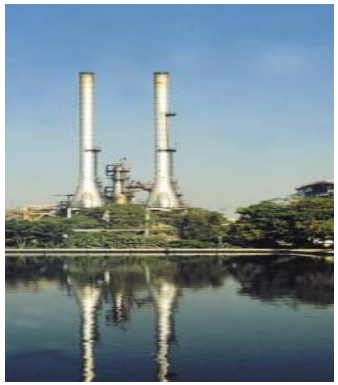
Engineers India Limited

इंजीनियर्स इंडिया लिमिटेड (भारत सरकार का उपक्रम)
ENGINEERS INDIA LIMITED (A Govt. of India Undertaking)



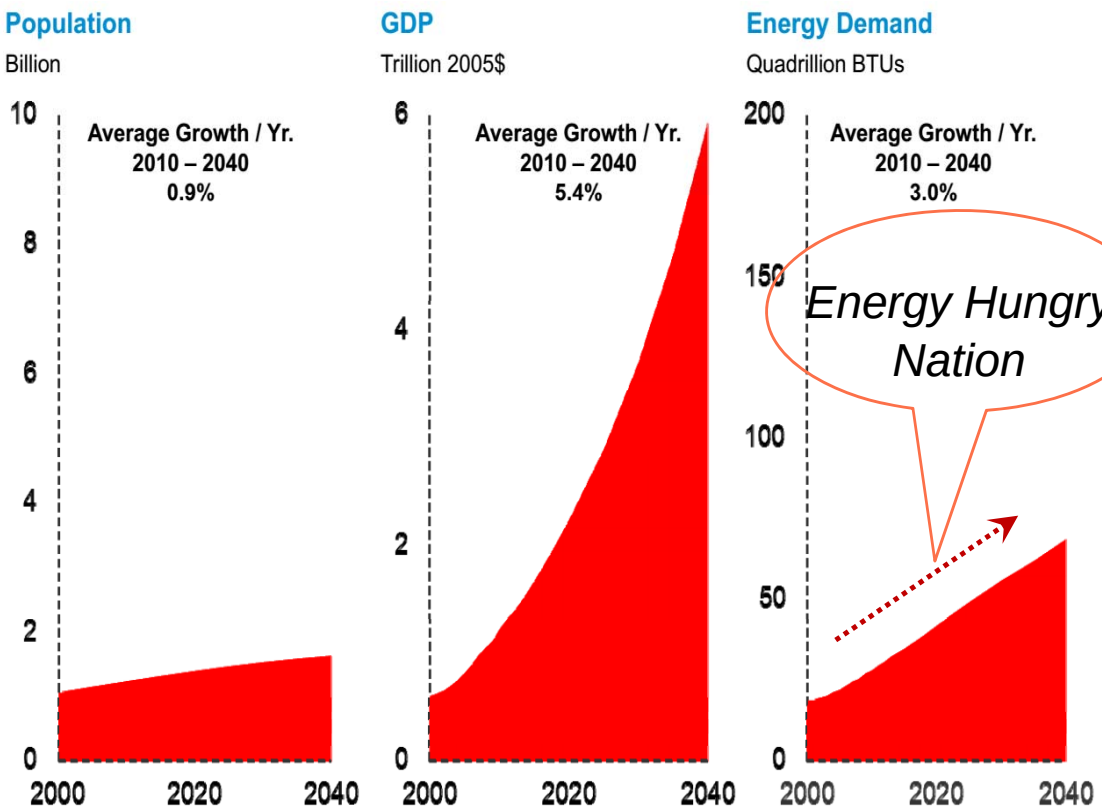
Multi product generation from Coal via gasification/catalytic gasification

Gasification India Feb 2016

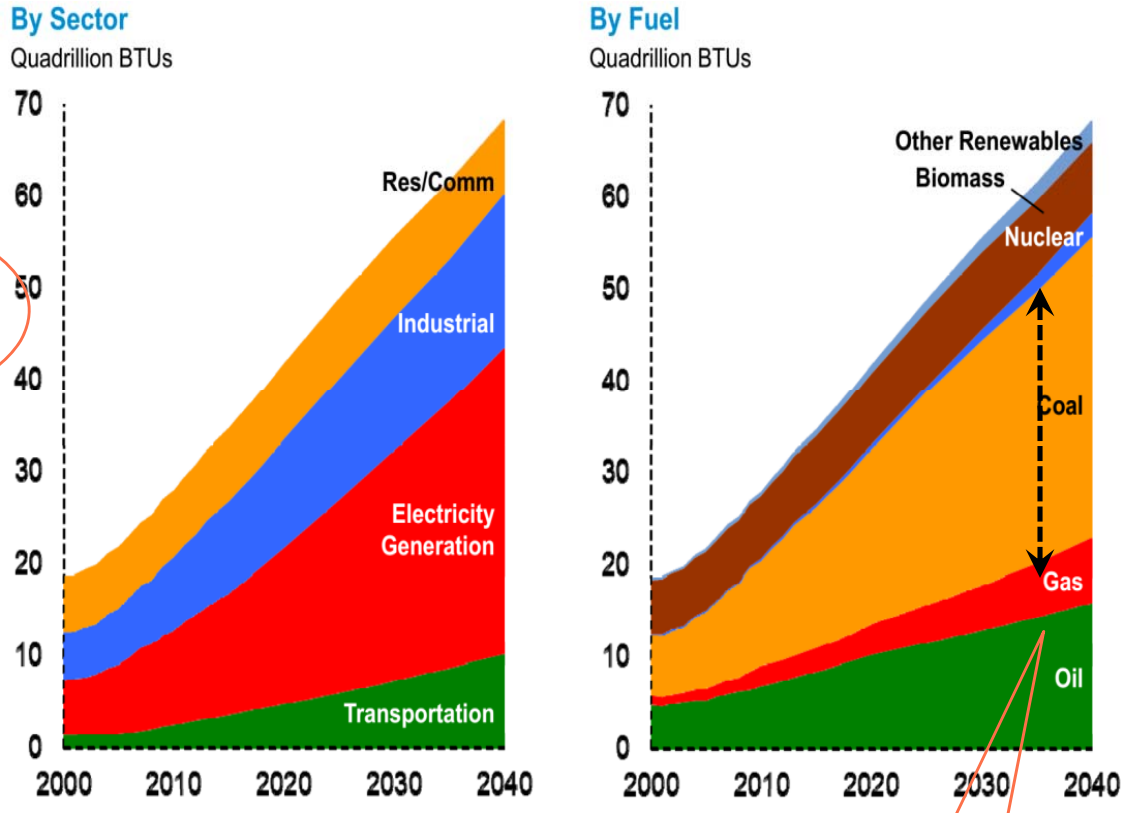
Outline

- Introduction
- Coal Gasification
- Coal Liquefaction Technologies
- Multiproduct Generation
  - Syngas Cleaning & Conditioning
  - Fischer-Tropsch Synthesis
  - SNG
  - Methanol
  - DME
  - Ammonia
- Directional Economics
- Challenges & Opportunities

Future Energy Scenario - India



(a) Growth Vs Energy Demand Trend



(b) Energy Demand and Supply

Fossil Resource Starving

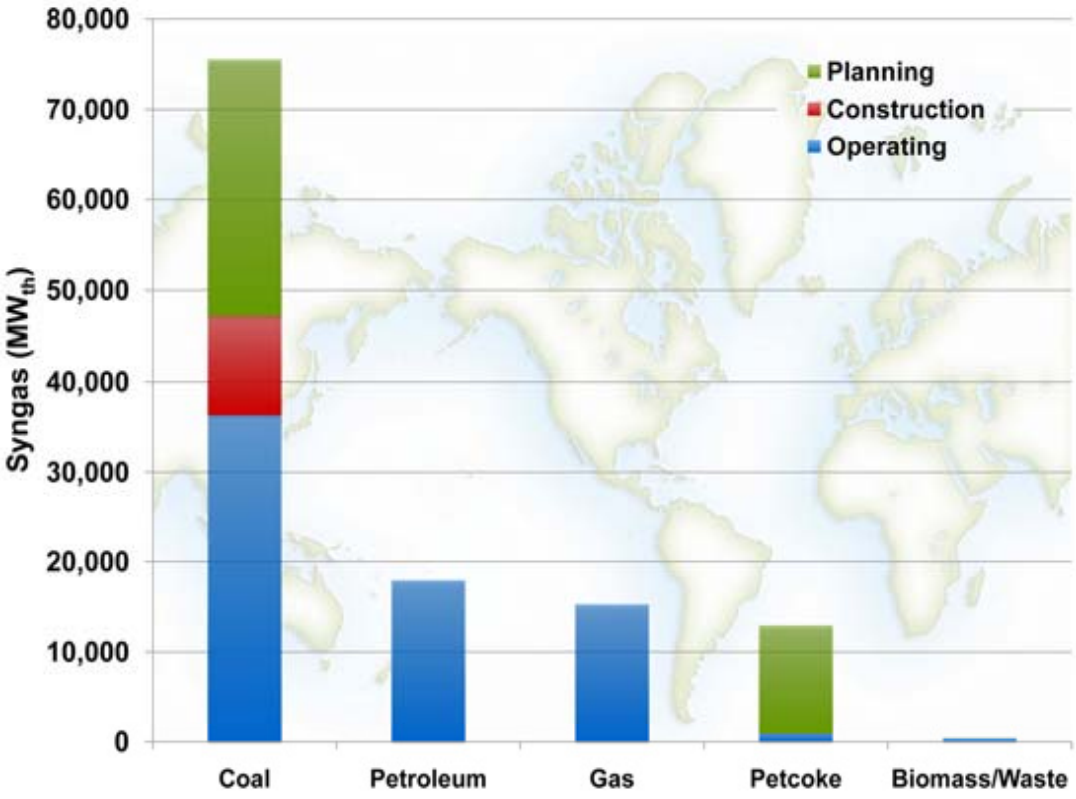
India Imports –
78 % of its oil,
35 % of its gas, &
even 34% of Coal

International Oil & Gas Price, Shortage of Resources are bottlenecks for **India's Economic Growth**

