Hydrogen Demand and Petcoke Options via Gasification and CFB

17th May 2010

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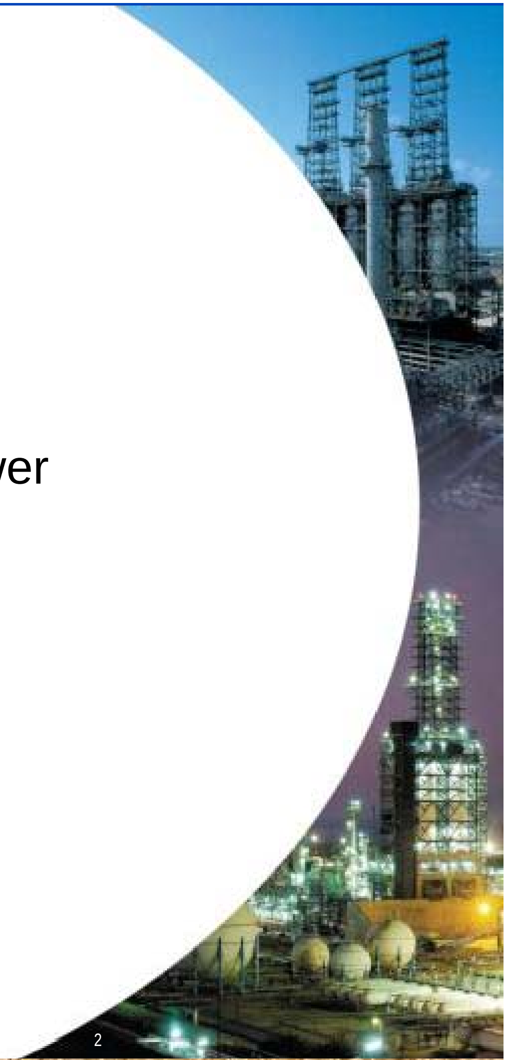
Agenda



- Session Introduction
- Hydrogen production with steam reformers
- Petroleum coke as source of hydrogen and electric power
- Chemicals from gasification of petroleum coke
- Conclusions

Session Introduction

Some Basic Facts

Market Drivers – recap

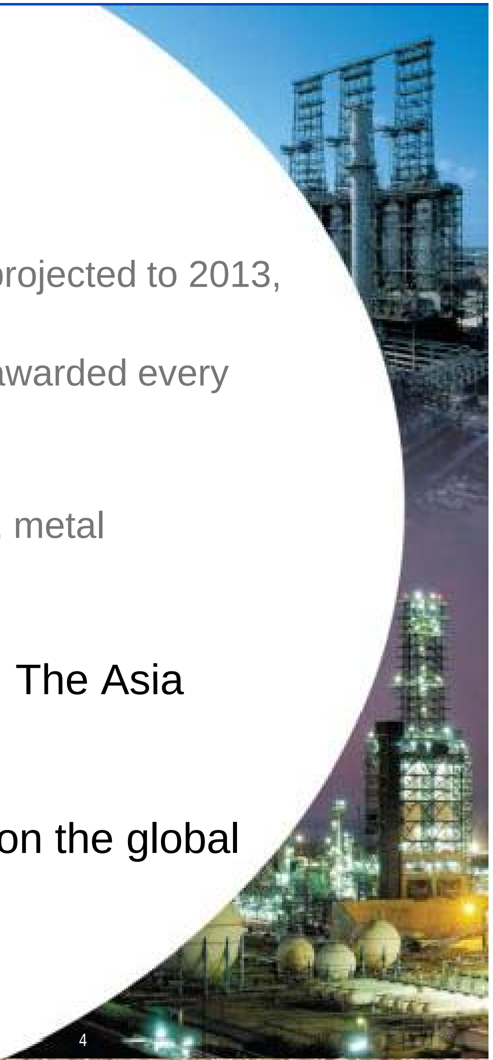
- Crude Prices – remain high
- Crude Quality – heavier and more contaminated
- Growing Dieselisation – with regional variations
- Significant impact of proposed fuel oil sulphur levels
- Ongoing Clean Fuels legislation
- Project Costs – trending downwards

Directionally

- Increasing value and optimising margins in refinery operation
  - Higher conversion
  - Clean fuels
- The Clean Fuels Driver
  - Demand for low sulphur, clean fuels requires huge amounts of hydrogen

Session Introduction

Hydrogen – a Key Resource



- Global demand growth for hydrogen
  - forecast to grow by 3.4% per year through 2013 to 475bn m^3
  - Of the anticipated 73bn m3 of increased global hydrogen demand projected to 2013, just under 84% will be consumed by refineries
  - This means that more than 18 plants sized 100,000 Nm3/h will be awarded every year
  - Out of which 15 will serve refineries
  - Other users – chemical manufacturing, semiconductors, float glass, metal components and food

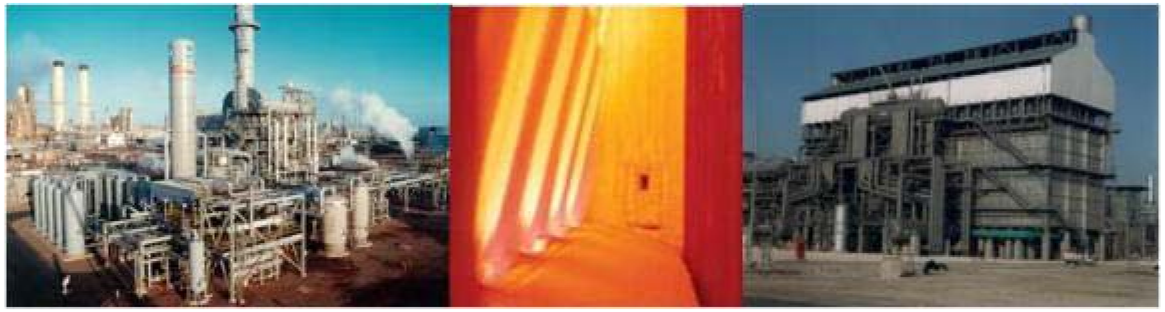
- In 2008, North America led the world in hydrogen consumption. The Asia Pacific region was a close second

- China, India and other Asia Pacific countries will make this region the global leader in hydrogen consumption well before 2013

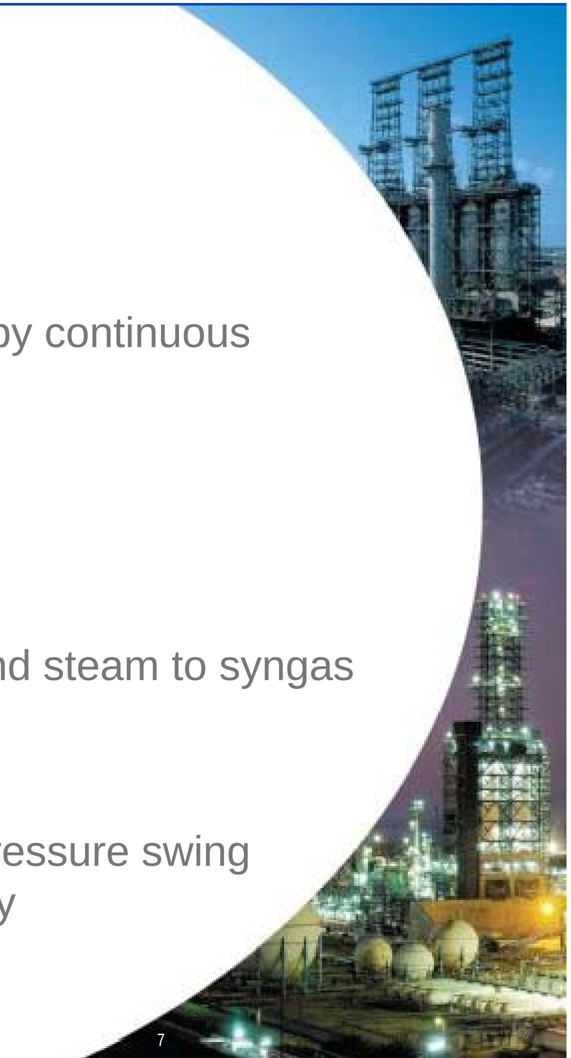
Hydrogen Production with Steam Reformers

Agenda

- Introduction
- Reforming and shifting reactions
- Plant process flow scheme
- Net thermal efficiency
- The Foster Wheeler Terrace Wall™ reformer
- Conclusions



Introduction



- Steam methane reforming (SMR)
  - remains the leading technology for hydrogen
- SMR is a mature technology
  - incremental economic improvements are being made by continuous development

- The plants consist of four basic sections:
  1. Treatment to remove sulphur and other contaminants
  2. Steam methane reformer, which converts feedstock and steam to syngas at high temperature and moderate pressure
  3. CO shift reactor/s to increase hydrogen yield
  4. Hydrogen purification, in which modern plants use a pressure swing adsorption (PSA) unit to achieve the final product purity

Reforming & Shifting Reactions: The Chemistry

The simplified reforming chemical reactions are:

for saturated hydrocarbons

$$C_nH_{2n+2} + nH_2O = nCO + (2n+1)H_2$$

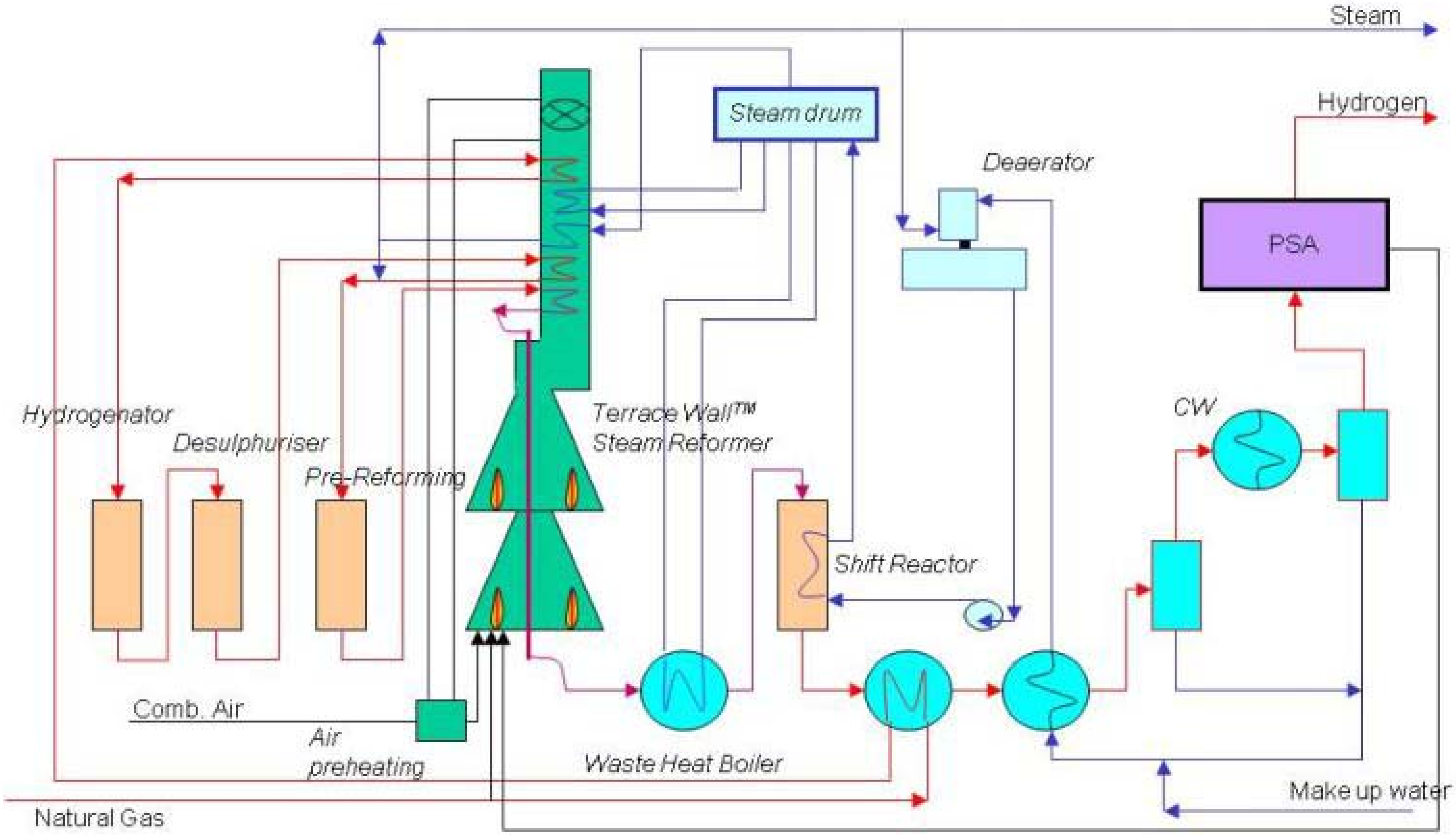
for methane

$$CH_4 + H_2O = CO + 3H_2 \quad \text{delta H} = +\ 206\ \text{kJ/mol}$$

The shift reaction is:

