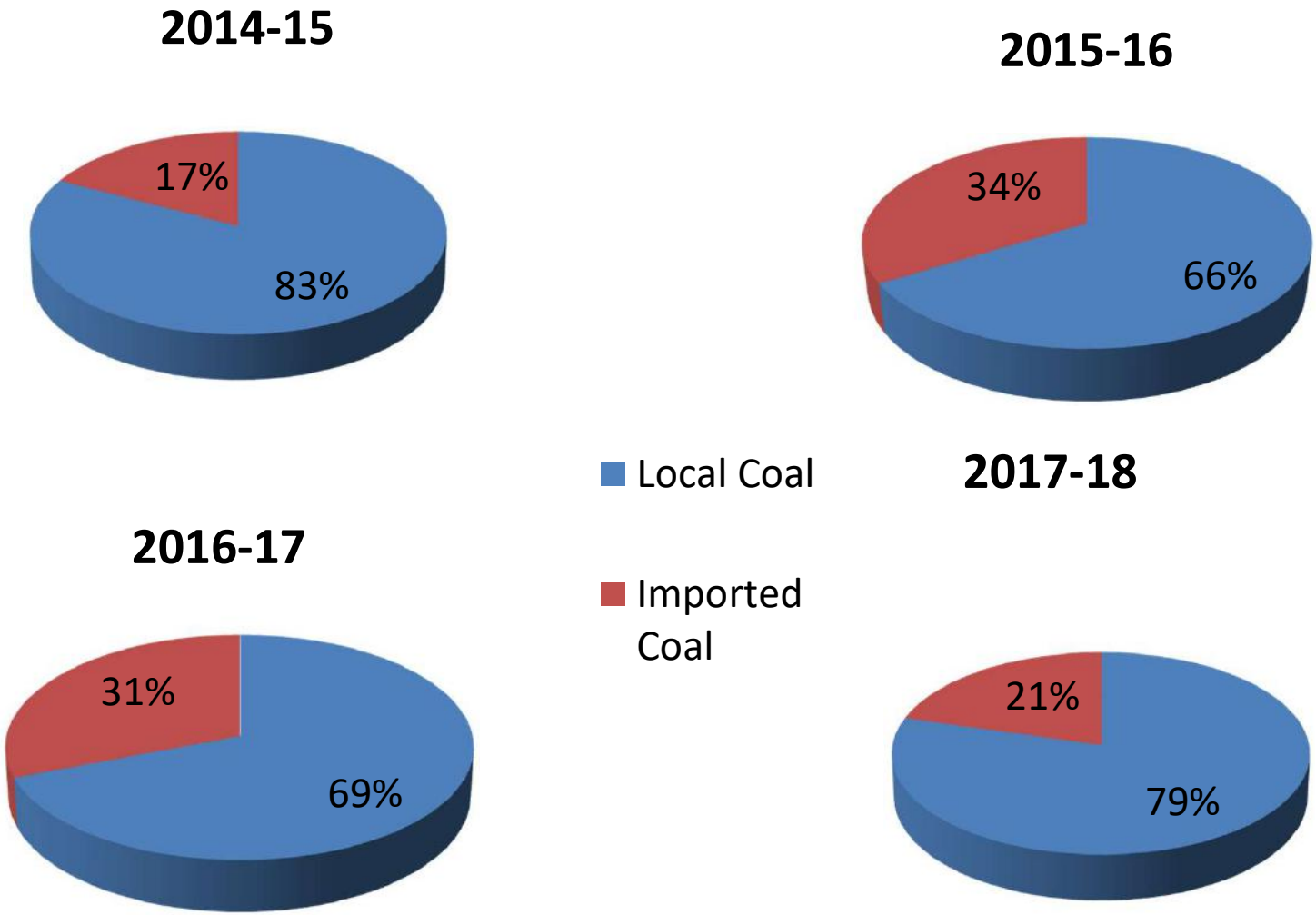
Gasification – Process overview contd..