Source: India: Towards Energy Independence 2030

Source: ExxonMobil 2014 Outlook for Energy

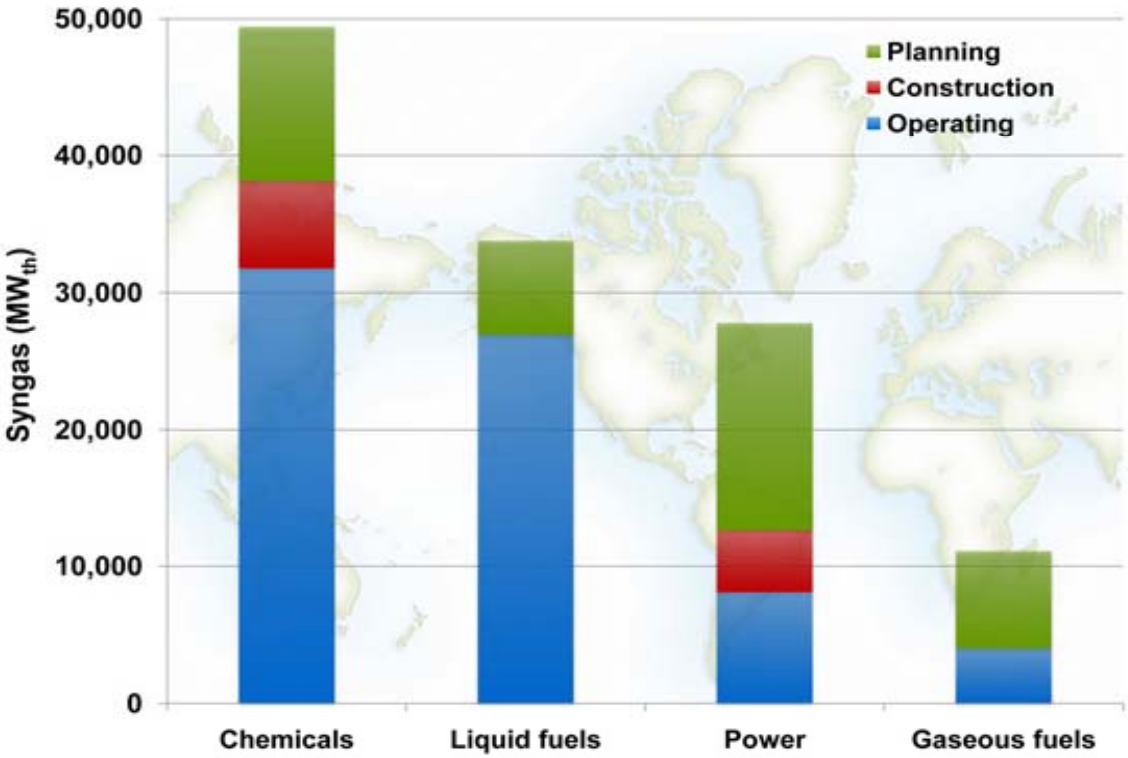
Gasification Feedstock

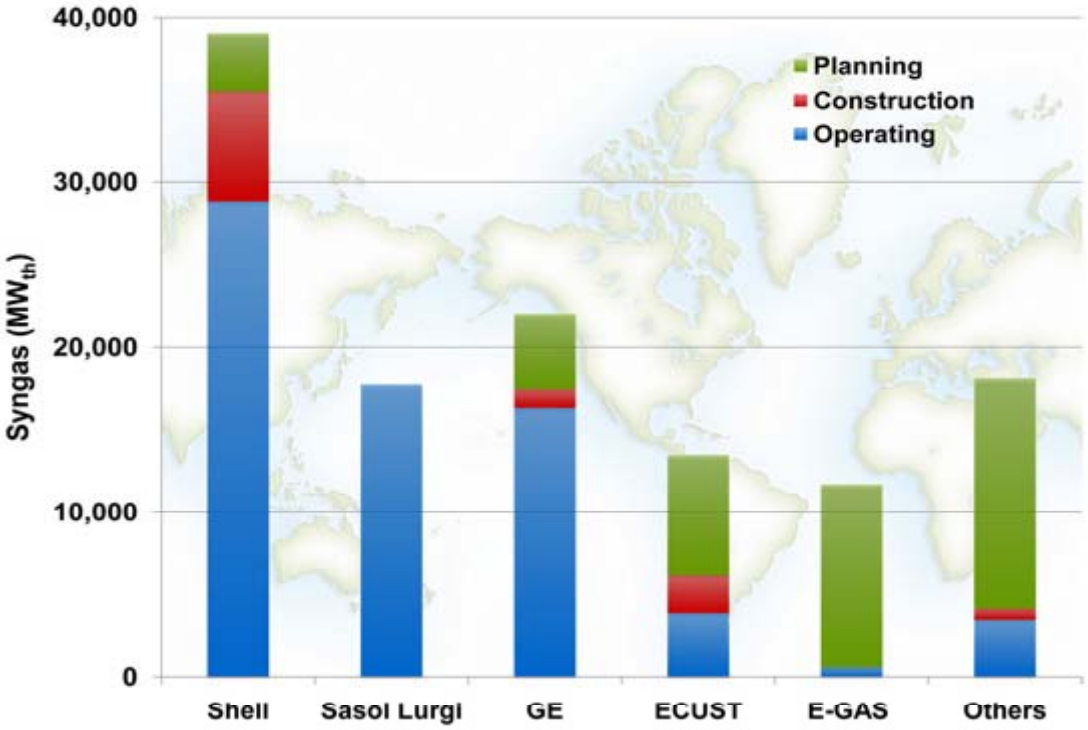


Feedstock		Operating 2010	Under Construction 2010	Planned 2011-2016	Totals
Coal	Syngas Capacity (MW_{th})	36,315	10,857	28,376	75,548
	Gasifiers	201	17	58	276
	Plants	53	11	29	93
Petroleum	Syngas Capacity (MW_{th})	17,938			17,938
	Gasifiers	138			138
	Plants	56			56
Gas	Syngas Capacity (MW_{th})	15,281			15,281
	Gasifiers	59			59
	Plants	23			23
Petcoke	Syngas Capacity (MW_{th})	911		12,027	12,938
	Gasifiers	5		16	21
	Plants	3		6	9
Biomass/Waste	Syngas Capacity (MW_{th})	373		29	402
	Gasifiers	9		2	11
	Plants	9		2	11
Total Syngas Capacity (MW_{th})		70,817	10,857	40,432	122,106
Total Gasifiers		412	17	76	505
Total Plants		144	11	37	192

- **Coal is at the leading position**
- **Plannned 48 new plants ; 93 gasifiers , 40 are coal based**
- **Plants under construction are mostly coal fired**
- **Planned addition of about 40,000MWth 7-% are coal fed and 30% are based on Petcoke**

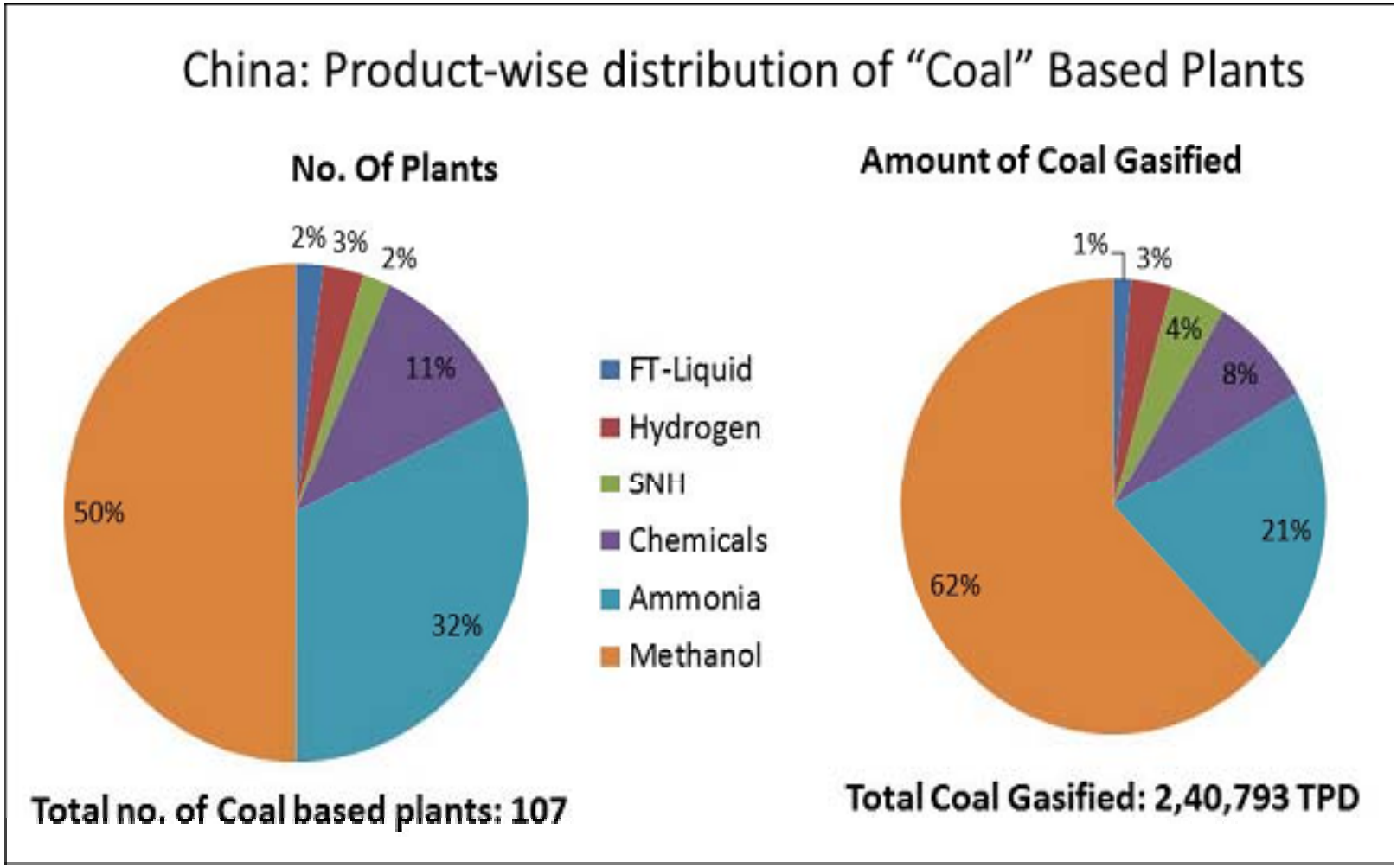
End Destination of Syngas





- **Chemicals leading position**
- **Plants under operation and construction are based on Shell technology**
- **Once planned capacities are added a larger proportion of plants will be sourced from GE**

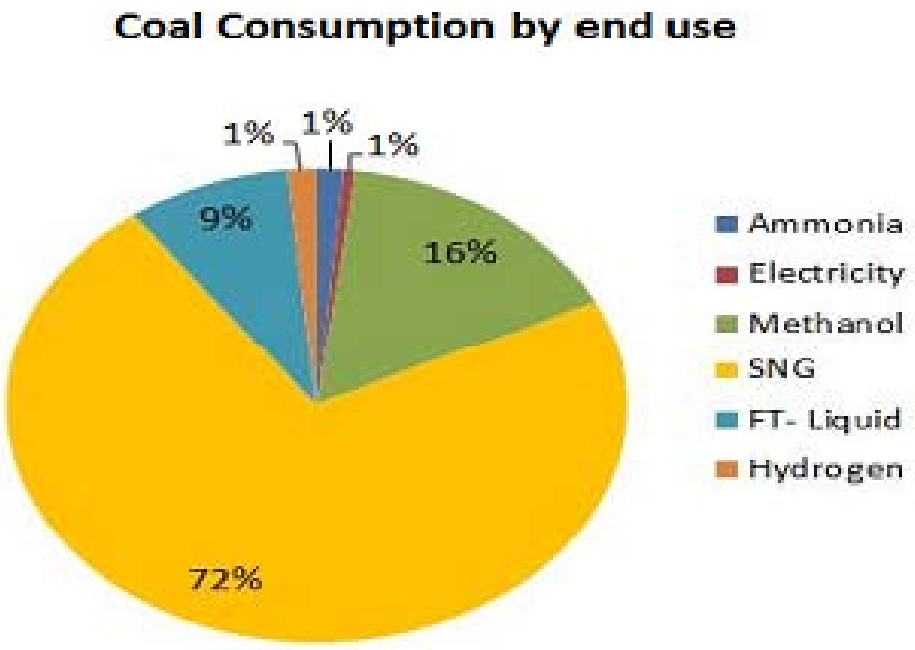
China Gasification- Applications



China Coal Gasification Projects - Trend

Chinese New Projects (2015 – 19): Coal Consumption Pattern

Chinese New Plants End Use		
End Product	**Number**	**Coal Consumed (TPD)**
Ammonia	3	8,250
Electricity	1	3,690
FT- Liquid	4	51,200
Hydrogen	2	9,000
Methanol	11	94,404
SNG	20	4,34,470
Total	**41**	**6,01,014**



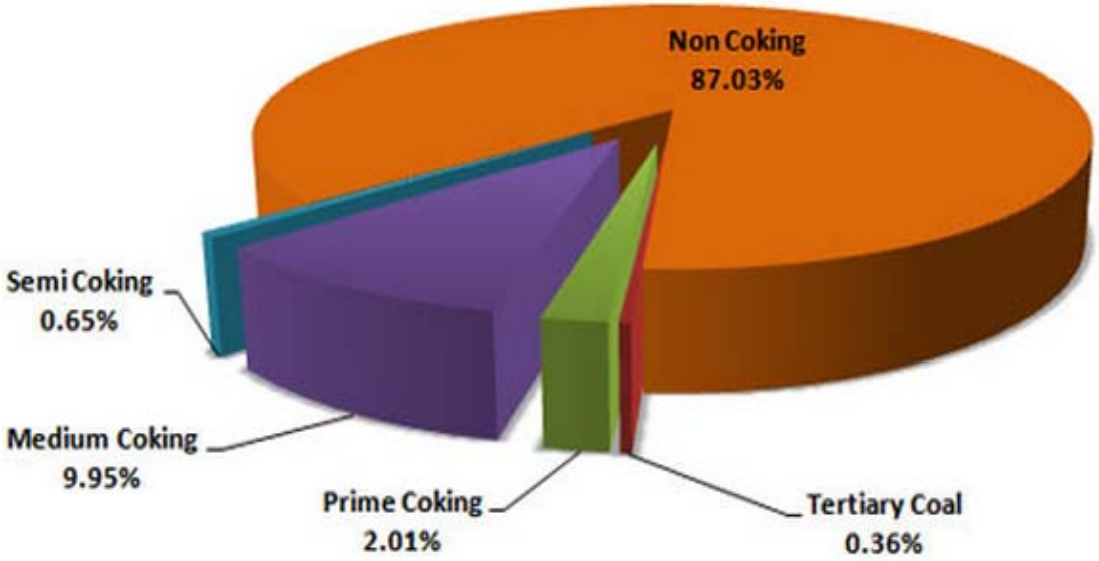
Huge Investment in Coal to SNG Projects in China

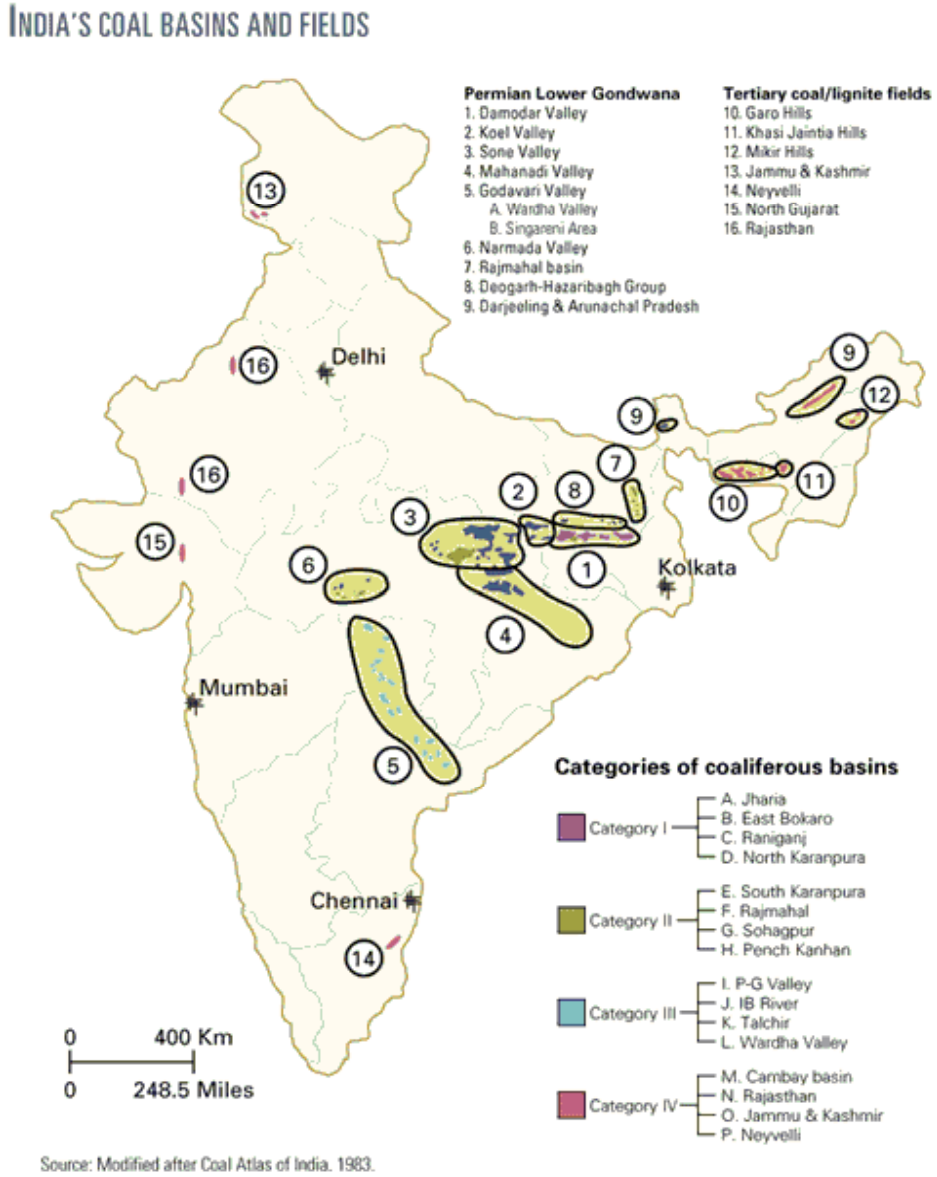
Major Characteristics of Indian Coal (1)

High Ash & Low Calorific Value- (less energy/ton coal).
Low Sulphur*
High Reactivity
High Ash Fusion Temperature (AFT)

*Some coal in Assam has high sulphur, low ash (2-10 %).