$$CO + H_2O = CO_2 + H_2 \quad \text{delta H} = -\ 41\ \text{kJ/mol}$$

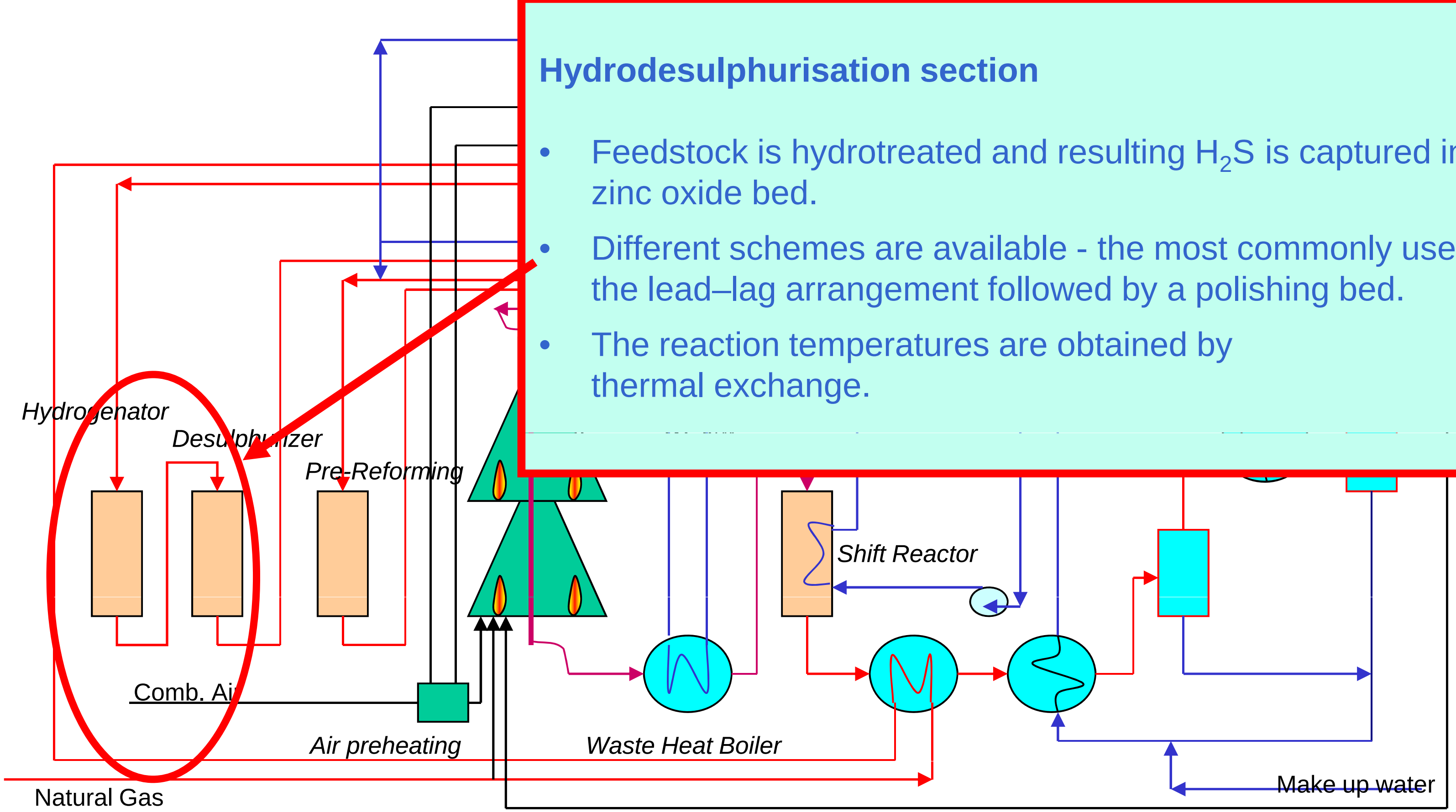
Plant Process Flow Scheme



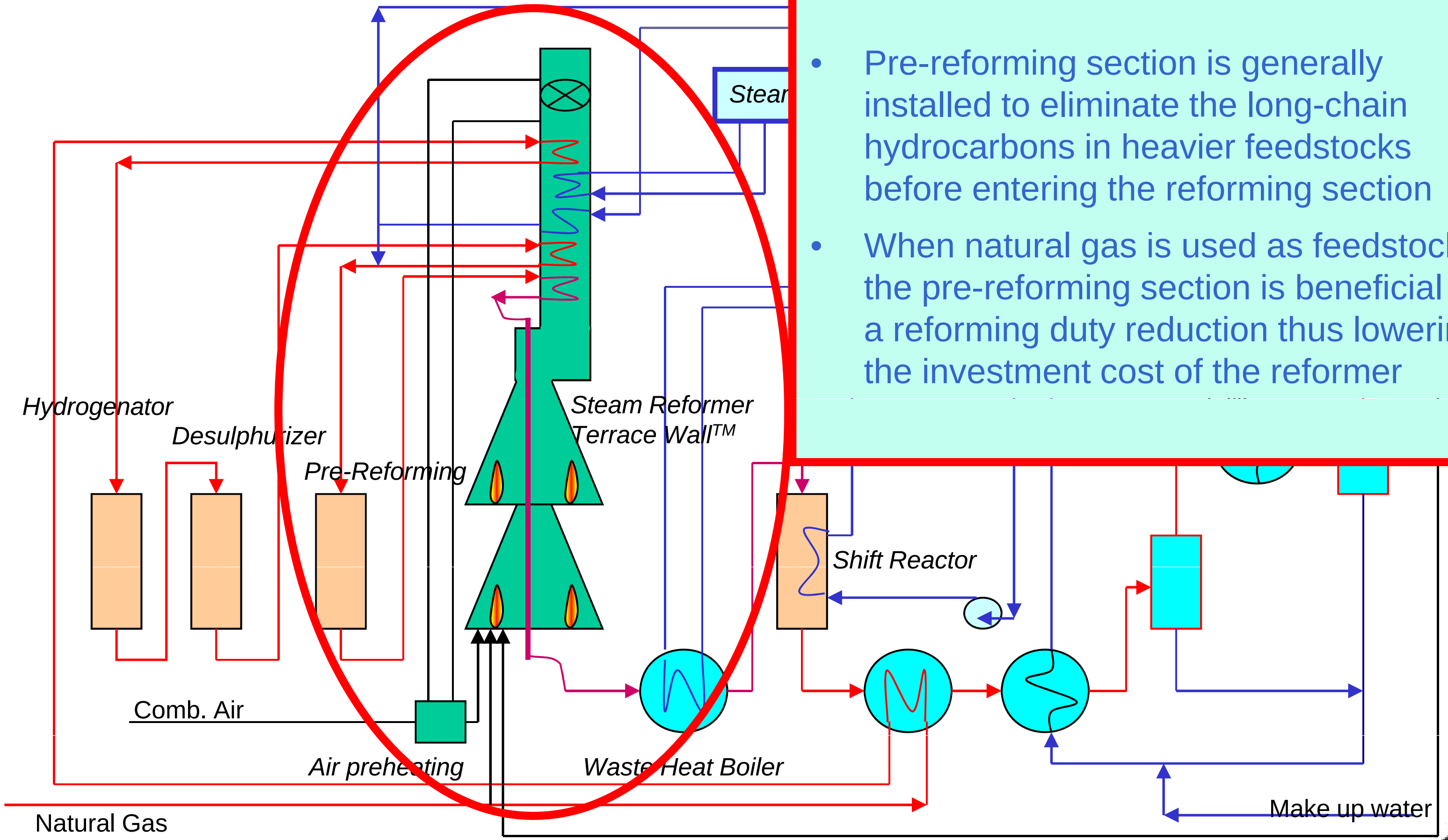
Plant Process Flow Scheme

Hydrodesulphurisation section

- Feedstock is hydrotreated and resulting H_2S is captured in a zinc oxide bed.
- Different schemes are available - the most commonly used is the lead–lag arrangement followed by a polishing bed.
- The reaction temperatures are obtained by thermal exchange.



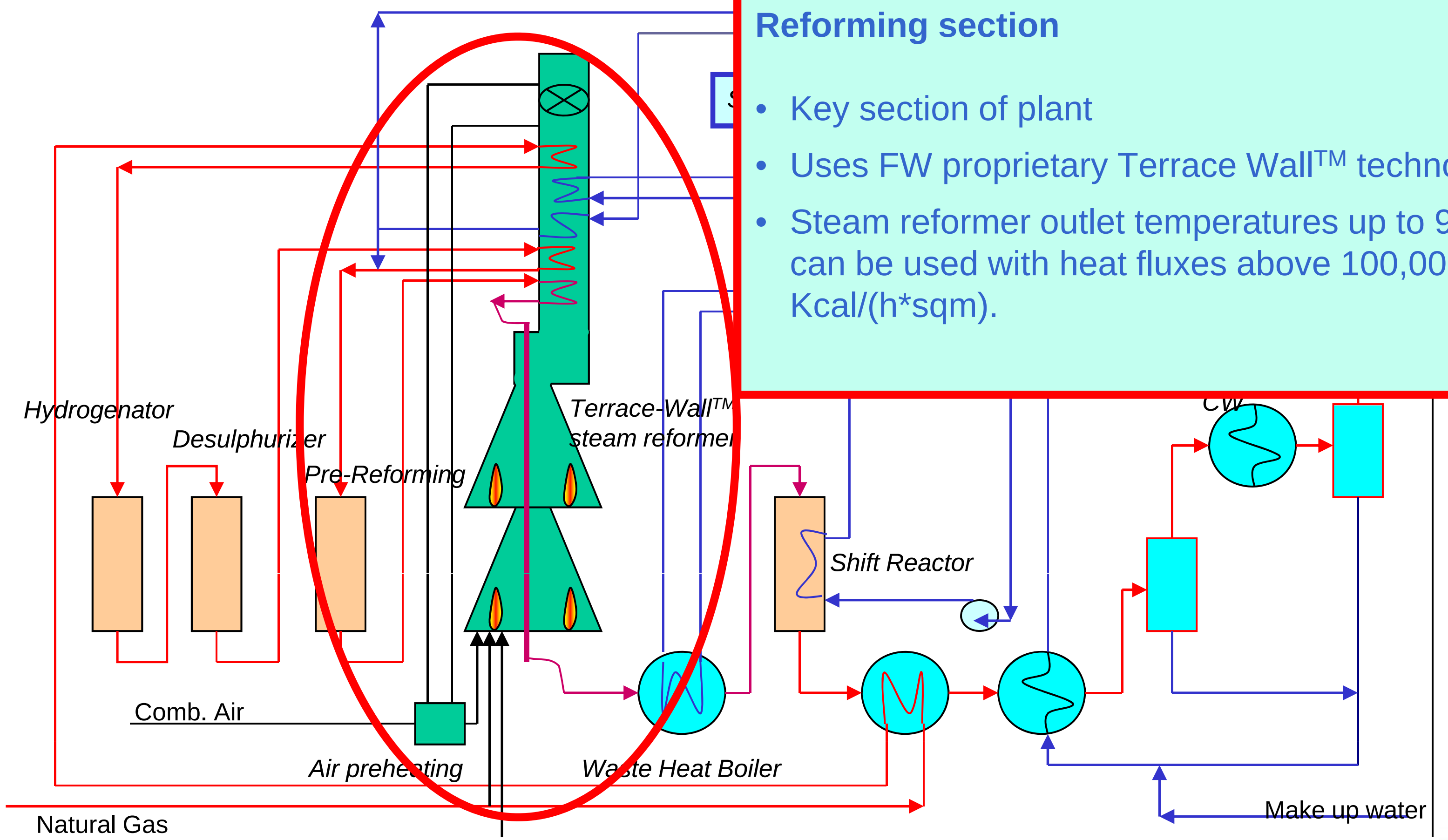
Plant Process Flow Scheme



Pre-reforming section

- Pre-reforming section is generally installed to eliminate the long-chain hydrocarbons in heavier feedstocks before entering the reforming section
- When natural gas is used as feedstock the pre-reforming section is beneficial to a reforming duty reduction thus lowering the investment cost of the reformer