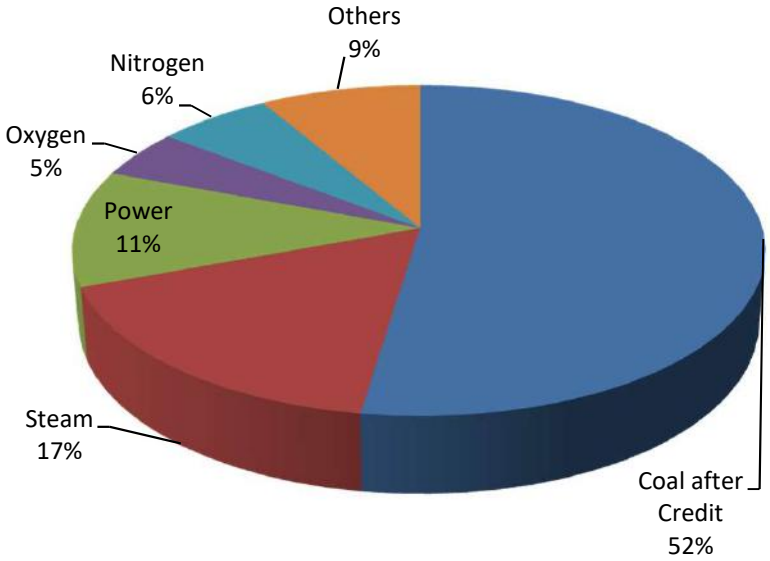
Coal Mix used at Angul



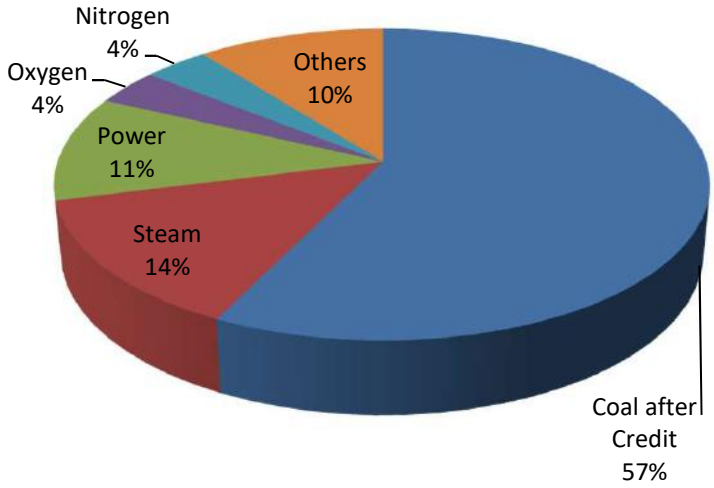
Coal Sourcing at Angul

Year	Coal	Washed coal	Imported Coal (SA)	PCI Coal	Raw coal	Anthracite Coal	ECL Coal	CCL Coal
FY 2014-15	7,23,675	5,98,340	1,25,336	0	0	0	0	0
FY 2015-16	9,51,427	6,23,909	3,07,613	15,307	4,598	0	0	0
FY 2016-17	7,90,000	4,37,808	1,46,694	45,918	90,341	51,545	12,935	4,759
FY 2017-18	1,47,984	94,373	30,283	152	11,113	0	9,410	2,653

Variable cost



2016-17



2015-16

> 90% variable cost of gas depends on coal

Specific consumption vs %FC

JAN 16 to MAY-16 & JAN 17

Month	JAN	FEB	Mar	Apr	May (till 19th)	Jan-17
%FC	44.82	41.41	41.11	41.50	45	37.3
SPC	1.13	1.25	1.20	1.26	1.14	1.41
Syngas/O2 ratio	4.80	4.57	4.5	3.91	4.43	3.87
SPC HP Steam	0.93	0.97	0.98	1.22	0.97	1.19
SPC O2	0.21	0.22	0.22	0.26	0.23	0.26
SPC N2	0.20	0.20	0.20	0.39	0.22	0.24
Syn Gas consp. MNM3	80.38	73.26	71.85	33.70	59.97	68.94