Distribution of Indian Coal According to Type





Source: Modified after Coal Atlas of India, 1983.

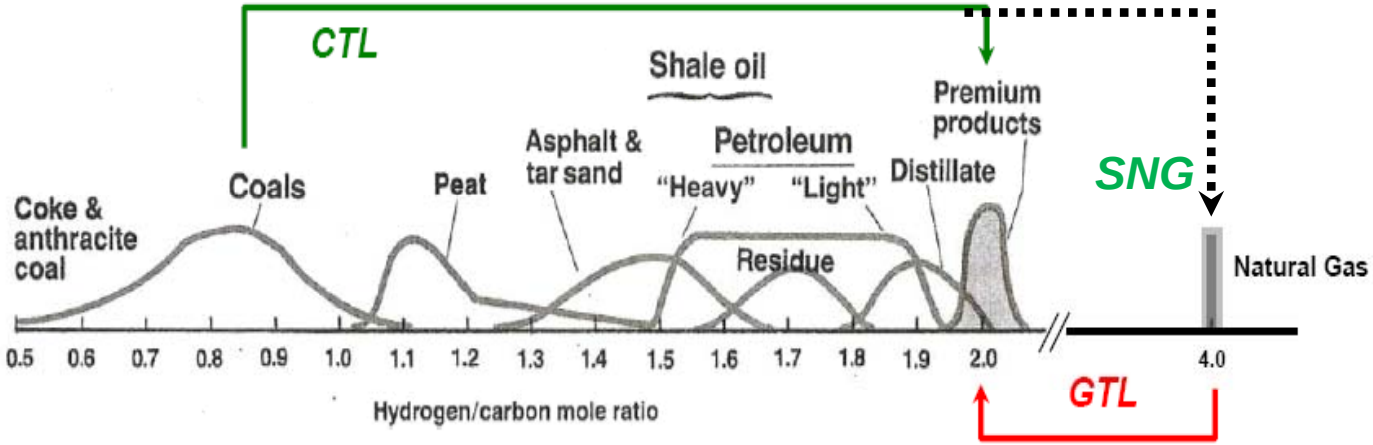
Major Characteristics of Indian Coal (2) - Examples

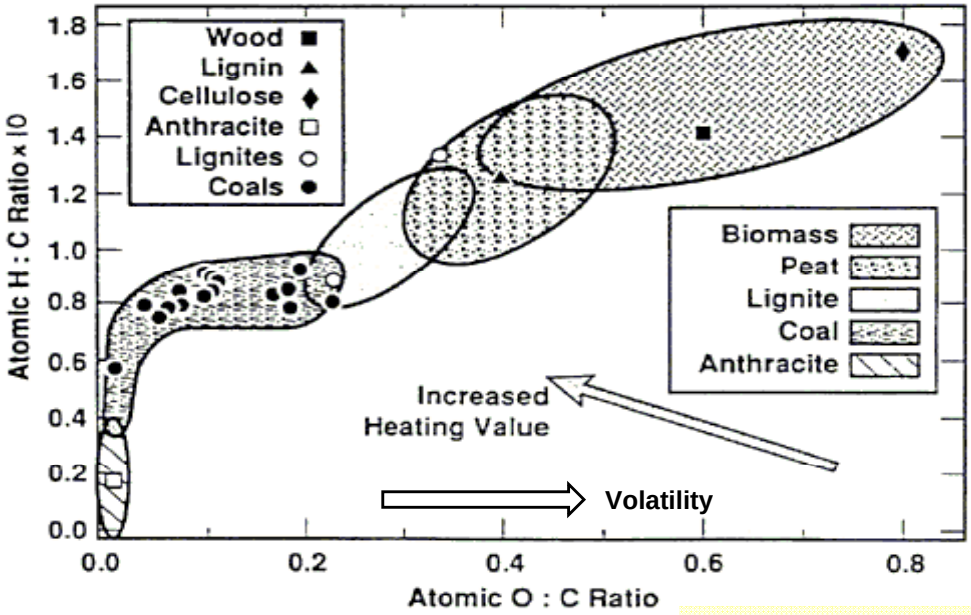
Parameter	Coalfield (colliery)				
	North Karanpura (Ashok/ Piparwar)	Korba (Dipka)	Singrauli (Bina)	Talcher (Gopal Prasad)	Ib-valley (Gopalpur)
Proximate (wt.%)[a]					
Moisture	5.0–9.0	6.0–8.0	6.0–8.0	6.0–8.0	5.0–8.0
Ash	22.0–48.0	33.0–43.0	40.0–45.0	40.0–50.0	40.0–50.0
Volatile matter	23.0–29.0	25.0–28.0	25.0–28.0	22.0–26.0	22.0–26.0
Ultimate (wt.%)[b]					
C	81.0–82.0	80.0–82.0	78.0–81.0	79.0–82.0	79.0–82.0
H	4.8–5.0	5.0–5.2	4.6–5.1	5.2–5.6	4.7–5.2
N	1.6–1.7	1.5–1.6	1.6–1.8	1.8–1.9	–
S	0.6–0.7	0.6–0.7	0.4–0.7	0.7–0.9	–
Gross calorific value (HHV), (kcal/kg)	3000–5700	3500–4300	3300–3700	2900–370	2900–3700
Ash fusion temps. (°C)					
Softening point	1190–1230	1180–1210	1120–1220	1100–1260	1030–1200
Hemispherical point	1400	1400	1400	1400	1400
Hardgrive grindability index	52–58	52–60	50–60	50–60	45–55

[a]Analysed at 40°C and 60% relative humidity.
[b]Analysed as dry ash free (d.a.f.).

Ref: Iyengar, R.K. & Haque R. Gasification of high-ash Indian coals for power generation. Fuel Processing Technology, 27 (1991) 247-262

Coal vs. other fuels





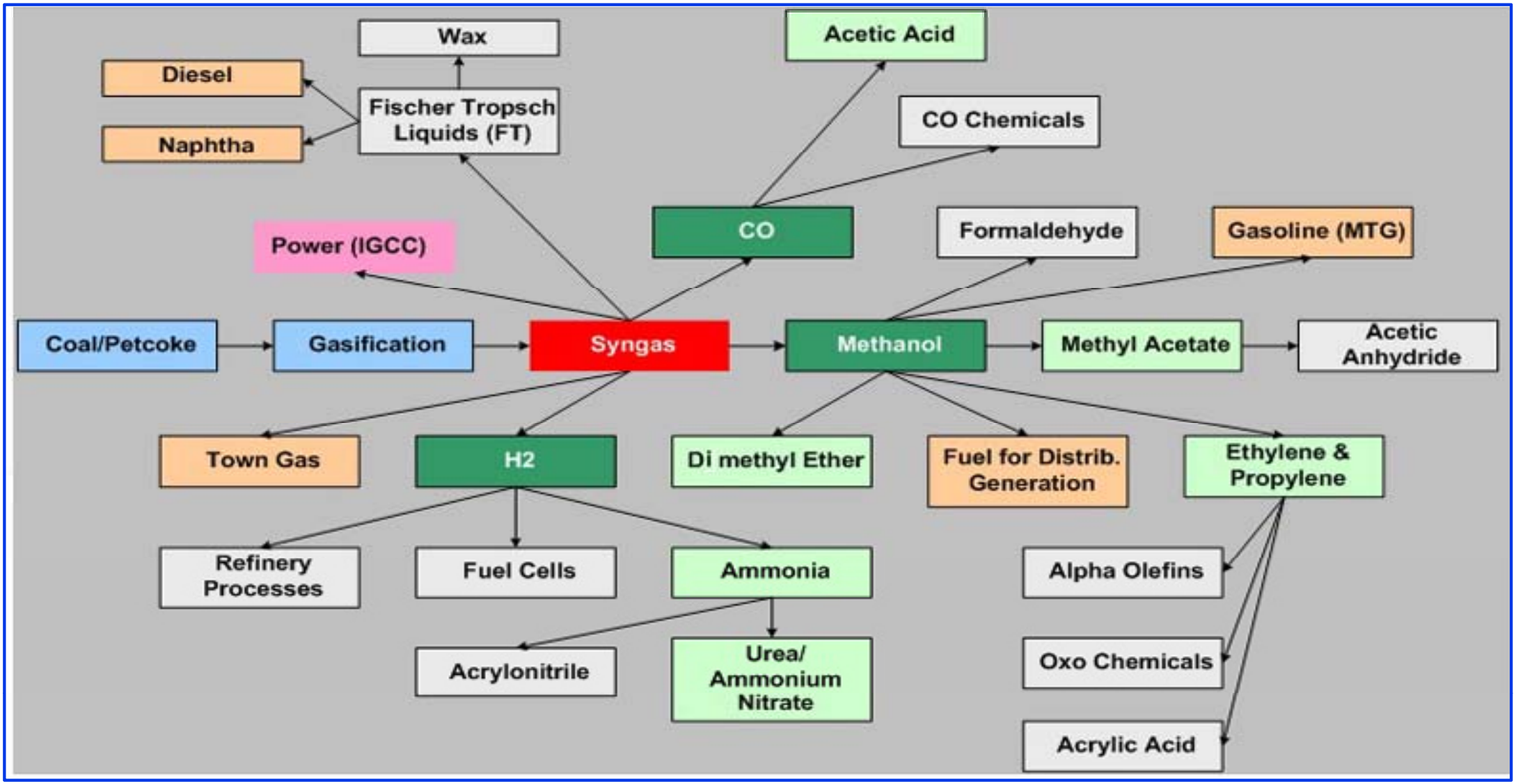
CTL - Add hydrogen or reject carbon

GTL - Reject hydrogen or add carbon.

CTG - Add more hydrogen or reject more carbon.

Coal- Low hydrogen, carbon rich source

Applications of Coal Gasification



Gasifiers once solved energy problems - they might, yet again.

Coal technologies

DCL (Hydro / direct Liquefaction)

Single Stage Process

H-Coal (HRI, USA)
Exxon donor solvent (Exxon, USA)
SRC-1 and II (Gulf Oil, USA)
Conoco zinc chloride (Conoco, USA)
Kohleoel (Ruhrkohle, Germany)
NEDOL (NEDO, Japan)

Two Stage Processes

Catalytic two-stage liquefaction (US DOE and HTI, USA)
Liquid solvent extraction (British Coal Corporation, UK)
Brown coal liquefaction (NEDO, Japan)
Consol synthetic fuel (Consol, USA)
Lummus (Lummus, USA)
Chevron coal liquefaction (Chevron, USA)
Kerr-McGee (Kerr-McGee, USA)
Mitsubishi Solvolysis (MHI, Japan)
Amoco (Amoco, USA) …

ICL (Indirect liquefaction)

Entrained Bed

GE
UDHE
Shell
MHI
CB&I (*erstwhile Philips 66)*
Siemens
OMB
MCSG
TPRI
HTL
Tsinghua
EAGLE etc

Fluidized Bed

UDHE (*erstwhile HTW*)
U-gas (SES)
(Transport) KBR,

Moving/Fixed Bed

SASOL / Lurgi
BGL,SEDIN

Catalytic Hydro-gasification

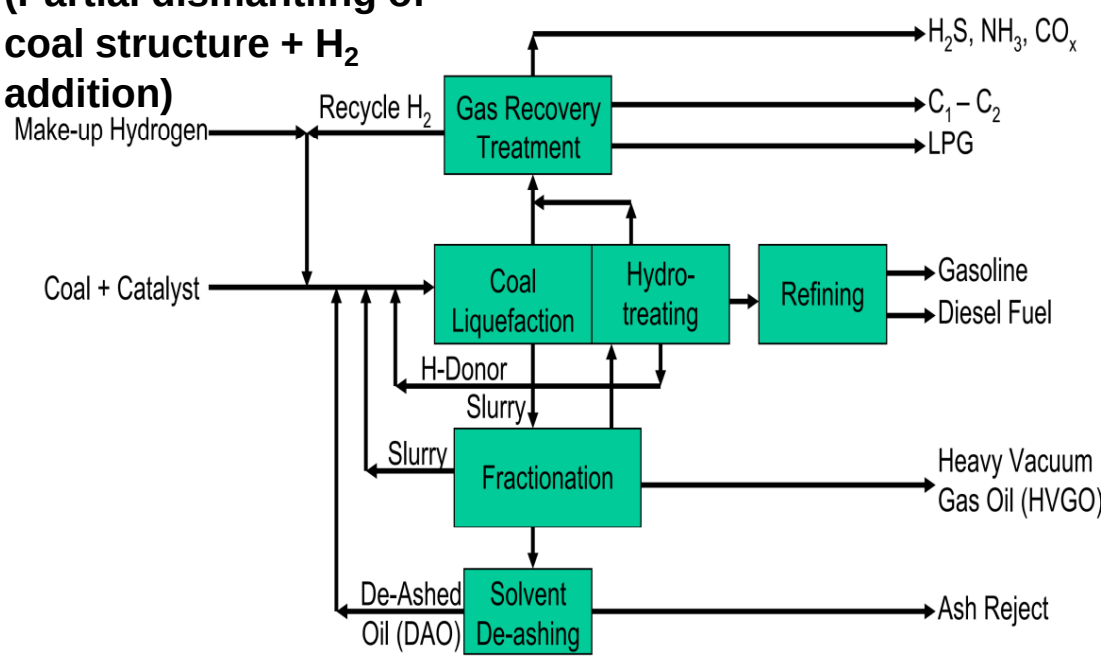
Greatpoint Energy
Research Triangle Institute (RTI)