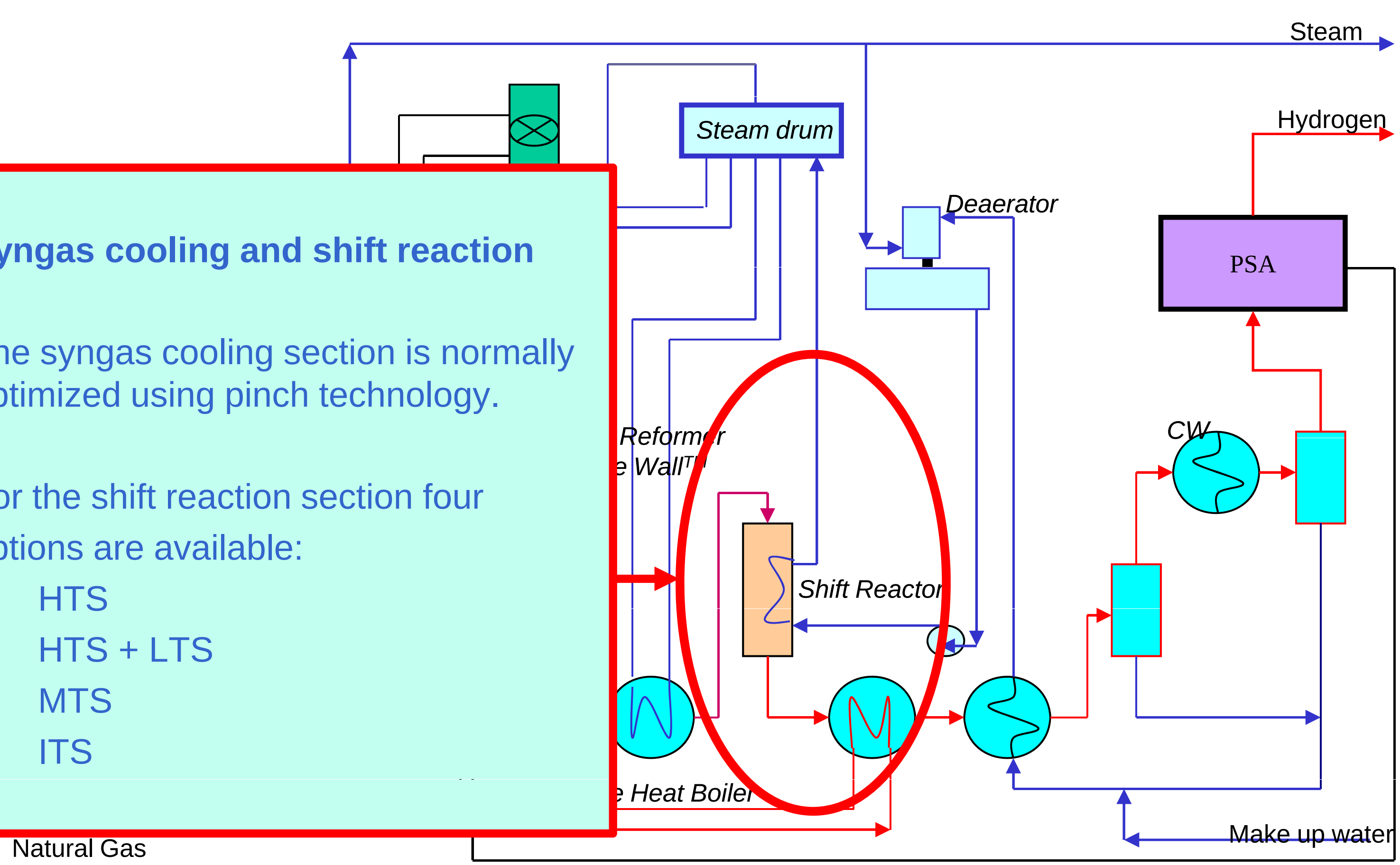
Plant Process Flow Scheme



Reforming section

- Key section of plant
- Uses FW proprietary Terrace Wall™ technology
- Steam reformer outlet temperatures up to 920°C can be used with heat fluxes above 100,000 Kcal/(h*sqm).

Plant Process Flow Scheme



Syngas cooling and shift reaction

The syngas cooling section is normally optimized using pinch technology.

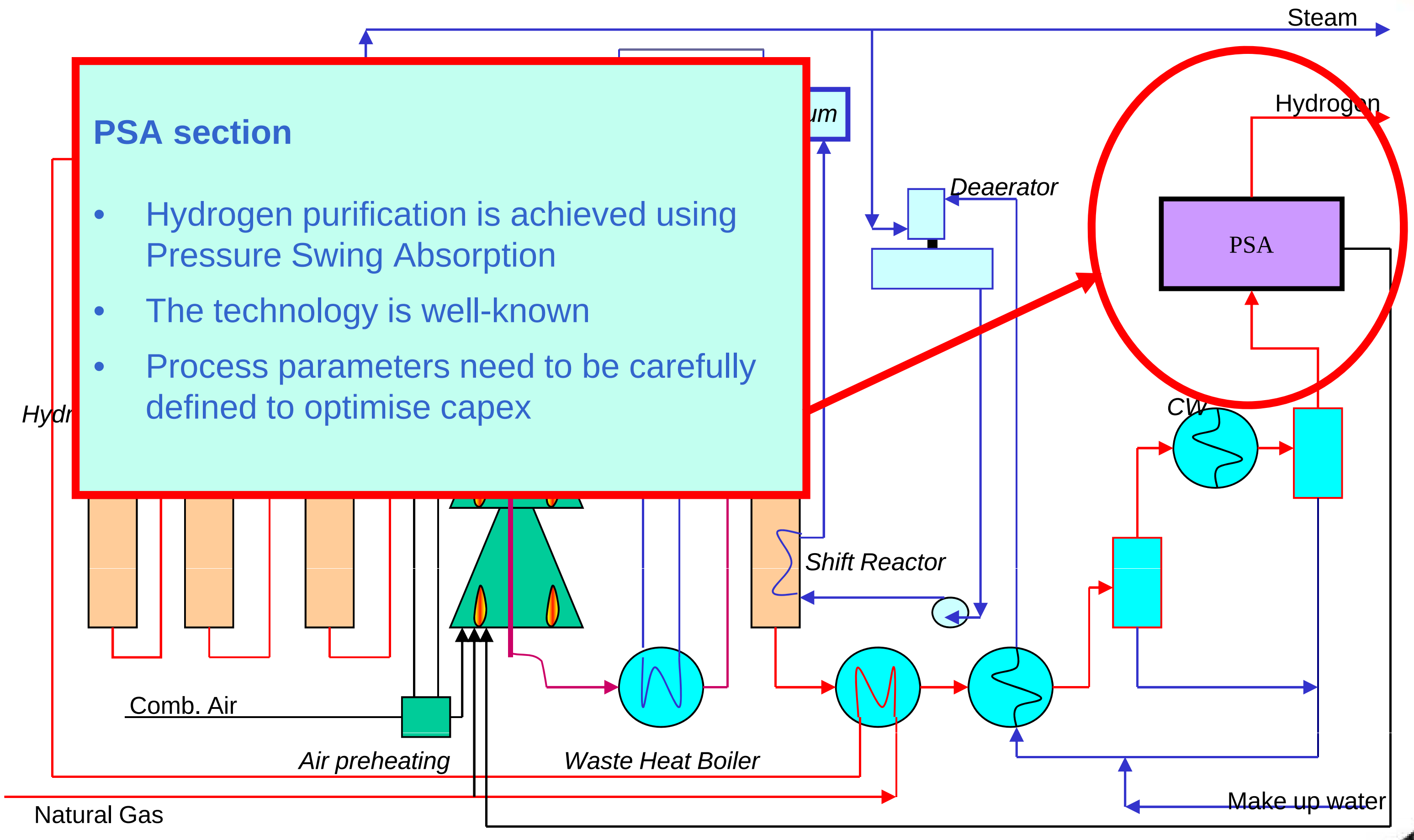
For the shift reaction section four options are available:

- HTS
- HTS + LTS
- MTS
- ITS

Plant Process Flow Scheme

PSA section

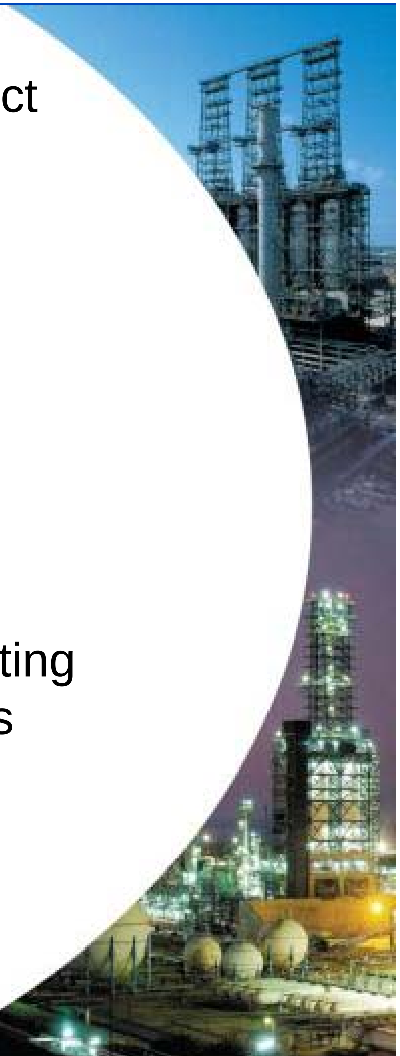
- Hydrogen purification is achieved using Pressure Swing Absorption
- The technology is well-known
- Process parameters need to be carefully defined to optimise capex



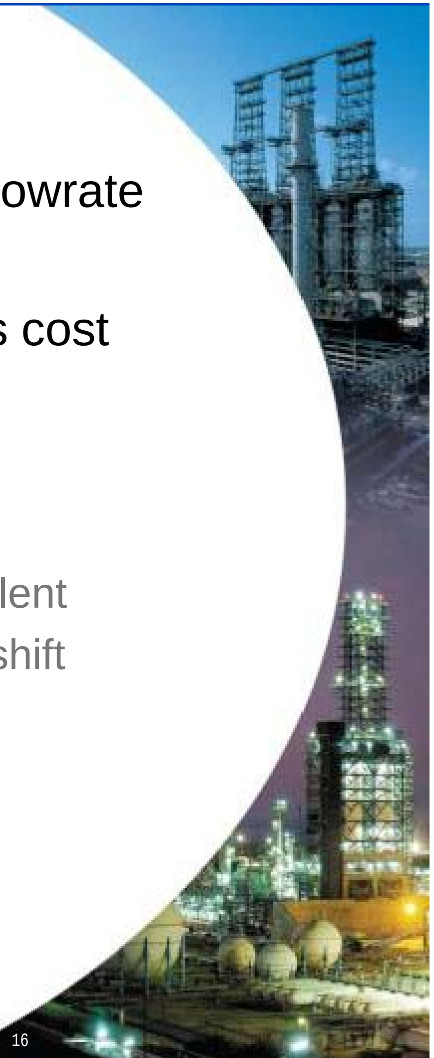
Plant Process Flow Scheme

- Refineries can use different feedstock, subject to internal price and availability:
  - Natural gas
  - Refinery gas
  - LPG
  - Light naphtha
  - Heavy naphtha
  - …. and even straight-run naphtha
- Optimising hydrogen plant design and operating parameters depends on the economic values attributed to the feedstock, fuel and steam