Gasification By Products

By Product	Description	Typical Uses	Potential Buyers
De-pitched Tar Acid (DTA)	▪ Tar acids are a mixture of phenols found in tars and tar distillates that is toxic combustible and soluble in alcohol and coal tar hydrocarbons	▪ Used as a wood preservative ▪ As insecticide for farm animals ▪ Disinfectants	▪ Chemical Industry (including insecticide and Detergent manufacturers) ▪ Furniture manufacturers
Phenolic Pitch	▪ Residual oil left as a by product with potential to be used as illuminating fuel or be further refined into	▪ Sasol in South Africa is using it's Lurgi gasification to provide coal oil that is being refined to gasoline or diesel fuel	▪ Petroleum and petrochemical companies
Rectisol Naphtha	▪ These are hydrocarbons that are recovered as a by-product during the removal of acidic gases from raw syngas	▪ As diluent in bitumen mining ▪ In the petrochemical industry for producing olefins and as feedstock for high octane gasoline	▪ Chemical industry ▪ Petrochemical industry ▪ Mining industry
Gasification Oil	▪ Oil is the hydrocarbon fraction with specific gravity<1 that is condensed when the raw syngas exiting the gasifier is cooled from 35-160 degrees C	▪ Can be used as the basis for further refining and processing to produce Fischer Tropsch liquids like diesel, furnace oil, gasoline etc.	▪ Petrochemical industry
Clear Tar	▪ Tar is a hydrocarbon fraction with specific gravity>1 that is condensed when raw syngas exiting the gasifier is cooled to +/-160 degree C	▪ Tar is a key component in road construction, and in manufacture of paints, synthetic dyes and photographic materials ▪ It is also used in medicinal shampoos and ointments	▪ Construction industry ▪ Paint and dye manufacturers ▪ Pharmaceutical companies

Gasification By Products contd..

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Additionally, these by-products can be further processed to value added products; benefit-cost analyses required to establish value

PRELIMINARY

Selected By-Products	Typical Value-Added Products	Potential End Products	Customer Industries
De-Pitched Tar Acid (DTA)	Phenols	Disinfectants	Chemical
	Cresols	Solvents	Chemical
	Light Oils	Gasoline Additives (Benzene)	Petroleum
	Heavy Oils	Dye (Chrysene)	Dye/Paints
Phenolic Pitch	Acetophenone	Resins, Fragrances	
	Phenol	Bakelite, Nylon	Clothing/Baking Goods
	Cumene	Phenol, Acetone	Baking Materials
Rectisol Naphtha	Ethylene	Packaging and Carrier Bags	Plastics/Packaging Material
	Propylene	Films and Packaging	
	Butadiene	Synthetic Rubber	Tires/Hoses
	Benzene	Gasoline Additives, Solvents	Petroleum
	Xylene	Solvents	Chemical
	Toluene		
Gasification Oil	Diesel (FT)	Feedstock, Direct Use	Energy/Power
	Gasoline (FT)		
	Waxes	Polishes	Varnish/Furniture
Clear Tar	Creosote	Antiseptic/Astringent	Cosmetics/Pharmaceutical
	Cresolene	Disinfectants	Chemical

Challenges for Gasification Technology

Challenges for Clean Coal

- Complex projects
- High cost of new technology
- Need to strengthen research environment
- Expensive & high risk investment for any single industry player
- Need collaborations with emerging technology providers
- Needs strong support from Indian Government
- Need Public/ Private partnerships and partnership with technologically advanced players

Challenges for Gasification Technology contd..