Multiproduct Generation From Coal

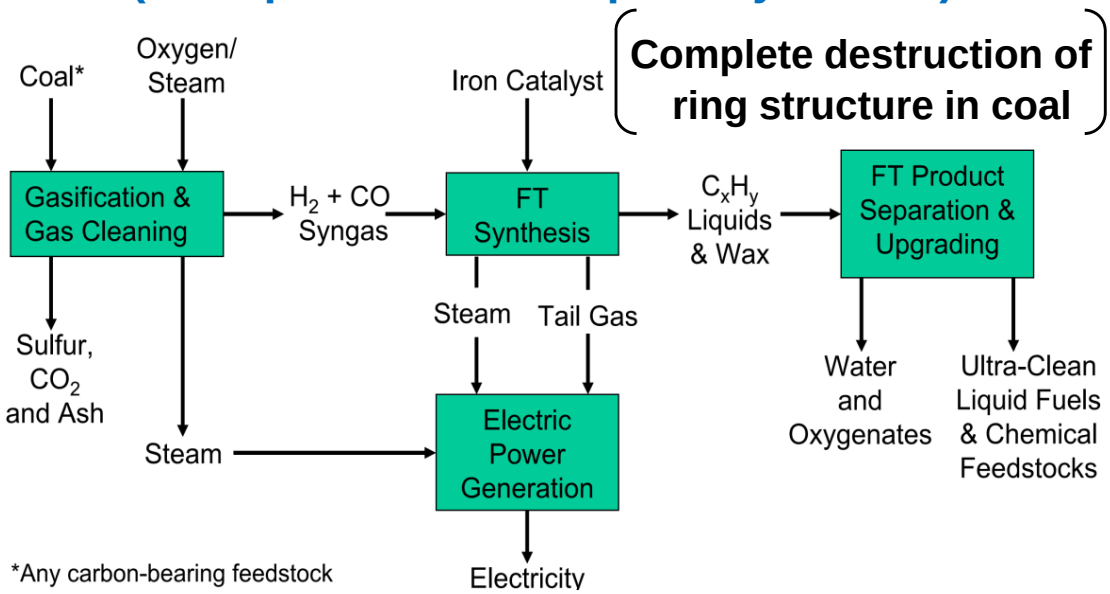
Coal liquefaction technologies for synthetic fuels (1)

Direct coal liquefaction

(Partial dismantling of coal structure + H_2 addition)



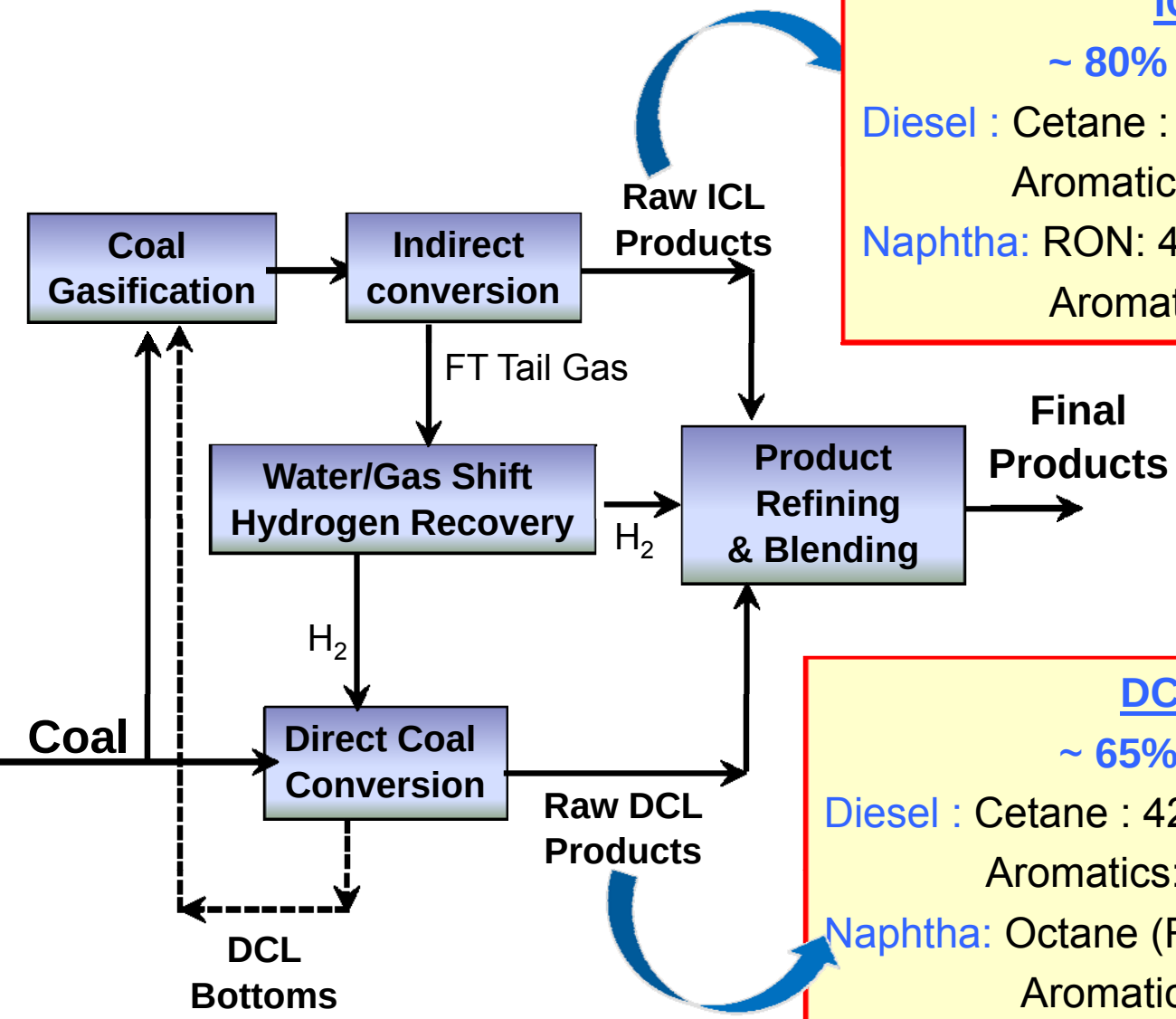
Indirect coal liquefaction (example- Fischer Tropsch synthesis)



- High efficiency potential
- No aromatics, high-octane gasoline, low-cetane diesel
- Products w/ higher energy density
- Water & air emissions issues
- Higher operating expenses
- 1 Commercial plant at China by Shenhua (~US$1.5 billion)
- (~25000 BPD , 3.5 million t/a coal)

- Mature & established but complex, less efficient - fewer BTUs per gallon
- Low-octane gasoline, ultra-clean diesel
- CO_2 capture & power co-production
- Use existing refining technologies
- Meet all current & projected specifications for sulfur & aromatic
- Production capacity >390000 bpd w/ largest operation by Sasol, South Africa

CTL Yields & Hybrid Coal Conversion



ICL product slate

~ 80% Diesel, 20 % Naphtha

Diesel : Cetane : 70-75, Sulfur:<1 ppm

Aromatics < 4 %, Sp. gravity : 0.780

Naphtha: RON: 45-75, Sulfur : Nil

Aromatics:2%, Sp. gravity : 0.673

DCL product slate

~ 65% Diesel, 35 % Naphtha

Diesel : Cetane : 42-47, Sulfur:< 5 ppm

Aromatics: 4.8 %, Sp. gravity : 0.865

Naphtha: Octane (RON): >100, Sulfur: <0.5 ppm

Aromatics:5%, Sp. Gravity :0.765

Hybrid concept

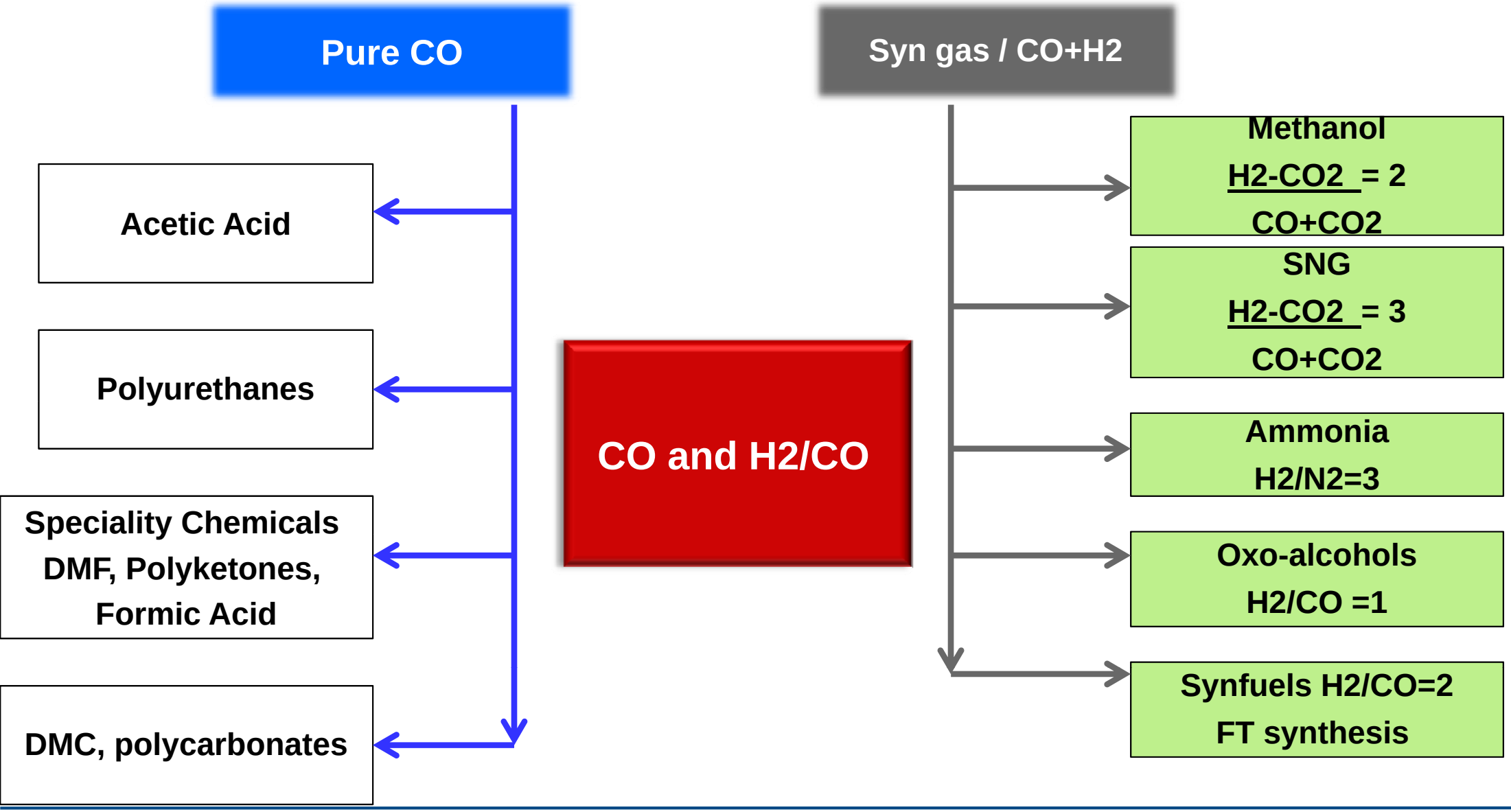
- **Integrated products complement each other**
- **balance between process efficiency and final fuel quality by blending**
- **improve process flexibility and maximize targeted product slate**

Syngas Cleaning & Conditioning

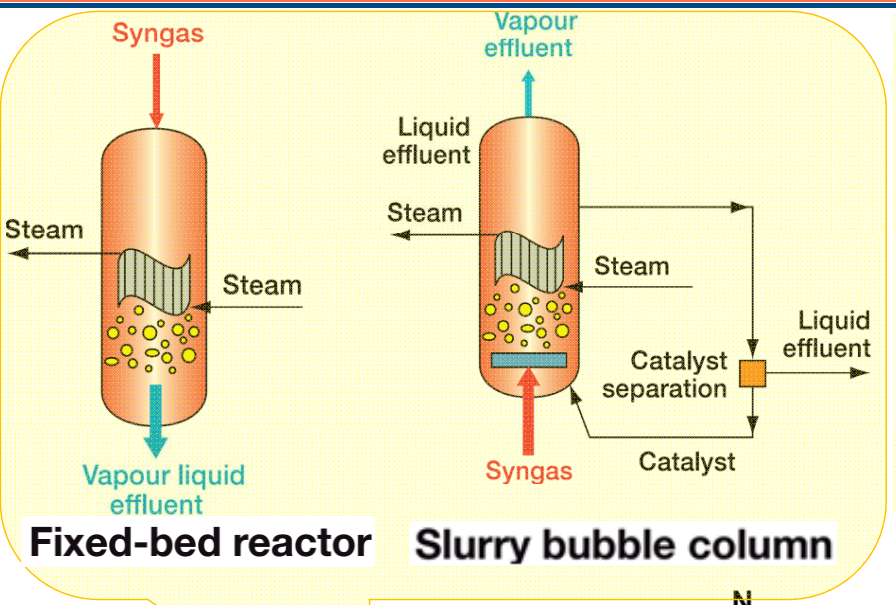
product	H_2/CO	total S	poisons	other
ammonia	∞	<100 ppbv	$CO + H_2O$ < 20 ppmv $O_2 + CO_2$ < 10 ppmv Cl < 100 ppbv P, As	$H_2/N_2 = 3.0$ inerts < 2%
hydrogen (by methanation)	∞	<100 ppbv	halides, As	$CO + CO_2$ < 2%
methanol	≈2.0 (H_2+CO_2) ≈2.05 ($CO-CO_2$)	<100 ppbv	halides < 10 ppbv NH_3 < 10 ppmv HCN < 10 ppbv Fe/Ni carbonyls < 10 ppbv C_2H_2 < 5 ppmv unsaturates < 300 ppmv	O_2 < 1% CO_2 ≈ 3%
oxo alcohols	≈1.0	[illegible]	O_2, strong acids, HCN, dienes	CO_2 < 0.5%
MEG (for cryogenic H_2-CO separation)	1.5	<100 ppbv		CO_2 < 100 ppmv H_2O < 10 ppmv
SNG	3.0	<20–100 ppbv	halides, As	
Fischer–Tropsch (dependent on process)	1.3–2.6	<10 ppb to <1 ppmv	NH_3, HCN < 1 ppmv halides < 10 ppbv alkaline metals < 10 ppmv tars, phenols Hg, As, Se	
DRI	0.5–∞ ($CO + H_2$) >2 ($CO_2 + H_2O$) preferred > 11	<0.3% preferred < 100 ppmv		N_2 < 6% preferred < 1% CH_4 3–4%