The characteristics of the feedstock will define the processing capabilities of the plant



Net Thermal Efficiency



- The optimum is achieved by minimising :
  (Feedstock(Gcal/h) + Fuel(Gcal/h) – Steam(Gcal/h)) / H_2 flowrate
- Improvement by associating to calorific content the calories cost
- In a refinery where:
  - Hydrogen demand is around 150,000 Nm^3/h
  - Caloric values of feedstock, fuel and steam are almost equivalent
  - Design includes pre-reforming / steam reformer / isothermal shift

a net thermal efficiency of less than 3.0 Gcal per 1,000 Nm^3 of produced hydrogen can be easily achieved

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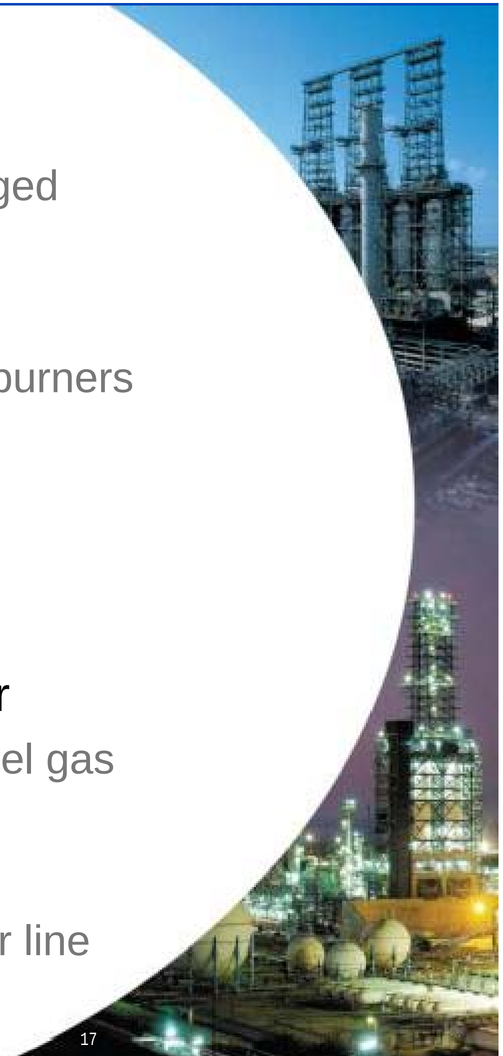
The Foster Wheeler Terrace Wall™ Reformer



- Side-fired heater
  - burners located along lateral walls, flames vertically arranged
- Radiant section
  - comprising a firebox with a single row of catalyst tubes
  - with two terraces on both sides of the tubes on which the burners are installed
- Catalyst tubes are flanged at the top
  - to allow loading and unloading of the catalyst
- Ultra-low-NOX burners
- Burners placed at two levels in the combustion chamber
  - equipped with a double set of firing tips, one for refinery fuel gas and one for vent gas from PSA unit
- Process gas boiler is natural circulation type
  - located at grade/middle of the radiant cell/avoiding transfer line

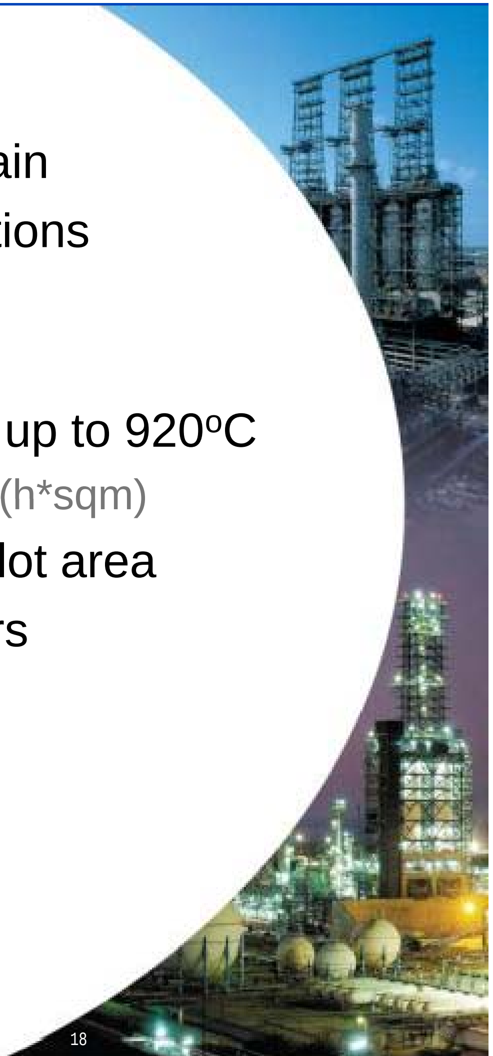
The Foster Wheeler Terrace Wall™ Reformer: design

Design

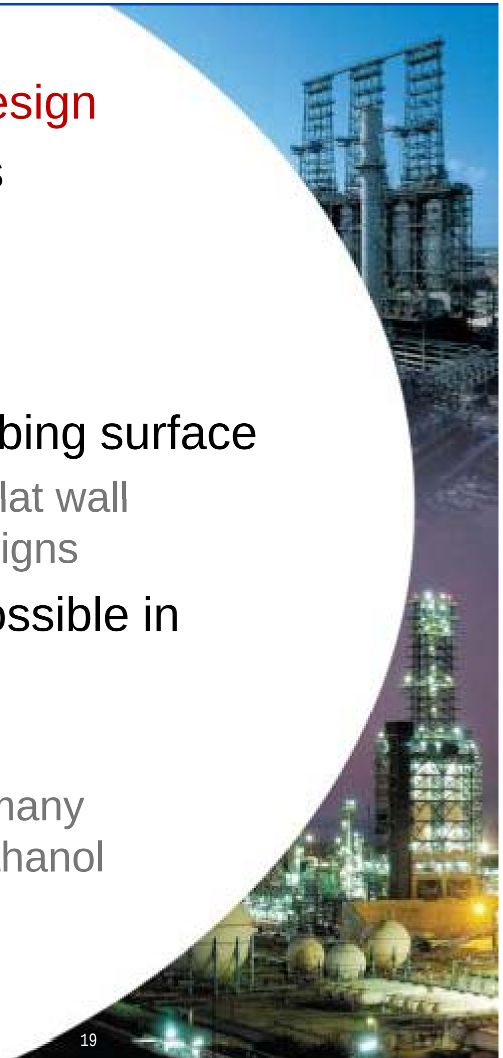
- 200,000 Nm^3/h hydrogen – single train
- Modular radiant and convection sections
  - reducing construction time and cost
- Forced or natural draft mode
- Steam reformer outlet temperatures up to 920°C
  - with heat fluxes above 100,000Kcal/(h*sqm)
- Very compact design reducing the plot area
- Minimum number of low-NOx burners

Leading to:

- Lower operating cost
- Lower maintenance cost
- Lower investment cost



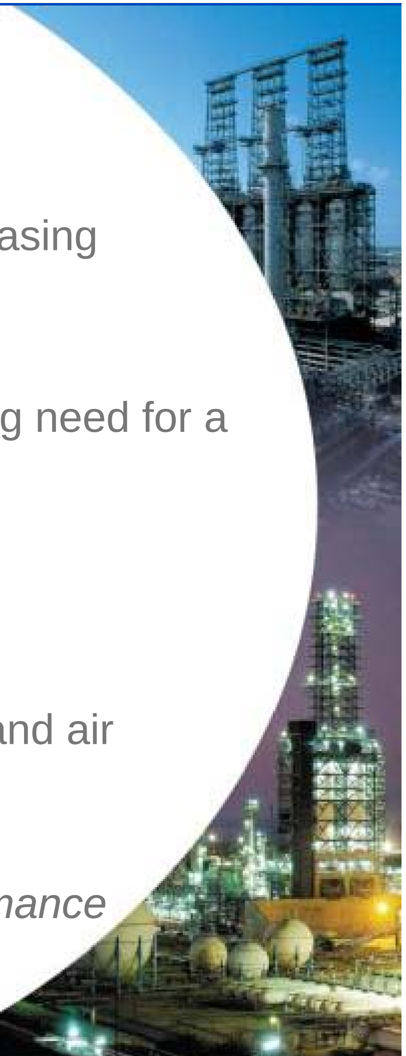
The Foster Wheeler Terrace Wall™ Reformer: design



Key advantages of the sloping walls in a Terrace Wall™ design

- Uniform heating vertically by the rising flow of hot gases
- Each terrace capable of being independently heated
  - specific control of heat flux desired in each zone
  - avoids 'hotspots', maximising tube life
- Maximum effectiveness of the "terrace" as a heat-absorbing surface
  - design accomplishes this to a far greater extent than any flat wall construction, and is distinctly better than in down-fired designs
- Flame impingement on catalyst tubes is practically impossible in the Terrace Wall™ design
- Proven design
  - FW Terrace Wall™ reformers have been in operation for many years, using a wide range of feedstocks for hydrogen, methanol and ammonia production

The Foster Wheeler Terrace Wall™ Reformer: design



Latest developments to deliver further benefits include:

- Modified geometry of the radiant section
  - to tailor flux profile and improve thermal efficiency without increasing catalyst tube temperature
- Outlet pigtails arranged vertically
  - providing better access for easier welding and nipping, removing need for a cold bottom flange for catalyst removal
- Vacuum-type catalyst removal systems
  - allow removal of catalyst via the tube inlet flange
- Reduced number of burners by about 30%
  - due to increased capacity, with new burners using staged fuel and air combustion techniques for lower NOx emissions

…And we are continuing to develop our design to deliver further performance enhancements

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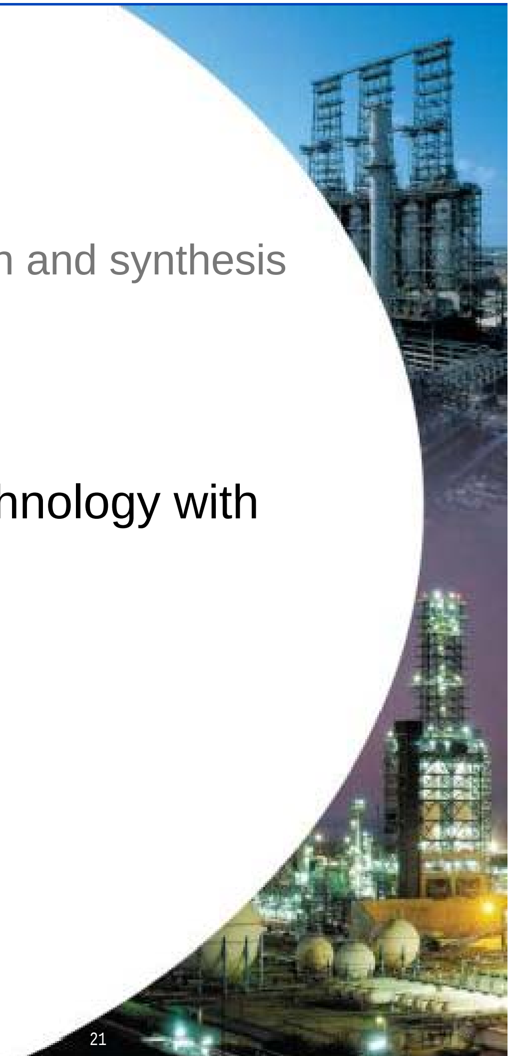
Conclusions



Foster Wheeler has:

- A first-class project execution track record
  - Designed, engineered and constructed over 100 hydrogen and synthesis gas plants with a total installed capacity of over 3bn scfd
- The Technology
  - Extensive experience with its Terraced Wall^{TM} reformer
- Significant expertise gained through integrating our technology with catalyst suppliers and hydrogen purification systems