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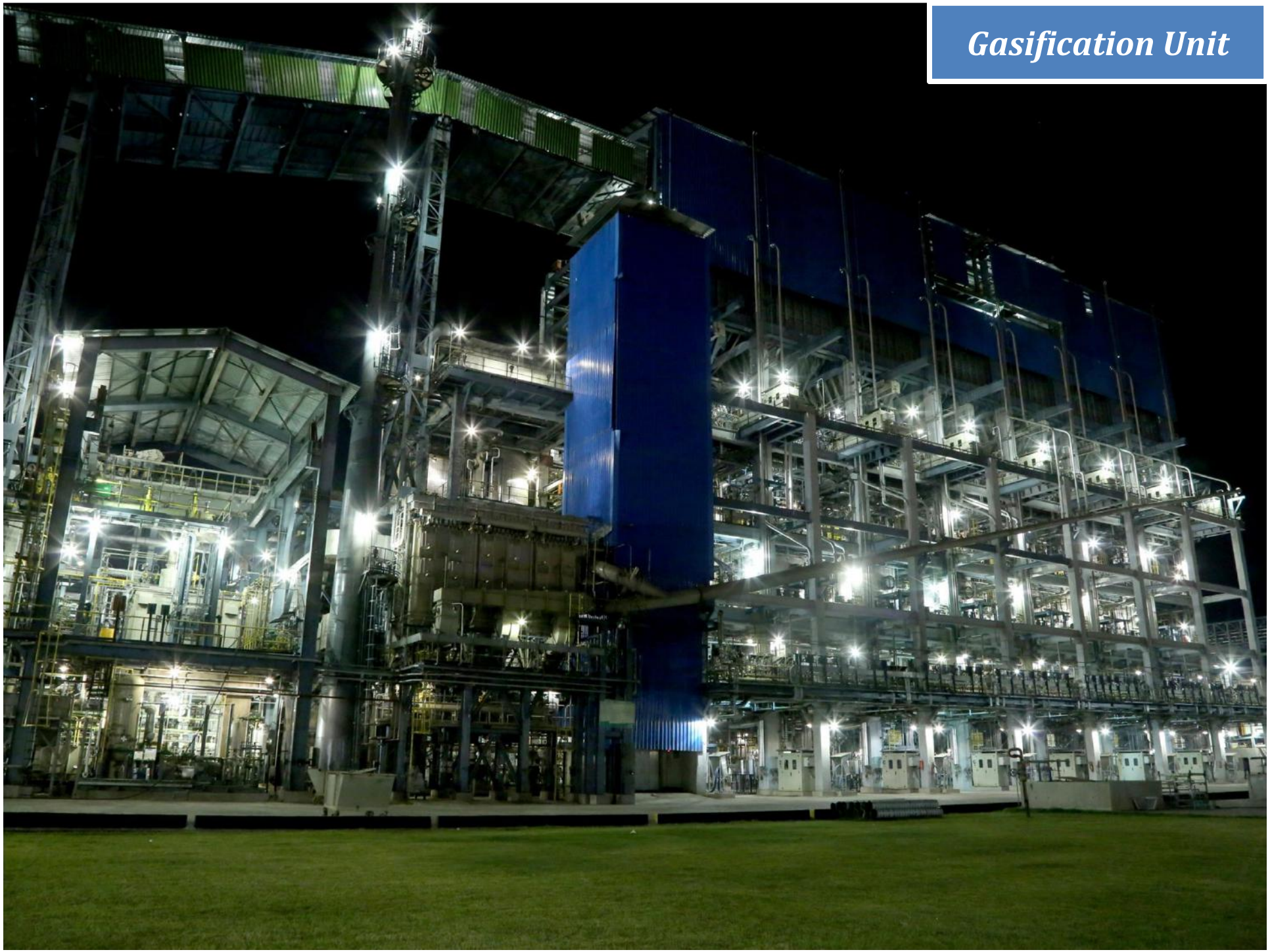
Progressive policy needed to accelerate improved coal utilization

- Accelerate opening up of Coal sector for private sector investments
- Develop clear policy on bidding and allotment of coal blocks
- Open new coal blocks for bidding
- Expedite clearances for new projects
- Strengthening of coal supply chain
- Promote consortia (private + public) for pre competitive technology development with financial support
- Policy concessions and economic incentives for development and deployment of new technologies in India
- Coal pricing to be market linked

Government's proactive role in building technical & operational capabilities is crucial



Gasification Unit

Gas Cooling Unit

Gas Liquor Separation Unit

18th December 2017

Rectisol

Phenosolvan unit

Ammonia Recovery Unit

Sulphur Recovery Unit


Flare Stack

THANK YOU