Syngas treatment and quality are critical

Syn Gas and Polygeneration



Fischer-Tropsch Synthesis - Technology



LT-FT: 220- 250°C

Cobalt catalyst

(Middle distillates/Waxes)

FIXED BED

Shell SMDS
BP

SBCR

Sasol SPD
Exxon Mobil
Statoil
Eni/IFP/Axens
Conocophilips

HT-FT: 350°C

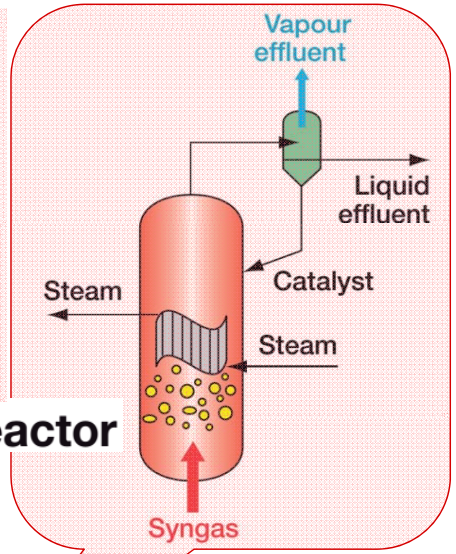
Iron catalyst

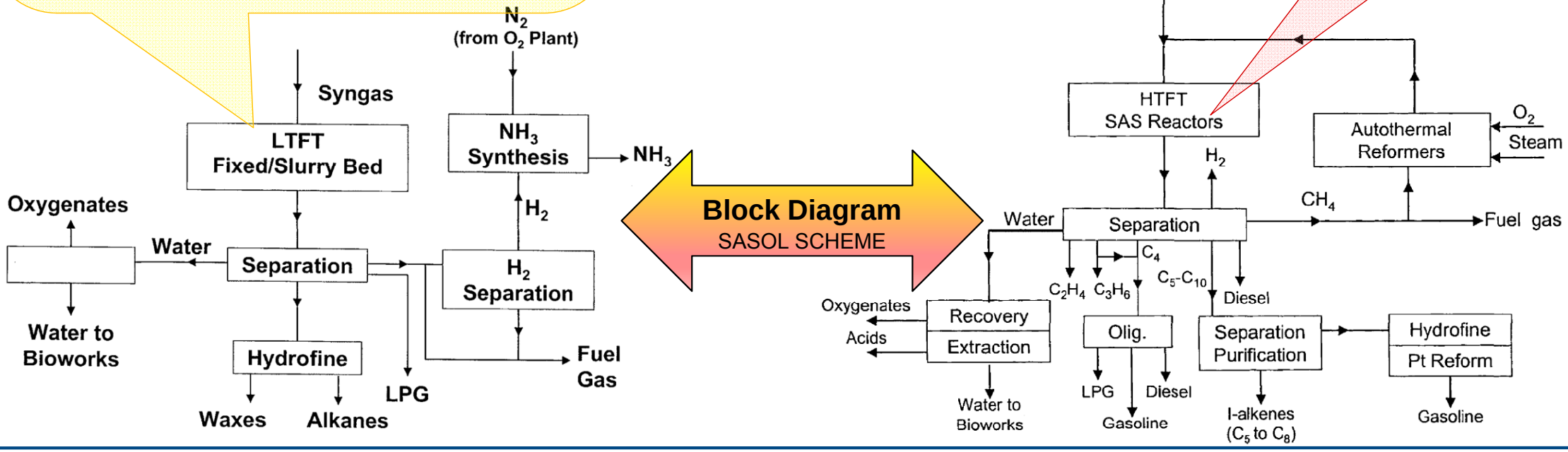
(Gasoline/Olefins / Chemicals)

TECHNOLOGIES

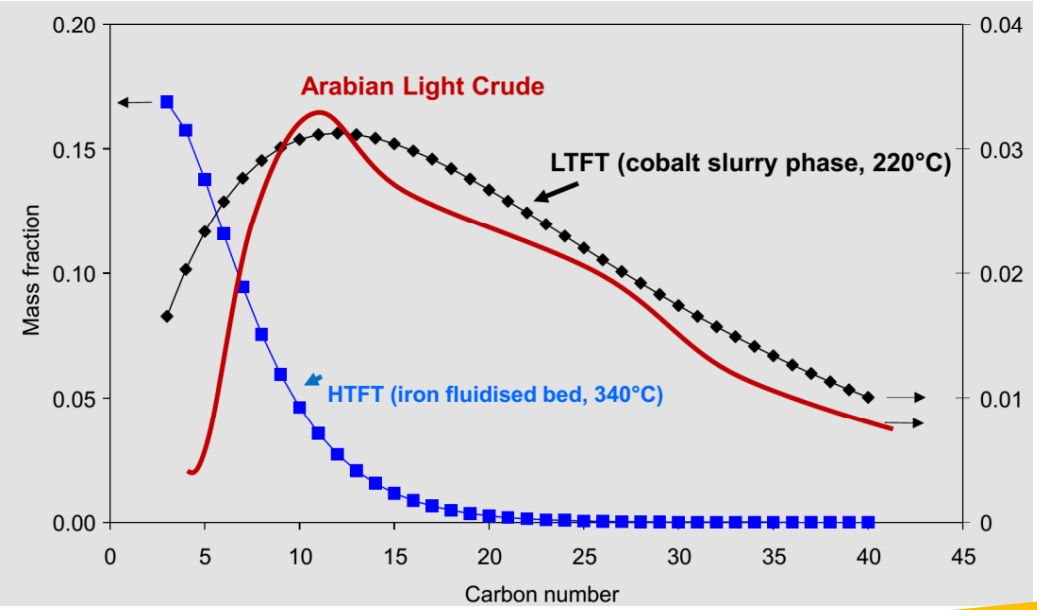
Sasol SAS (FFB)
Sasol Synthol (CFB)

Fluidised-bed reactor





Fischer-Tropsch Synthesis



Compound class	Crude oil	HTFT syncrude	LTFT syncrude
Linear paraffins	major product	> 20%	> 60%
Naphthenes	major product	< 1%	< 1%
Olefins	none	> 60%	> 20%
Aromatics	major product	5-10%	none
Oxygenates	< 1% O (heavies)	5-15%	5-15%
Sulfur compounds	0.1-5% S	none	none
Nitrogen compounds	< 1% N	none	none
Metal containing compounds	phorphyrines	carboxylates	carboxylates
Water	0-2%	major by-product	major by-product

Distillate Product of HTFT

Property	*HTFT[a]*	*Crude oil derived diesel*
T95 boiling point, °C	363	360
cetane number	60	55
viscosity at 40 °C, cSt	2.2	2.8
density at 15 °C, kg m^{-3}	808	842
total aromatics (HPLC),	25	39

Distillate Product of LTFT

Property	*Units*	*Sasol SPD™ LTFT distillate*
Olefins	*vol-%*	*< 1*
Oxygen	*ppm*	*80*
Aromatics	*mass-%*	*0.14*
Density @ 20 °C	*kg/ℓ*	*0.765*
Viscosity @ 40°C	*cSt*	*1.97*
Cetane number		*>72*
O_2 stability	*mg/100mℓ*	*0.21*
Net heating value	*MJ/ℓ*	*33.5*
HFRR WSD	*µm*	*651*

Fischer-Tropsch Synthesis (2) - Technology

Objective of efficient FT Process-

- Production of more valuable steam for powering the process
- Maintaining the selectivity to heavy hydrocarbons
- High material conversion efficiency

MTFT

Latest development (Synfuels China HTSFTP process)

HIGHER OVERALL ENERGY EFFICIENCY

Heat recovery

Better recovery - production of more valuable steam

20% of the calorific value of the syngas is released during FT synthesis

Selectivity

Sensitive to catalyst & operating conditions

Cobalt based – Not suitable

Iron based - Suitable

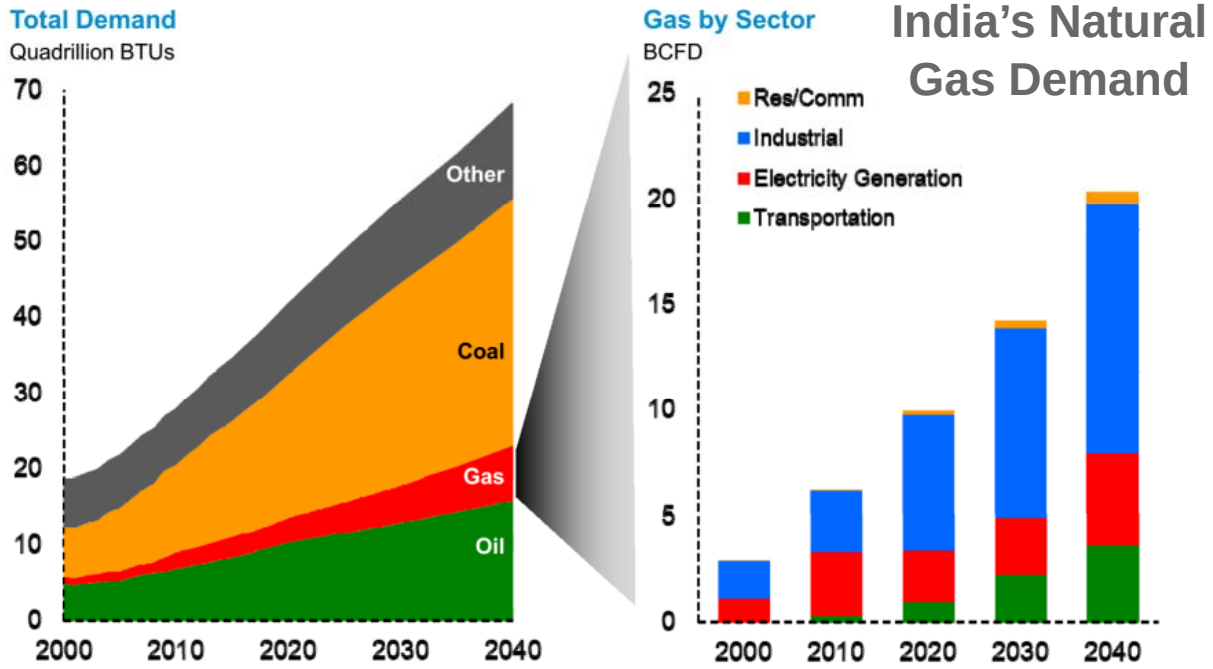
Product Slate

Similar to LTFT

Heavy products w/ high selectivity

Future direction for a good FT process is that of most efficient energy conversion

Coal to SNG



India's Natural Gas Demand

(Source- ExxonMobil 2014 Outlook for Energy)

Natural gas consumption is significant

- Demand outpacing production
- India - fourth largest LNG importer
- Imports expected to rise ~30% in 2015
- National coal reserves is the key