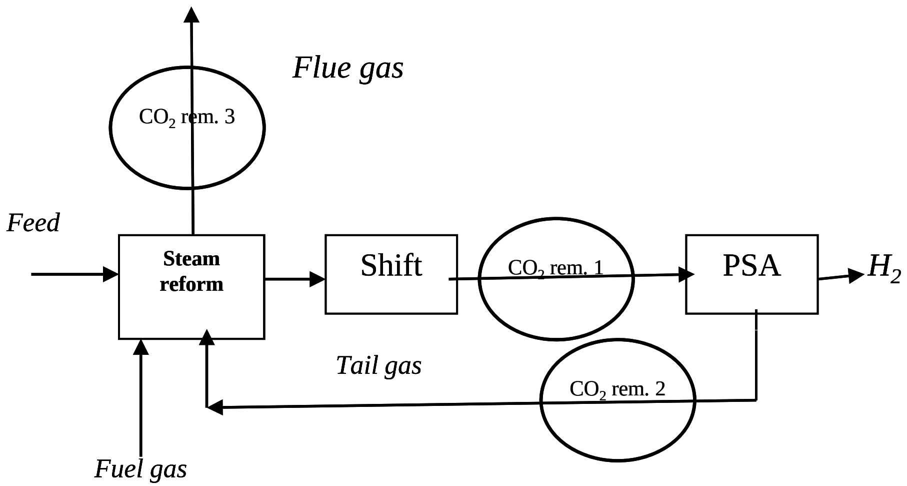
We also have significant experience and expertise in:

- Optimizing and revamping existing hydrogen systems
- Integrating new and existing systems

Conclusions …. and more, CO_2 removal option

Achievable CO_2 removal

CO_2 removed from:	CO_2 removed from each stream (%)	Overall ηCO_2 (%)
1. Raw H_2 (PSA inlet)	~100	60
2. PSA tail gas	90	55
3. SR flue gas	90	90

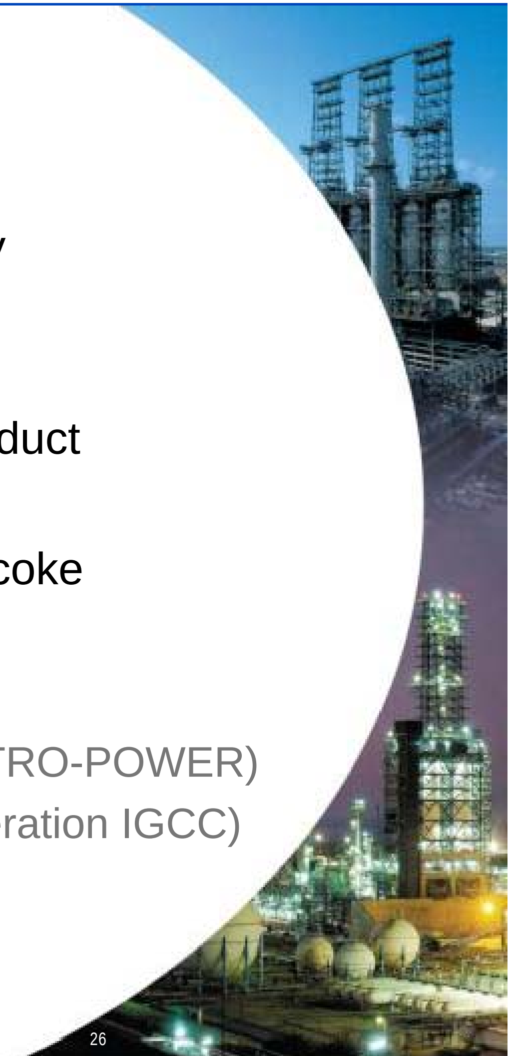


Petroleum coke as source of hydrogen and electric power

Agenda

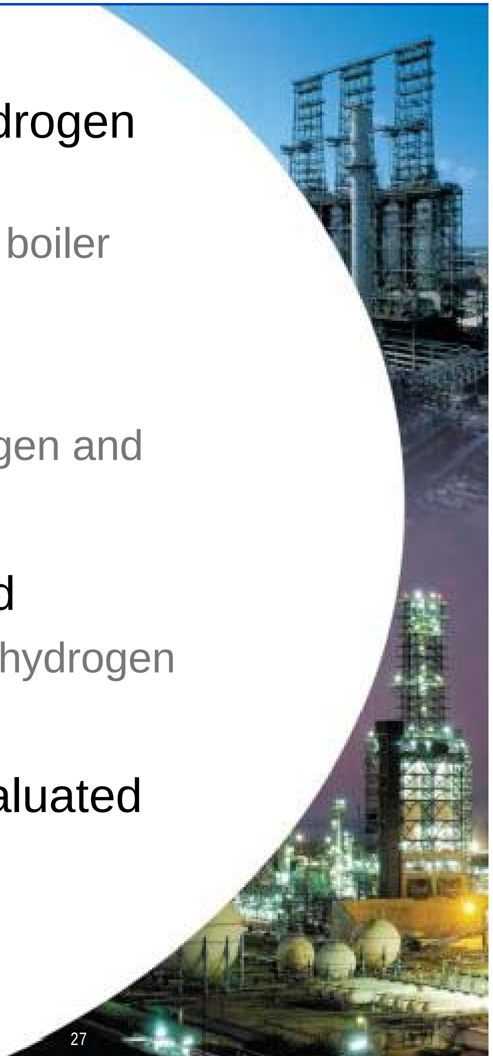
- Introduction
- Gasification
- CFB combustion
- Economical analysis
- Description
- Overall performances
- Investment cost data
- Production cost
- Sensitivity analysis
- Conclusions

Introduction



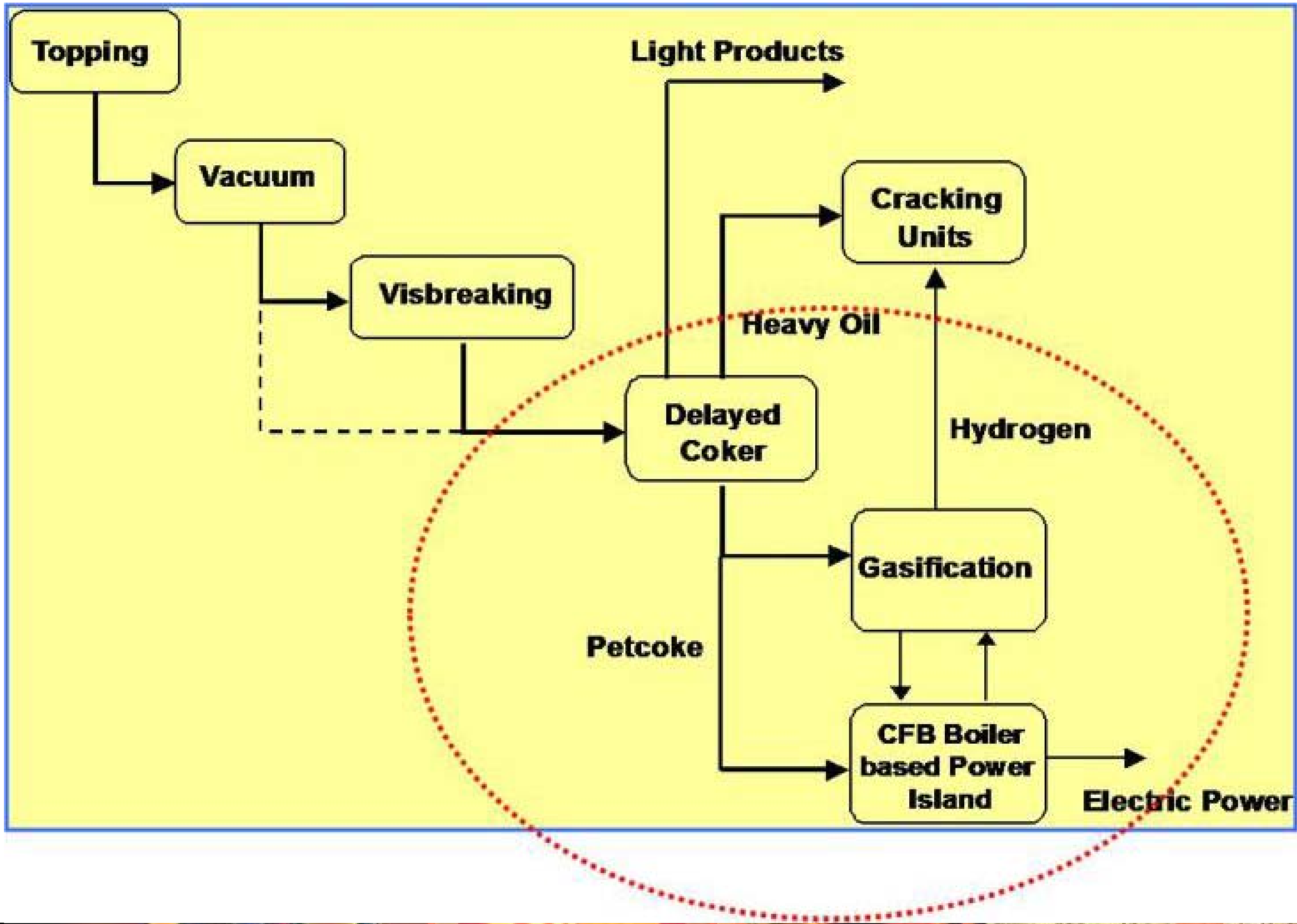
- Crude oils are getting heavier and more contaminated
  - demand and the quality of light products is increasing
- Conversion technologies have been developed significantly
  - however the zero residue production still remains a target
- Conversion leaves the refineries with a residual bottom product
- Delayed Coker – the residual bottom product is petroleum coke
- Petroleum coke uses include:
  - steam and electric power for internal use and export (PETRO-POWER)
  - gasify petcoke for Hydrogen and electric power (polygeneration IGCC)

Introduction

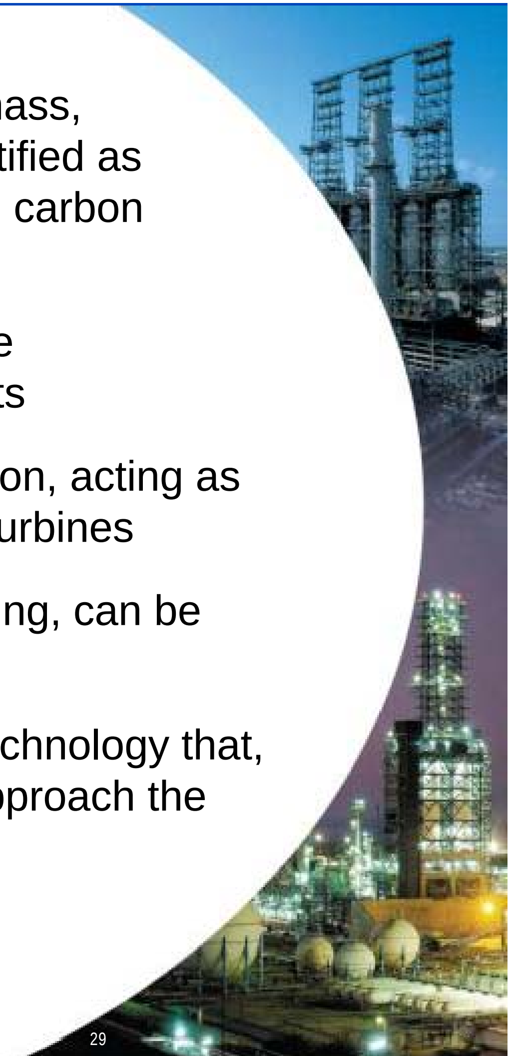


- A novel configuration for the combined production of hydrogen and electric power
  - DCU petcoke – partially gasified and partially burnt in CFB boiler (PETRO-HY-POWER)
- Configuration based on:
  - oxygen-blown entrained-bed gasification to produce hydrogen and
  - CFB combustion to produce electric energy
- Overall performance and investment costs are evaluated
  - sensitivity analysis on cost of electricity (COE) and cost of hydrogen (COH)
- Impact of carbon dioxide (CO_2) sequestration is also evaluated