Costly LNG import substitution

- Country's economic potential

Easy to implement

- Technology well developed

Conventional fuel

- Infrastructure already in place

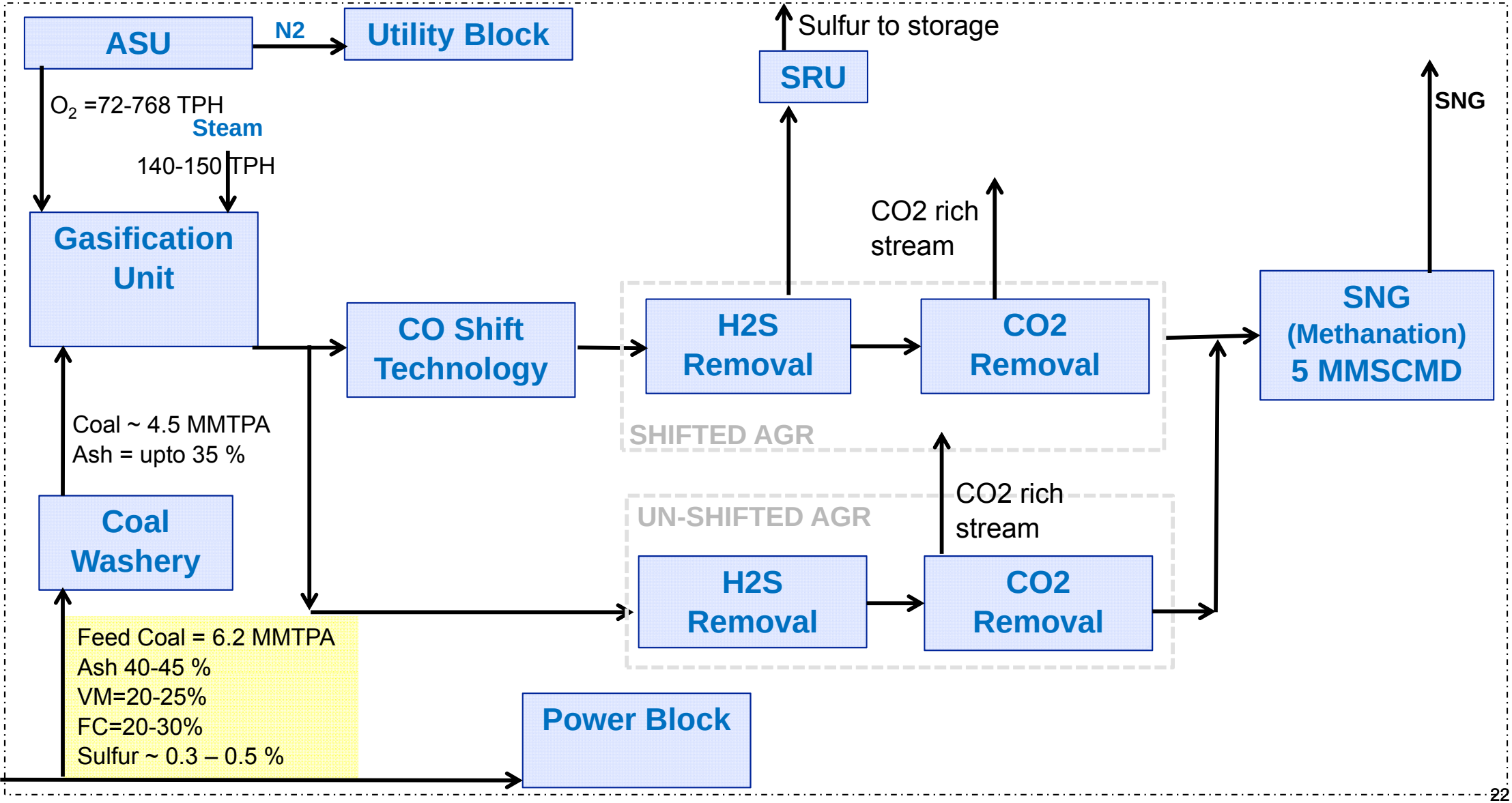
MMSCMD	2012-13	2016-17	2021-22	2026-27	2029-30
Domestic sources	101.1	156.7	182	211	230
LNG Imports	44.6	143.0	188	214	214
Gas Imports (Cross-border pipeline)	0.0	0.0	30	30	30
Total	145.7	299.7	400	454	474

Source wise supply of Natural Gas

Expected growth at an average of 6.8% /year

(Source- Vision 2030 Natural Gas Infrastructure in India)

SNG From Coal – 5 MMSCMD



Coal to SNG

$CO + 3H_2 \rightarrow CH_4 + H_2O$ $\Delta H = -210$ kJ/mol
$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ $\Delta H = -113.6$ kJ/mol

Methanation - Haldor –Topsoe, Air-Liquide, MHI

Hydrogasification

Exothermic

Uses H_2 to gasify coal - research stage

Catalytic Steam Gasification

More efficient than steam gasification

Lower operating temperature (650^0C-700^0C)

GreatPoint Energy developed catalytic hydro-methanation process. Expected Pipeline quality SNG price - $3 per MMBtu (Fairley, 2007). Thermal efficiency – 70 -80 %

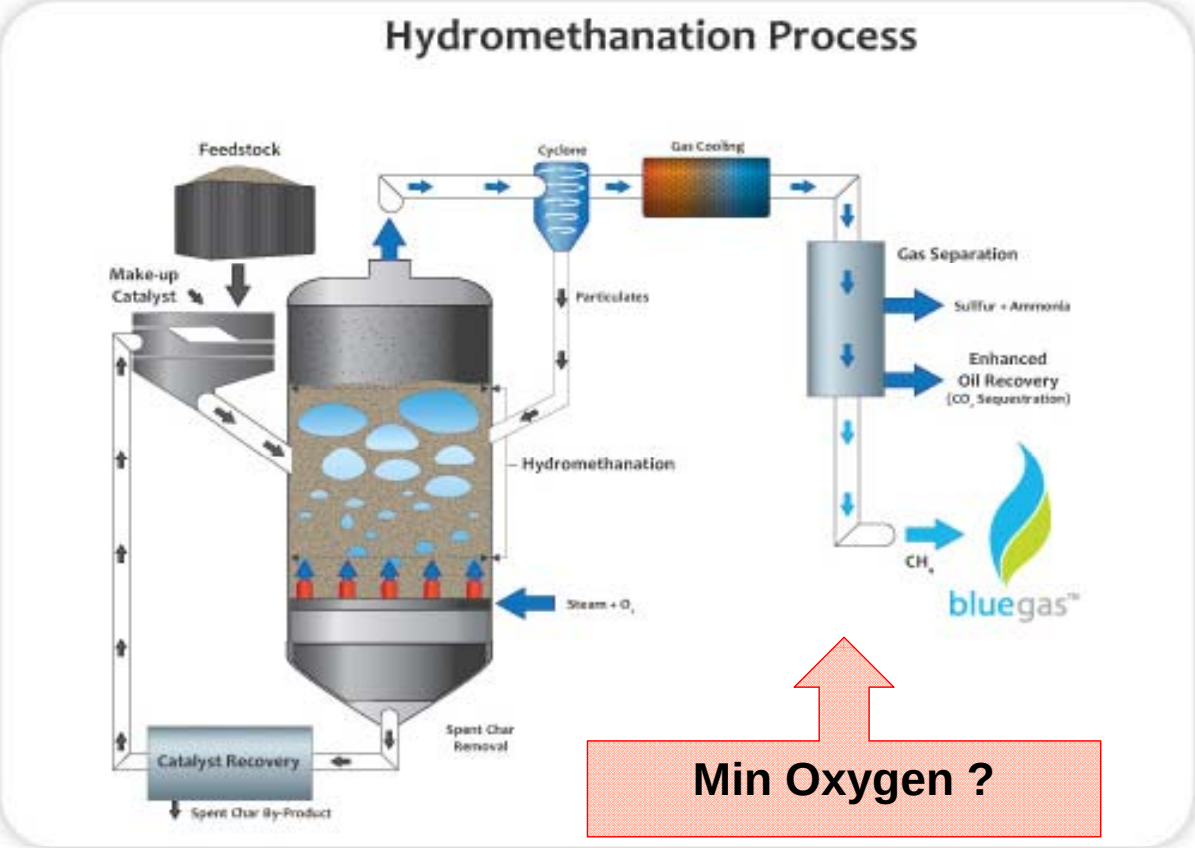
Steam/Carbon :	$C + H_2O \rightarrow CO + H_2$
Water Gas Shift:	$CO + H_2O \rightarrow H_2 + CO_2$
Methanation:	$CO + 3\,H_2 \rightarrow CH_4$ (Methane) $+ H_2O$
Overall:	$2C + 2H_2O \rightarrow CH_4 + CO_2$

Steam Oxygen Gasification

(Gasification+ Gas Cleaning+ Methanation)

Proven & commercially demonstrated.

Great Plains synfuels plant (since 1984) - 54 billion scfa SNG from 6 million ton lignite



Comparison Convectional Vs. Catalytic

	High Temp. Oxygen Gaisfication	Catalytic Gasification
Gasification T & P	>1200 ℃、30 atm	< 700 ℃、35 atm
Oxygen Plant	Yes	No
Thermal Efficiency	61.9 %	71.4 %
Methanator	Yes	No
Capital Investment $ per MSCF per day	$ 6250	$ 4688
Catalyst requirement	No	Yes (20% of coal, $500/ton)
Production cost $ per MSCF methane	6.10	5.12
End use	Multi-End use (Syn Gas, Methane, Power)	Methane production only

Coal to Chemicals (CTC) - Methanol

Methanol

- is starting point for the synthesis of a wide range of industrial Chemicals
- as an alternative fuel

"India imports large amount of methanol (about 80% of domestic demand in 2009),*

- ICI low-pressure methanol process
- Lurgi two-step reforming
- Haldor Topsoe two-step reforming process

MTG (Methanol to Gasoline) Process

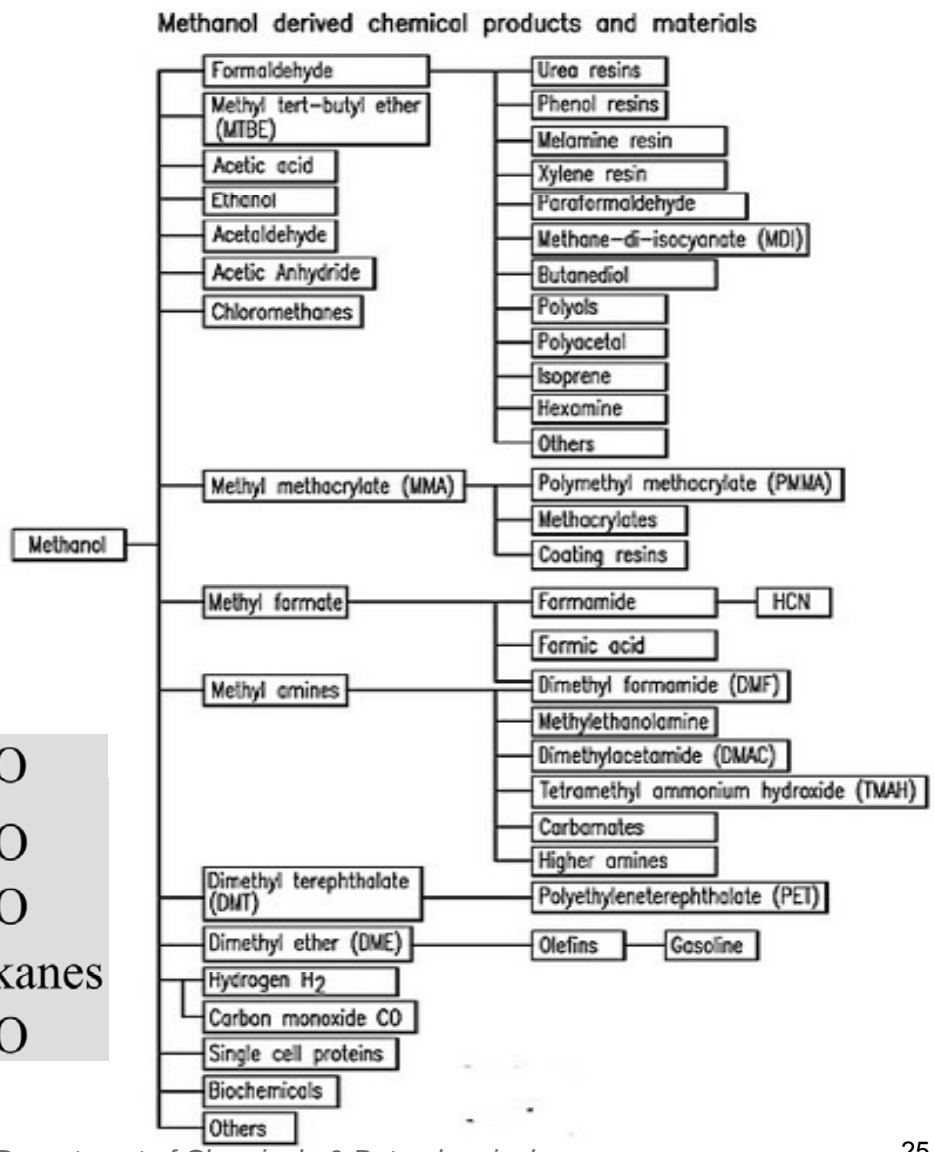
$$2\,CH_3OH \rightleftarrows H_3C\text{-}O\text{-}CH_3 + H_2O$$

$$H_3C\text{-}O\text{-}CH_3 \rightarrow \text{Light alkenes} + H_2O$$

$$\text{Light alkenes} + H_3C\text{-}O\text{-}CH_3 \rightarrow \text{Heavy alkenes} + H_2O$$

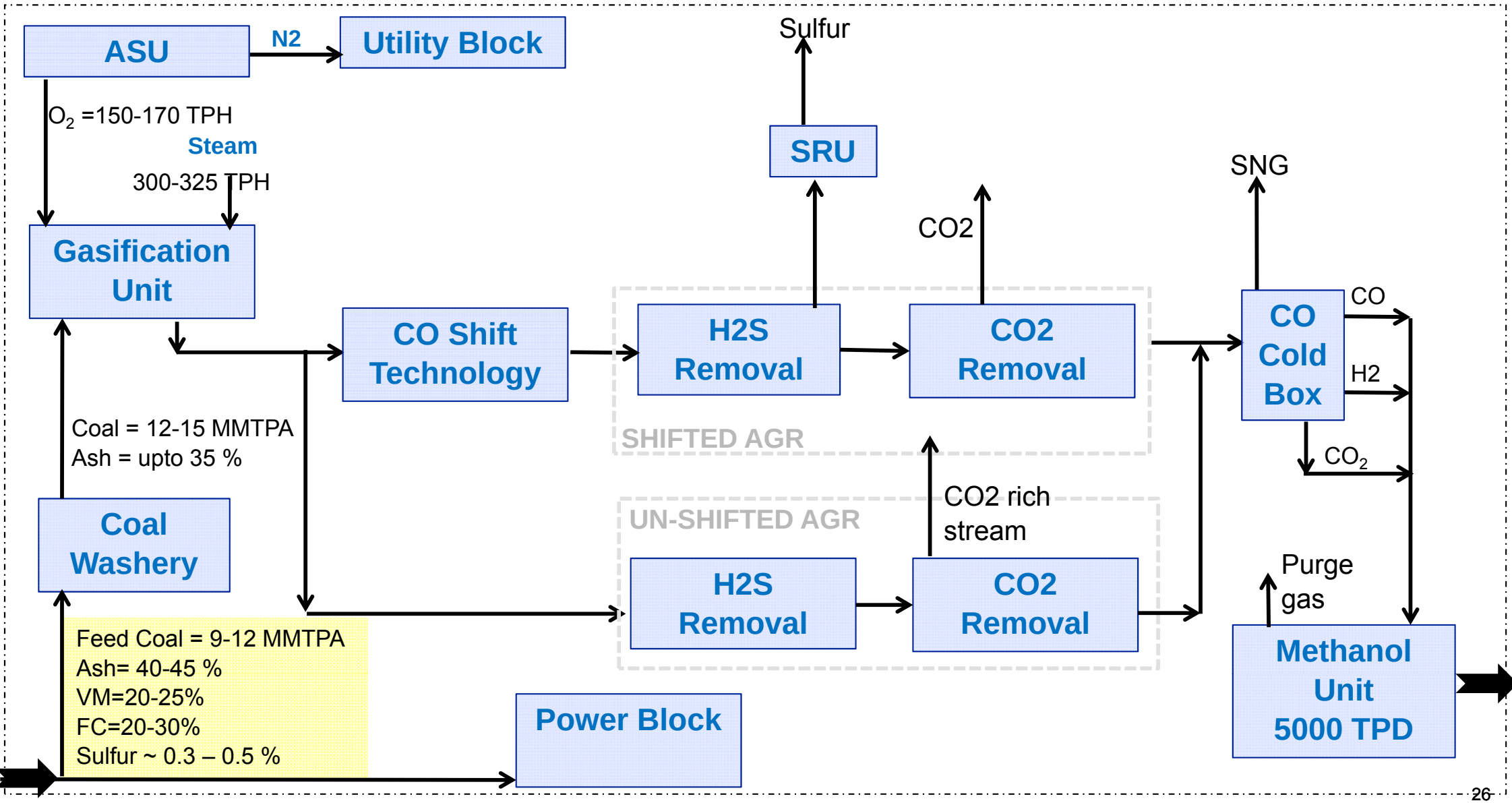
$$\text{Heavy alkenes} \rightarrow \text{Aromatics} + \text{Alkanes}$$

$$\text{Aromatics} + H_3C\text{-}O\text{-}CH_3 \rightarrow \text{Higher aromatics} + H_2O$$



*Ref.- Draft National Chemical Policy 2012, Government of India Ministry of Chemicals & Fertilizers Department of Chemicals & Petrochemicals.

METHANOL MATERIAL BALANCE – 5000 MTPD



Coal to Chemical (CTC) – DME (1)

Licensor: JFE

Coal Gasification

Licensor: Haldor-Topsoe Lurgi, Toyo, MGC, SWI,etc.

DME Production

(1 Step process)

H_2,CO

Methanol

(2 Step process)

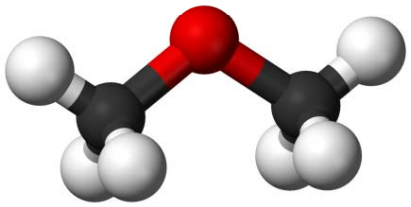
DME Usage

DME

Clean Fuel for

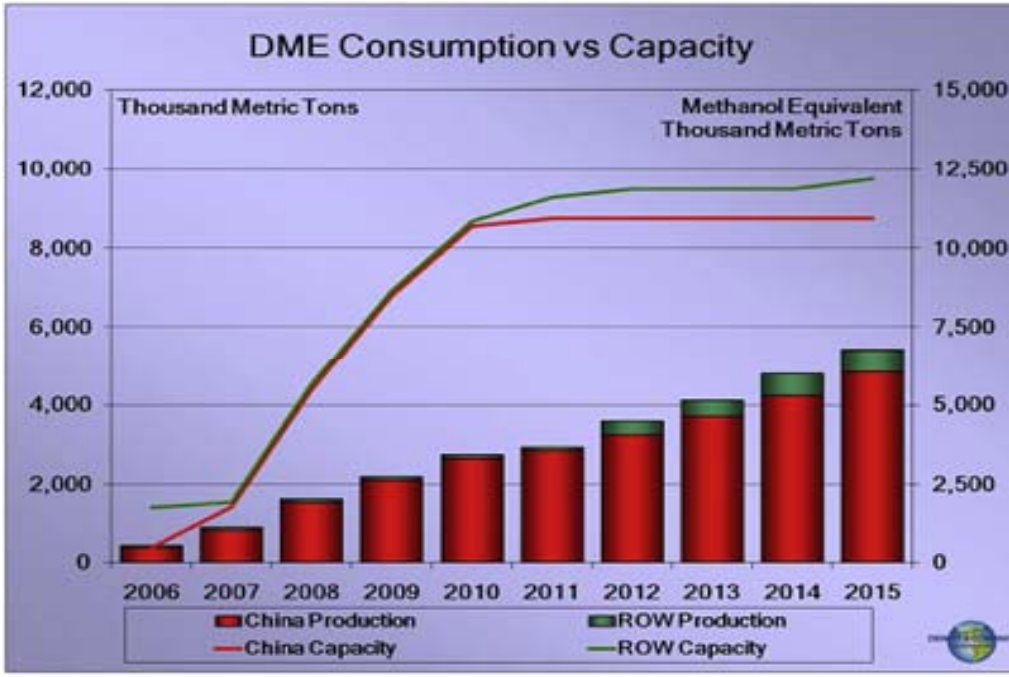
- Residential
  - LPG substitute
- Transportation
  - Diesel fuel
  - FC vehicle
- Power generation
  - Gas turbine
  - Diesel co-generation

Chemical use



Nearly all of the DME is produced in China and is coal derived."

Promising future, either as a fuel, or as an intermediate in the production of hydrocarbon fuels and chemicals



T.H. Fleisch et.al., The status of DME developments in China and beyond, Journal of Natural Gas Science and Engineering 9 (2012):

Coal to Chemical (CTC) – DME (2)

DME as LPG Substitute

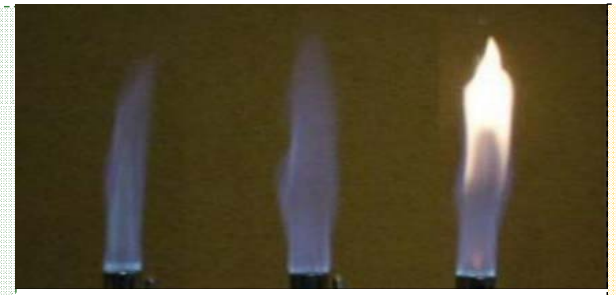
– Burns like Natural Gas

Wobbe Index 52 (Natural gas 54)
Boiling point -25°C (Propane -42)
Vapour pressure 0.53 MPa (Propane 0.91)

– Handles like LPG

Completely miscible in LPG
Existing LPG infrastructure - Below 20 % DME.
For neat DME, minor changes in sealing materials and burner tip.

Same efficiency and emission as LPG from cooking stove to industrial boiler.



Methane DME Propane

Outstanding Diesel Alternative

– Clean-burning alternative to diesel

Cetane number 55-60 (Gas oil 40-55)
No smoke, no sulphur
NOx : ~ 90% reduction
CO2 : ~ 95% reduction

– Cost – Relatively moderate

(with very high conversion efficiency)

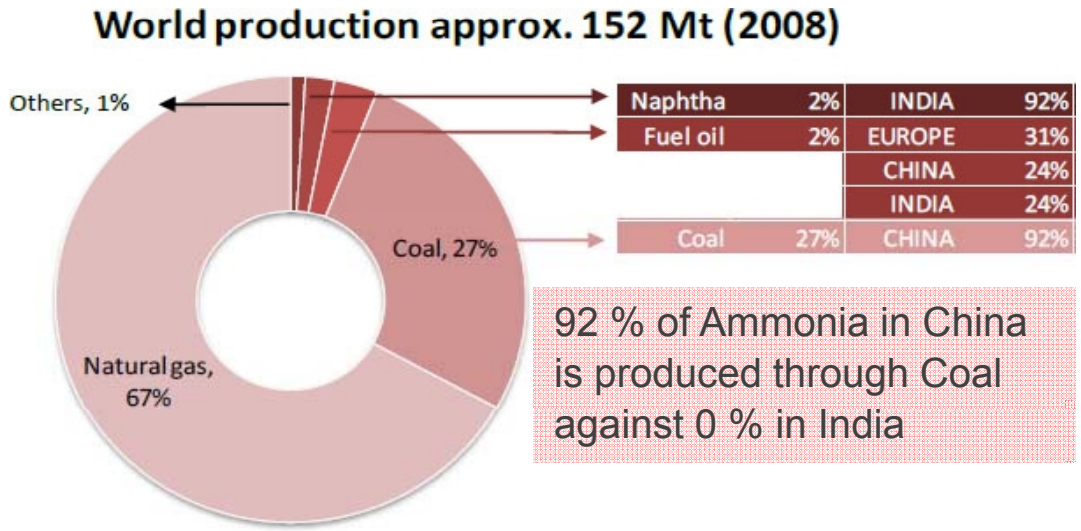
– Energy density

Lower than diesel (must be pressurized to be used in modified diesel engines)

Significant interest in this diesel substitute in Japan and other parts of Asia.

Today,150,000 t/y as aerosol propellant, plus 300,000 t/y for emerging fuel market

Coal to Chemical (CTC) - Ammonia



World ammonia production by feedstock type. Source: IFA, 2010b

Global demand for ammonia, exceeded 170 million metric tonnes in 2013……*IHS report*

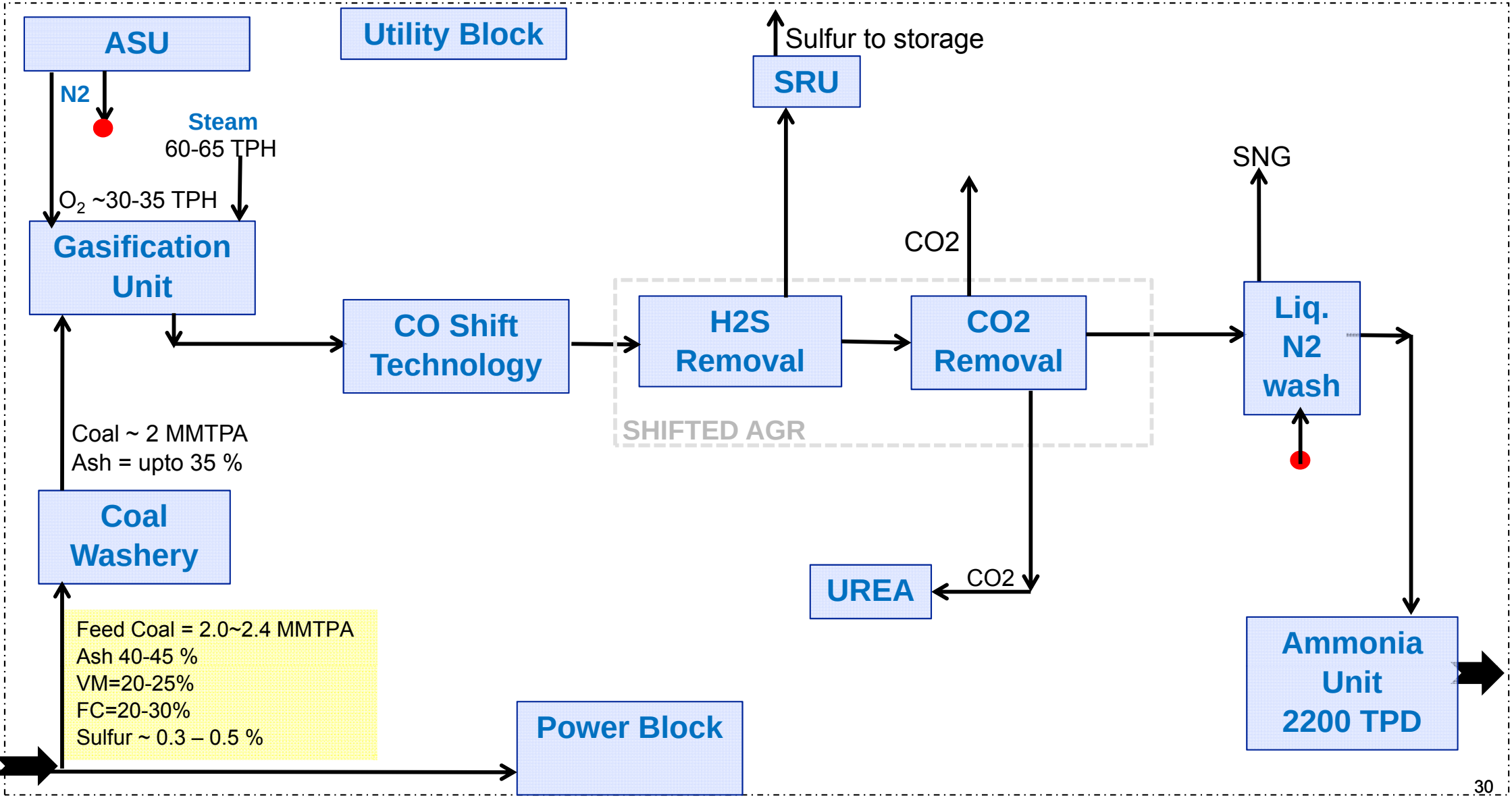
	NG	Naphtha	Fuel Oil	Coal
Relative investment	1.0	1.15	1.5	2.5
Relative sp. Energy requirement (based on LHV)	1.0	1.1	1.3	1.7

Relative ammonia plant investment and relative energy requirement for 1800 t/d NH_3

Commercial technology

- Johnson Matthey
- Linde
- Kellogg Brown and Root
- Haldor Topsøe
- Ammonia Casale
- Uhde

AMMONIA MATERIAL BALANCE – 2200 MTPD



Overall Cost Comparison (million US$, NG price at 8.59$/MMBTU,)