Concept Description

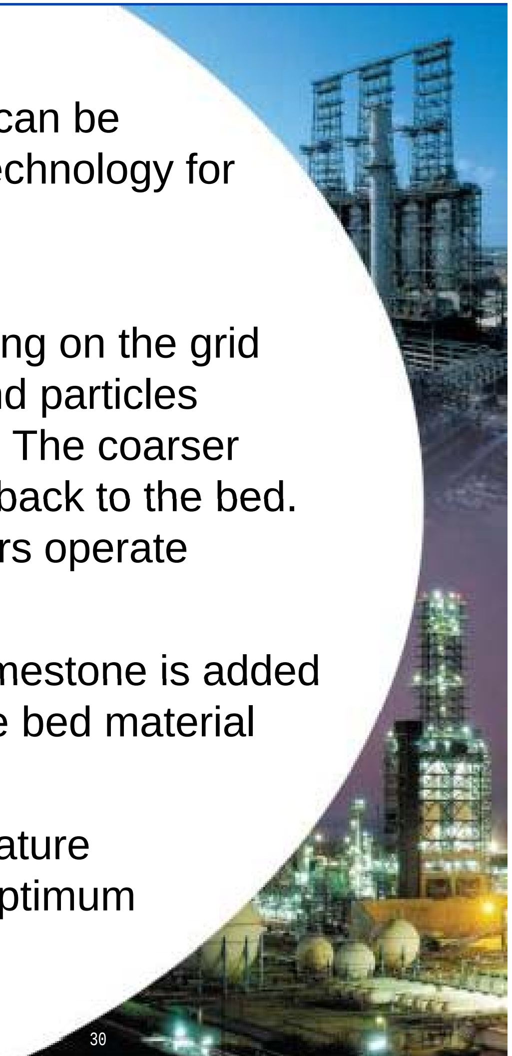


Gasification



- Gasification is the conversion of either a solid (coal, coke, biomass, solid waste) or a liquid fuel (oil, tar, pitch) into a gas, often identified as syngas, in which the major components are hydrogen (H2) and carbon monoxide (CO)
- In latter part of 20^{th} Century gasification was mainly used in the petrochemical industry for the manufacture of chemical products
- Today gasification is sometimes integrated with power production, acting as a bridge between coal, petcoke or heavy fuel oils and the gas turbines
- Gasification of such fuels generates a fuel gas that, after cleaning, can be used in a gas turbine combined cycle power plant
- The resulting process configuration, IGCC, is the only power technology that, even burning coal or high sulphur residues like petcoke, can approach the environmental performance of natural gas fired systems

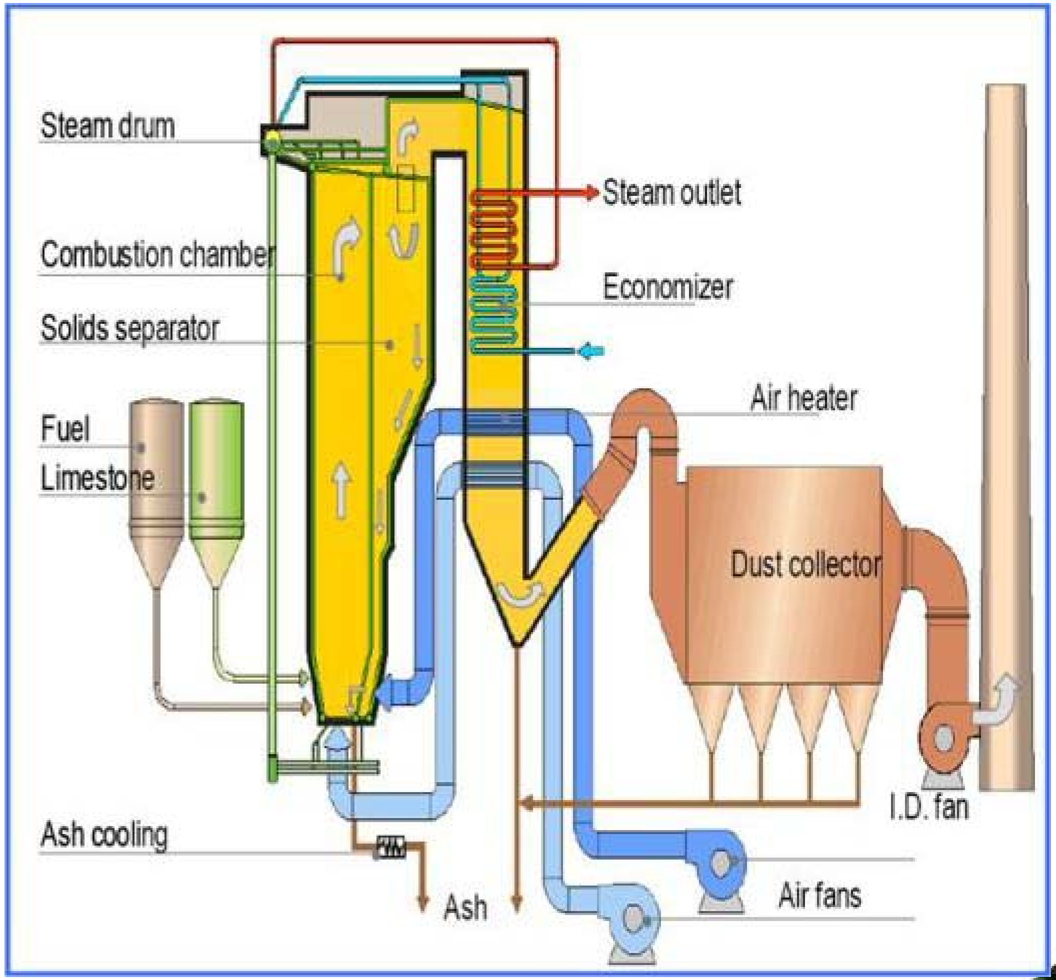
Circulated Fluidized Bed Combustion



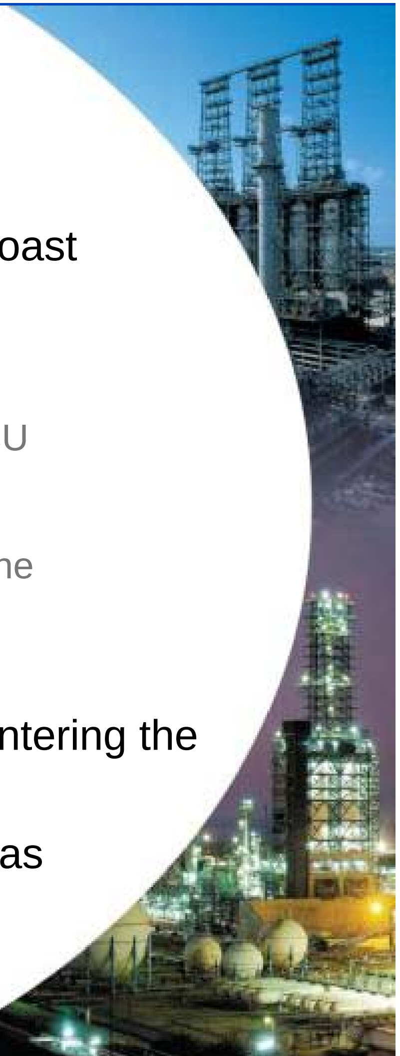
- A clean and more efficient use of petcoke for power production can be achieved in a CFB boiler, by far the most suitable combustion technology for low reactivity, high sulphur fuels like petcoke
- Fluidizing is achieved by blowing air through the bed material lying on the grid (air distributor). Above a certain air velocity, the bed expands and particles become entrained in the flue gas and are carried out of the bed. The coarser entrained particles are separated in a hot cyclone and returned back to the bed. This is the circulating fluidized-bed principle on which CFB boilers operate
- For petcoke which is characterized by a high sulphur content, limestone is added to capture the sulphur, constituting together with the fuel ash the bed material
- The combustion chamber is maintained at a relative low temperature (850-900°C) by suitable heat absorbing surface, thus allowing optimum condition to remove the sulphur and control the NOx emissions

Circulated Fluidized Bed Combustion

Long solids residence time in the furnace results in high combustion efficiency through recirculation of solids via the cyclone, plus the vigorous solids/gas contact in the furnace caused by the fluidization airflow.



Basis of design for the analysis



- The plant is designed to process petcoke
  - LHV equal to 33,867 kJ / kg and 6.73% wt sulphur content
- The site conditions assumed for the plant are a green field on a seacoast
  - average air temperature and average sea water temperature of 15°C
- Plant capacity
  - 100 t / h (dry basis) petcoke flowrate as resulting from a 55,000 BPSD DCU
- The petcoke stream entering the plant is split into two parts
  - The first one necessary to produce 100,000 Nm^3 / h hydrogen is sent to the gasification island
  - The remaining part is fed to the CFB boiler to produce power
- Base case: carbon dioxide removed from the hydrogen rich stream entering the purification unit is vented to the atmosphere
- Alternative case: drying and compression of CO_2 captured from syngas

Basis of design for the analysis

	CFB boiler (@ 6% O_2 vol. dry)
NO_x (as NO_2)	$\leq$ 200
SO_x (as SO_2)	$\leq$ 200
CO	$\leq$ 150
Particulate	$\leq$ 30

The gasification is based on oxygen-blown entrained-bed gasification, operating at a pressure suitable to produce a Hydrogen stream at 30 barg.

The plant's main products are hydrogen and electric energy.

By-products are: sulphur (liquid or solid), solid by-products (metal cake and CFB bottom ash) and carbon dioxide (alternatives with CO_2 capture).

The overall gaseous emissions from the plant, referred to dry flue gas with 6% volume oxygen (O_2), shall not exceed the European Directive limits (refer left).

These limits are met without the need to install downstream flue gas treatment facilities other than filter bags or electrostatic precipitator (ESP) for dust collection.

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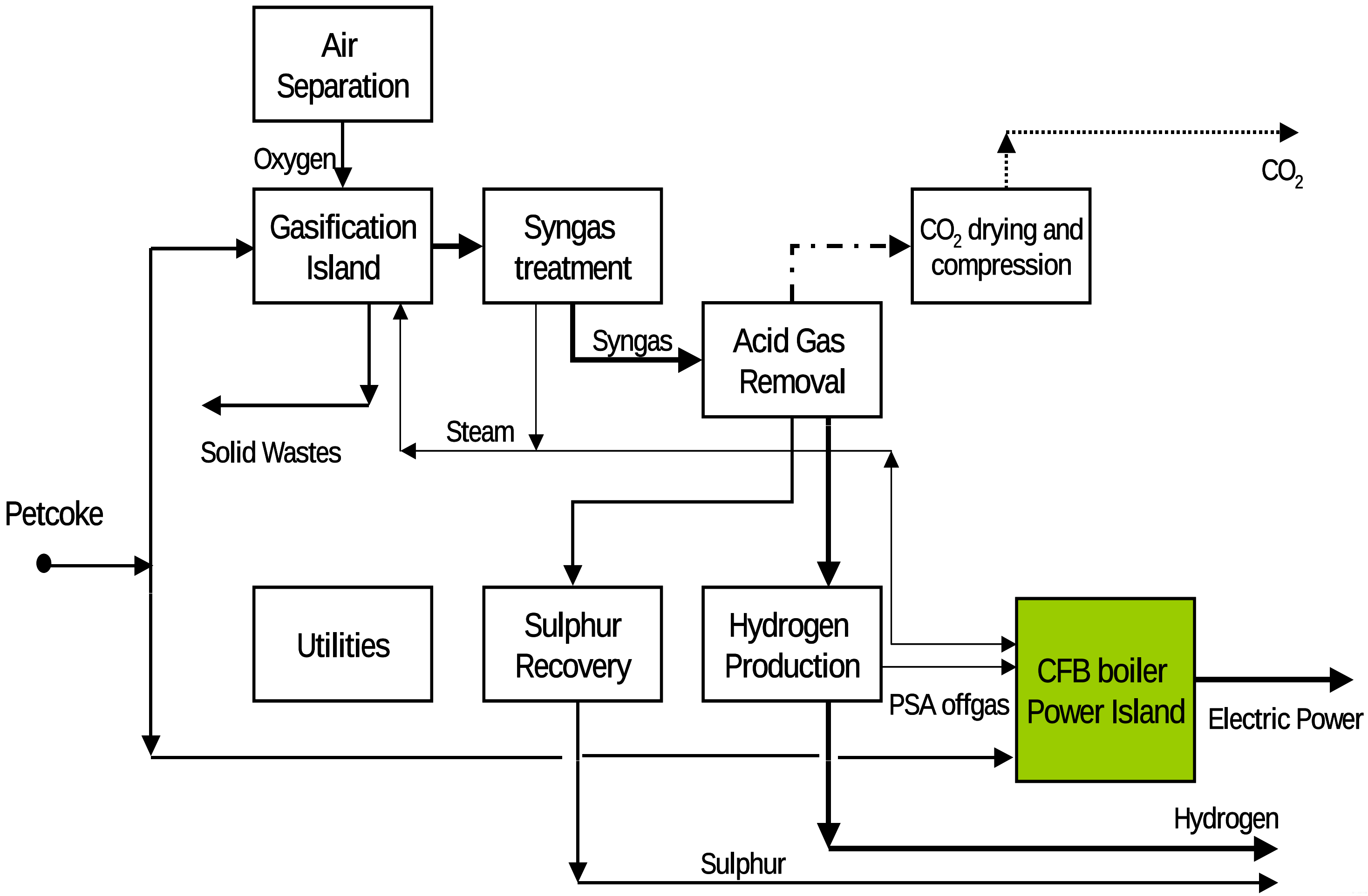
Description