Description	Clean Syn Gas	SNG (5MM SCMD)	Methanol 5000(MTPD)	Ammonia/Urea 3850(MTPD)
Project Cost (Billion USD)	9.5	0.183	0.476	0.464
Total Production	~1.8MM	5	5000	3850
Operating cost Variable	750	539	613	244
Fixed	310	9.1	22.5	24
Financial	1500	28.2	53	66
Total	2560	576	688	334
	(-)550	(-)78	(-)242	(-)92
Net Cost	2010	258	672	306
Cost of Production, USD	9.5/MMBTU	8.5/MMBTU	270/MT	190/MT

Gasifier Pilot Plant (FB Type)

- **A coal gasification fluidized bed plant is designed and installed at EIL-R&D center**
  - **Capacity: 150 kg/h**
  - **O2 purity: 93% by volume**
- **The plant consists of**
  - **Coal crushing & feeding system**
  - **High pressure gasifier with ash removal system**
  - **Cyclones**
  - **Syngas cooling systems**
  - **Ash disposal system**
  - **Air separation unit, etc.**

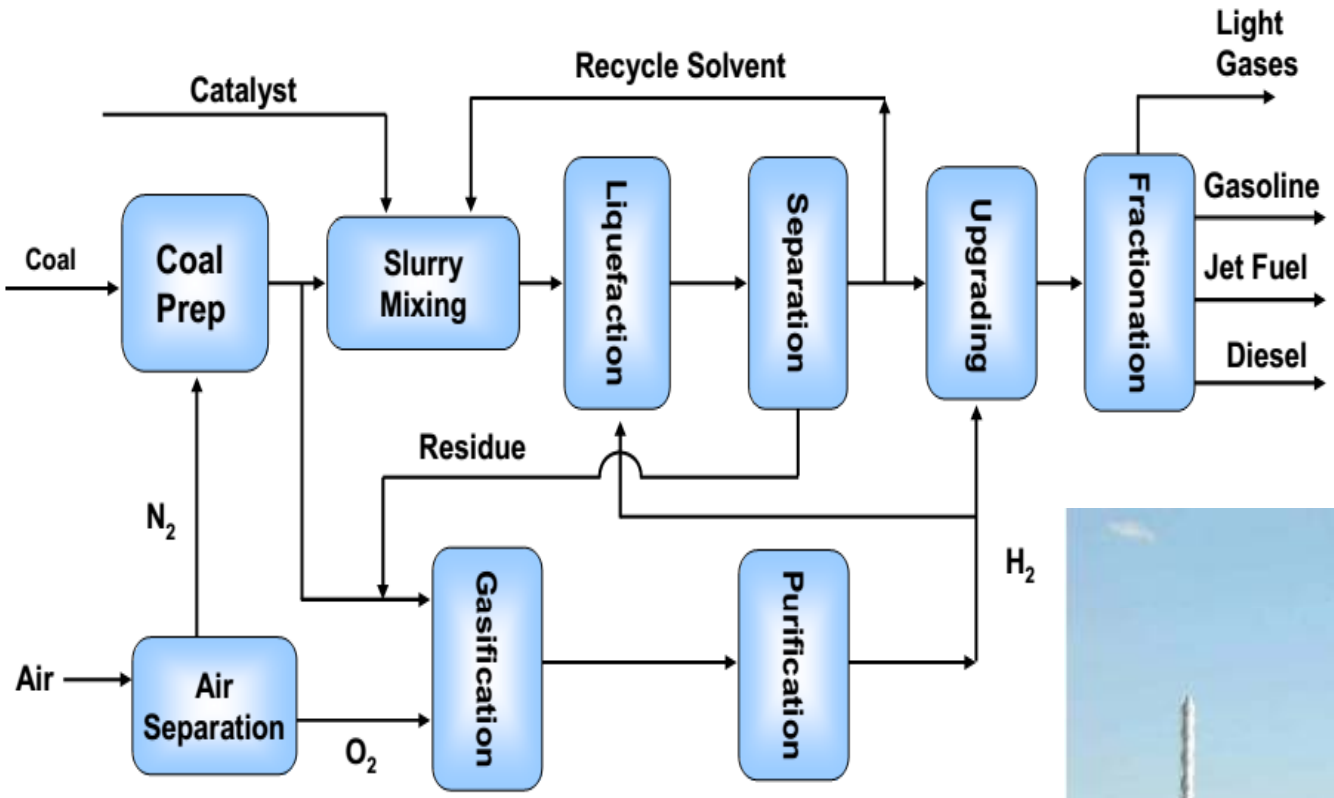
Gasifier Pilot Plant

Challenges & Opportunities

- Assess, source, market need, location for a project, energy security
- Complex High investment projects
- High Cost of New Technology, future with CO2 fixation and CCS
- Need to strengthen the R&D environment
- High Investments linked to price volatility, high risk
- Need Collaborative approach , parternerships
- Policies in place to give impetus to clean coal technologies

THANK YOU

Commercial Application - DCL



World's only commercial DCL plant

Shenhua DCL utilizes technology pioneered by DOE integrated with German and Japanese technologies, and combined with Shenhua innovations

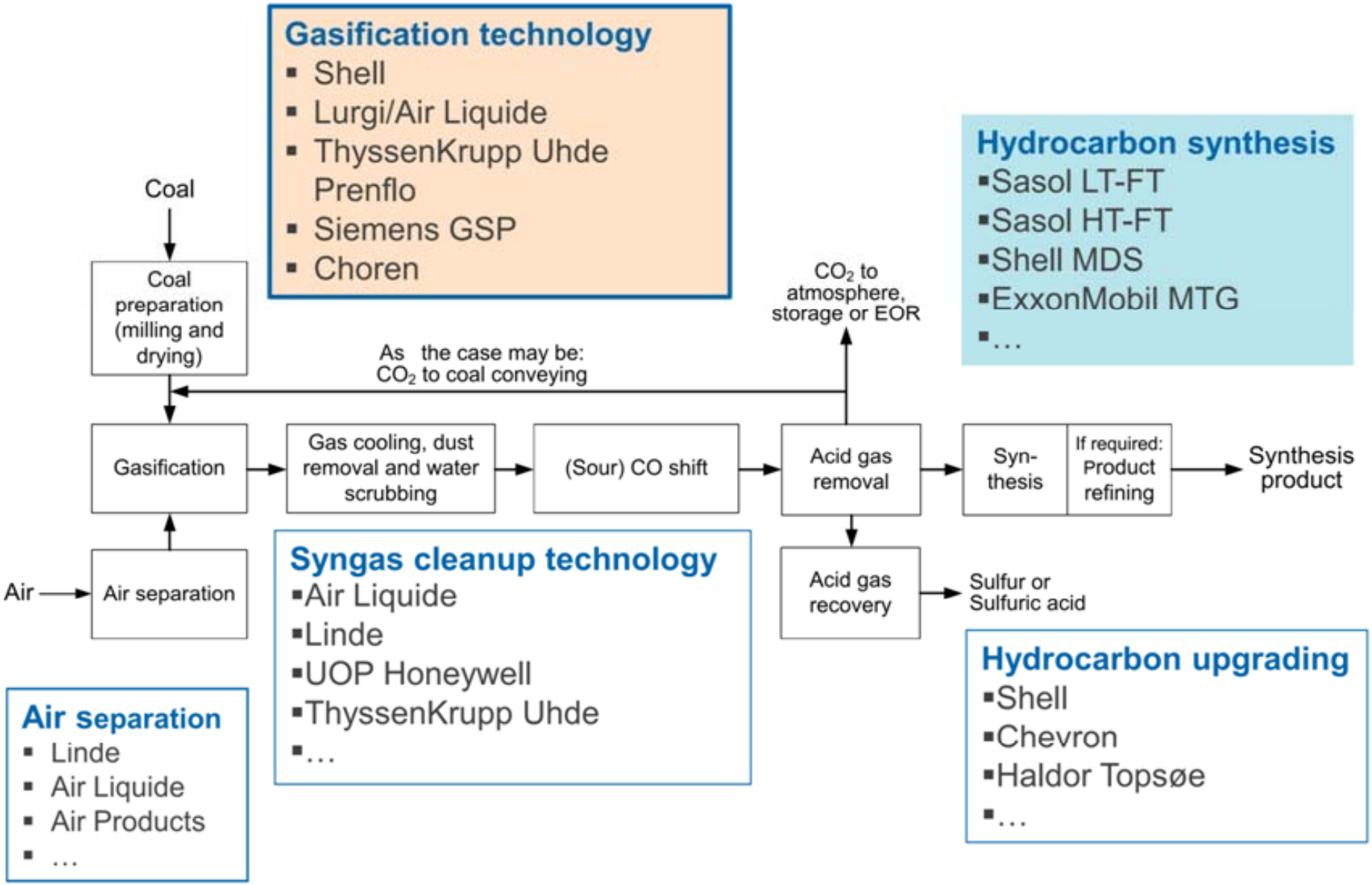
Production Capacity:

1.08 M tons/yr (~24,000 BPD) liquid products (mainly diesel & naphtha) from 3.5 M tons/yr coal

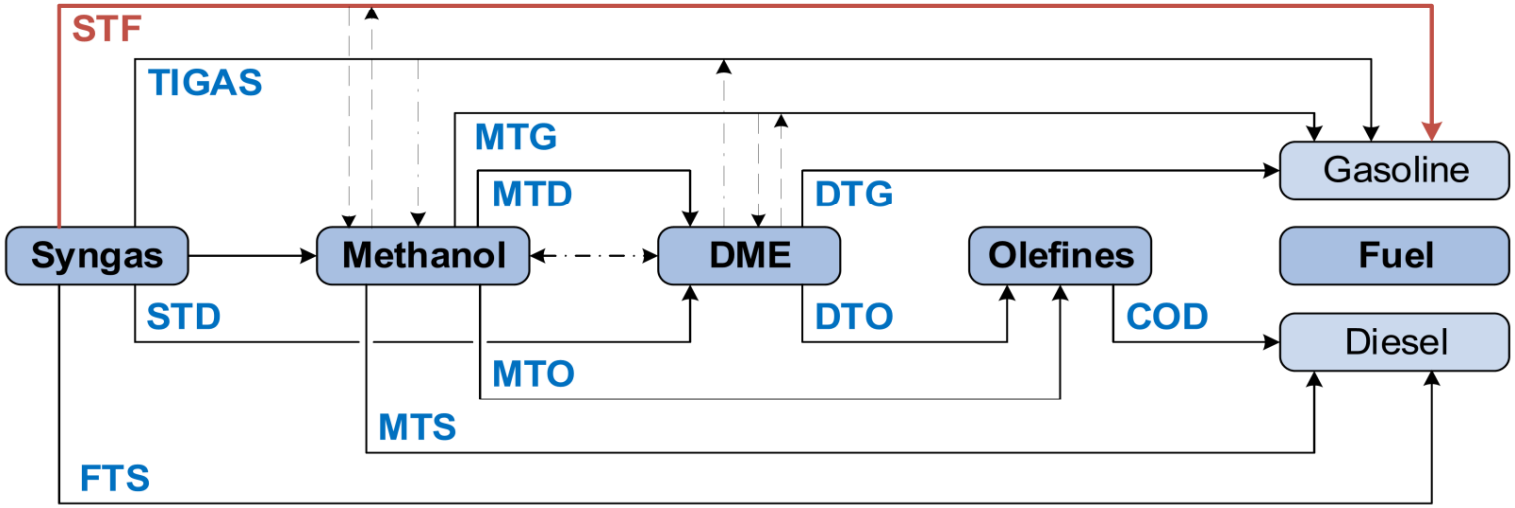
Plant Cost: $1.5 B USD

4 years of construction (2004-2008).
Commissioned 2008

Indirect coal liquefaction



Methanol-based fuel production



TIGAS Topsøe Integrated Gasoline Synthesis
MtG Methanol-to –Gasoline e.g.. ExxonMobil (Uhde)
DtG Dimethyl ether-to-Gasoline (e.g.. Karlsruhe Institut fürTechnology)
DtO Dimethyl ether-to -Olefins (e.g.. Karlsruhe Institut für Technology)
MtO Methanol-to -Olefins (e.g.. UOP, MtP by Lurgi/ Air Liquide)

StF Syngas -to -Fuel (CAC, TU Freiberg)
MtD Methanol-to -Dimethyl ether (eg. Lurgi/ Air Liquide)
StD Syngas -to -Dimethyl ether (eg JFE)
COD Conversion of Olefins to Distillates (e.g. Lurgi/ Air Liquide)
MtS MtSynfuels ® by Lurgi/ Air Liquide

Challenges & Opportunities

High Cost
Production & handling in comparison to Petroleum / NG

- Exploit economy of scale
- Extensive optimization to cut down CAPEX & OPEX
  e.g. eliminate spare gasifier & cost reduction in utilities like oxygen

Use poly-generation option, Process integration
Locate plant near to coal source

Energy Efficiency & CO_2 Emissions
Varying quantities of O_2 & Organic impurities

- CO_2 capture compliant technology. Exploit CCS & CO_2 chemical fixation
  (If a CO2 tax or other penalty is introduced and no other energy carrier than coal is available, the gasification route remains the most efficient in applying CO2 capture and sequestration)
- As a result of extensive research; future technologies utilizing CO_2 e. g. methanol production from CO_2 (CAMERE Process) , Dry Reforming etc.

Low Hydrogen Carbon Source
low molar H/C ratio compared to hydrocarbons

- Exploit availability huge reserves available
- A general advantage of coal as feedstock is the even distribution of large reserve across country.
- Alternatively using for CO chemicals

Resource, Environment, & Industrial Policy Challenges

- High water & land usage, pollution
- public resistance to coal use

- Uniform Coal Policies & Government Support
- Optimize & reuse water, If possible, locate at coastal location.
- Optimize land usage – Exploit Process Integration Opportunities & UCG

Global Energy Scenario
Oil price fluctuations, demand & supply, new technologies like shale gas, CBM etc.

- Energy security- Coal gasification always appears as an attractive option if competing energy carriers experience high price levels or national independence of energy supply plays a role

Gasification can be one way to use coal especially, if high ash contents are present. This is true for the residues of coal washing or other beneficiation processes. Price Competiveness to be seen