Description

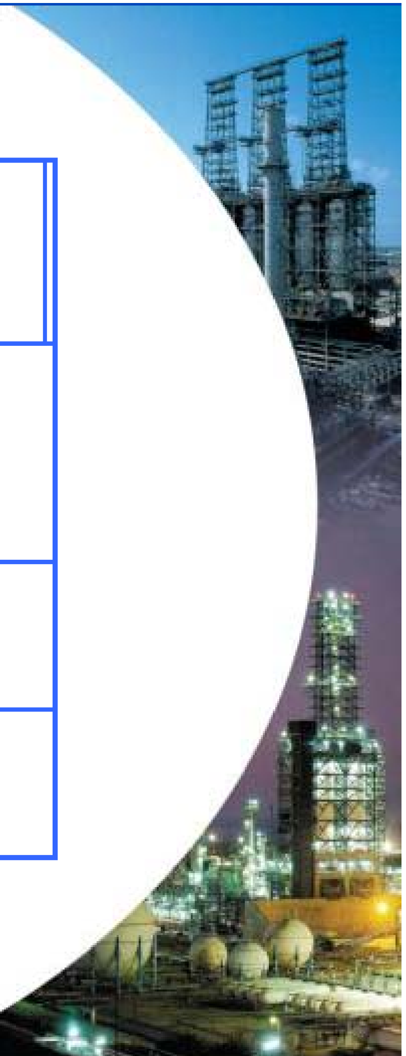
Further evaluations will investigate the potential of CFB oxycombustion applied to the same plant configuration.

R&D activities for CFB oxycombustion are in progress by Foster Wheeler Global Power Group.

Overall performances

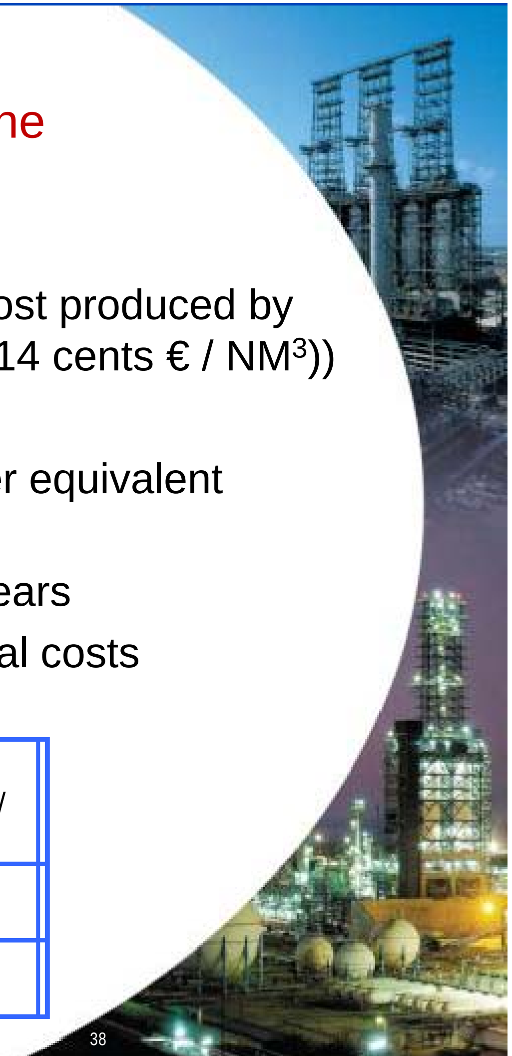
CASES		Base Case	with CO_2 capture
Petcoke flowrate (dry),	t/h	**100**	
Petcoke flowrate (as received),	t/h	105.6	
Petcoke flowrate for gasification unit (as received)	t/h	61.4	
Petcoke flowrate for CFB unit (as received)	t/h	44.2	
Thermal Power (Petcoke LHV basis)	MWt	953.3	
PSA offgas thermal power	MWt	48.1	
HYDROGEN PRODUCTION	Nm^3/h	**100,000**	
Gross Power Electric Power Output	MWt	**211.6**	
Power Island Consumption	MWe	12.2	12.2
Gasification Island Consumption	MWe	41.8	50.8
Electric Power Consumption	MWe	54	63
NET ELECTRIC POWER OUTPUT	MWe	**157.6**	**148.5**
Power Island Net Electrical Efficiency	%	44.6	42.5
CO_2 captured	t/h	-	158.4
Capture Rate	%	-	**49.3**

Investment cost data



CASE	MAIN IGCC SECTIONS INVESTMENT 10^6 Euro					Total Investment 10^6 Euro
	Air Separation	**Process Units**	**CO_2 Compression**	**Power Island**	**Utilities & Offsites**	
Base case	64	271	0	194	133	**662**
with CCS	64	271	14	194	135	**676**

Production cost



The cost of electricity has been evaluated on the basis of the following assumptions:

- Cost of petcoke: 15 Euros / t
- Price of hydrogen: 0.09 Euro / NM^3 (derived from hydrogen cost produced by SMR with natural gas price of 6 US$ / MMBtu (approximately 14 cents € / NM^3))
- No selling price is attributed to the sequestered CO_2
- Hydrogen equivalent availability equal to 98.5%. Electric power equivalent availability equal to 90%
- 10% discount rate on the investment cost over 25 operating years
- Maintenance cost equivalent to approx 3.5 % of the total capital costs

CASE	**Hydrogen prod.**, Nm^3 / h	**Cost of H_2** Cent € / Nm^3	**C.O.E.** Cent € / kWh
Base Case	100,000	9	5.9
with CCS	100,000	9	6.5

Petroleum coke as source of hydrogen and electric power

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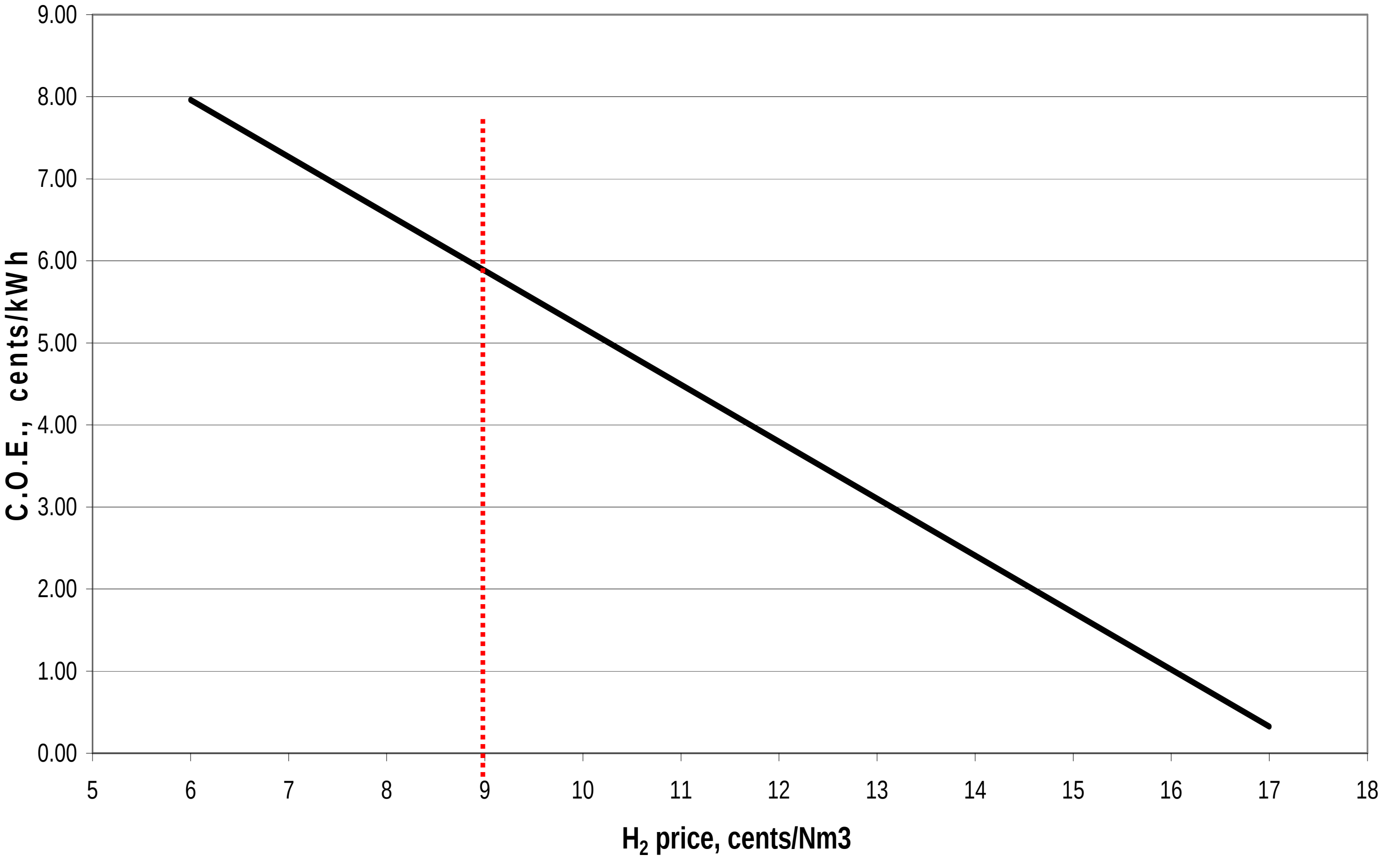
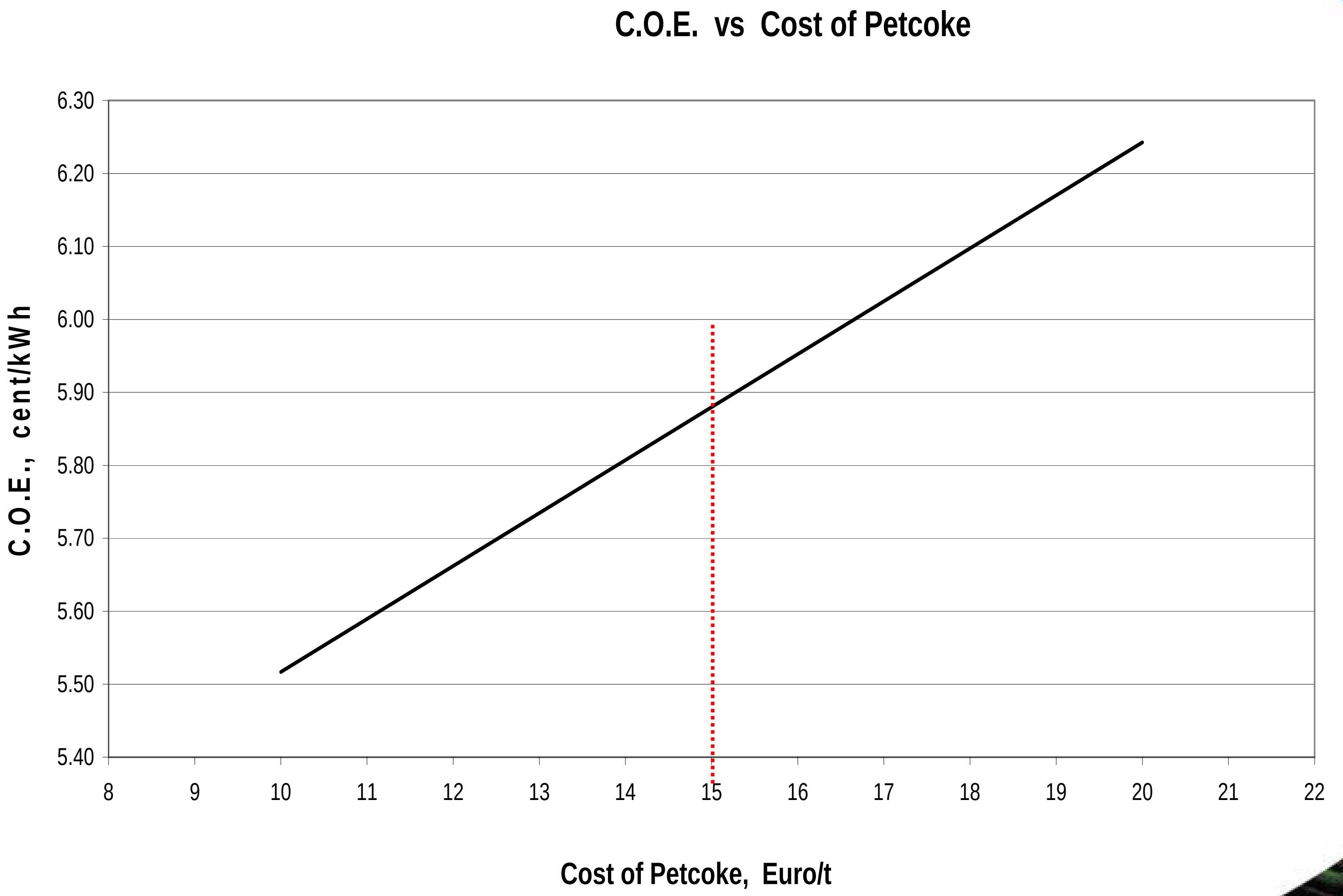
Sensitivity analysis

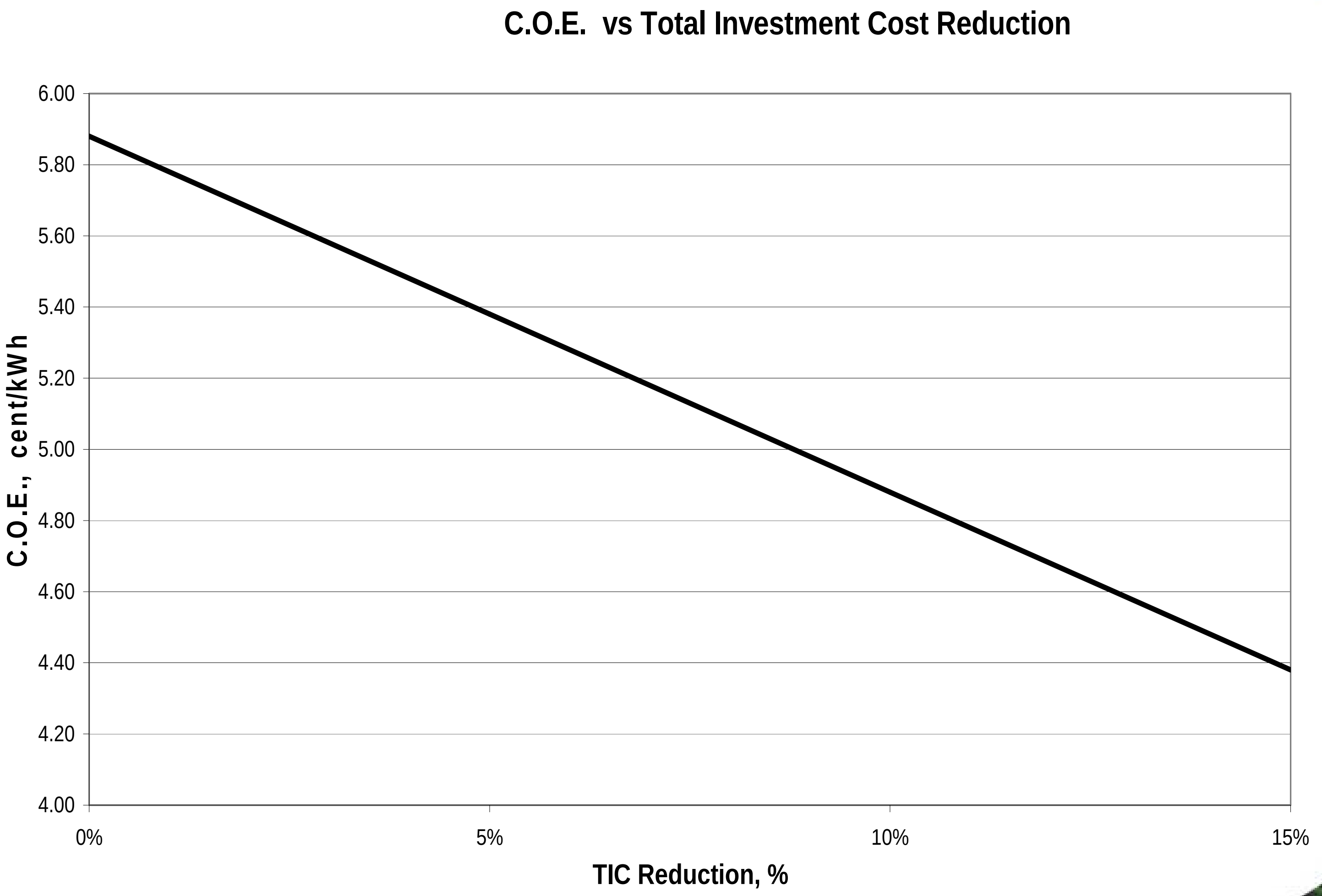
C.O.E. vs Hydrogen price (Petcoke cost = 15 Euro/t)



Sensitivity analysis



Sensitivity analysis



Comparison with IGCC option

Techno-economic evaluations are compared with the corresponding IGCC plant designed for co-production of hydrogen and power.

Petcoke flowrate, t / h	129.6 **(*)**
Hydrogen Production, Nm^3/h	100,000
Net Electric Power, MWe	185.2

(*) set to produce 100,000 Nm3/h H2 and to meet the appetite of one gas turbine, class E, 130 MWe nominal power output

	IGCC	**NOVEL PLANT CONFIGURATION**	**DIFFERENCE, %**
@COH: 9 cents / Nm^3	6.1	5.9	- 3%
@COH: 14 cents / Nm^3	3.3	2.4	- 28%

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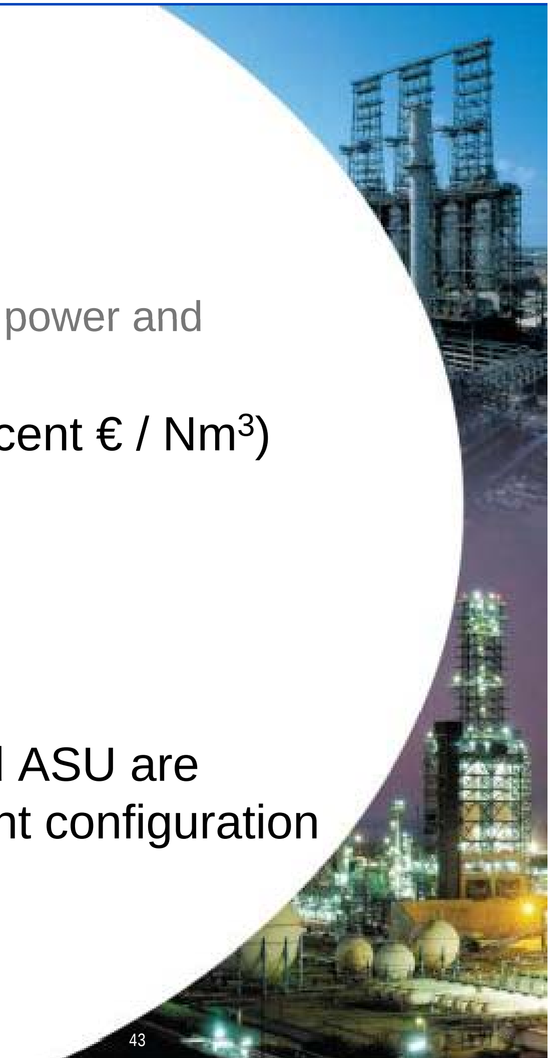
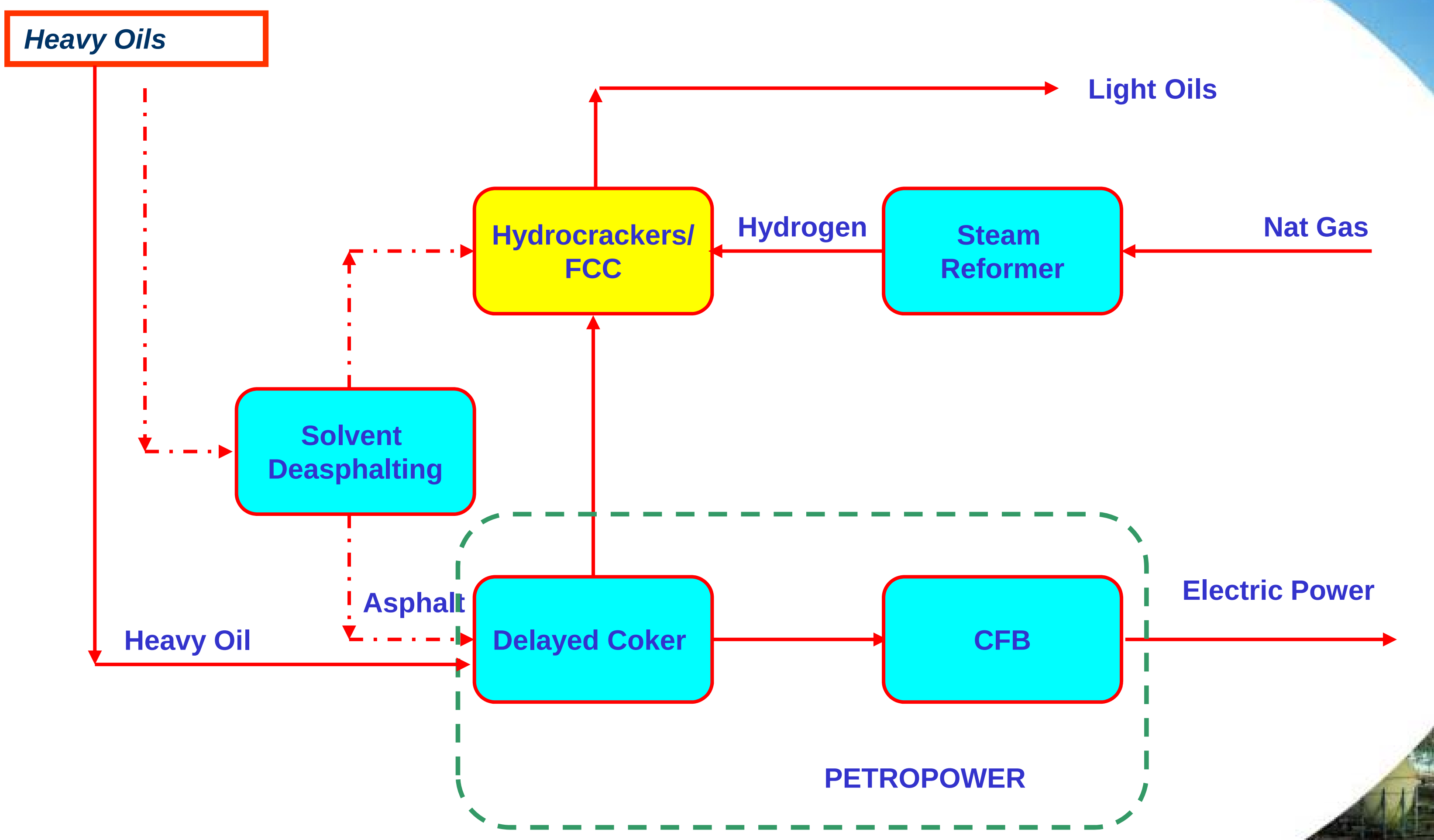
Conclusions



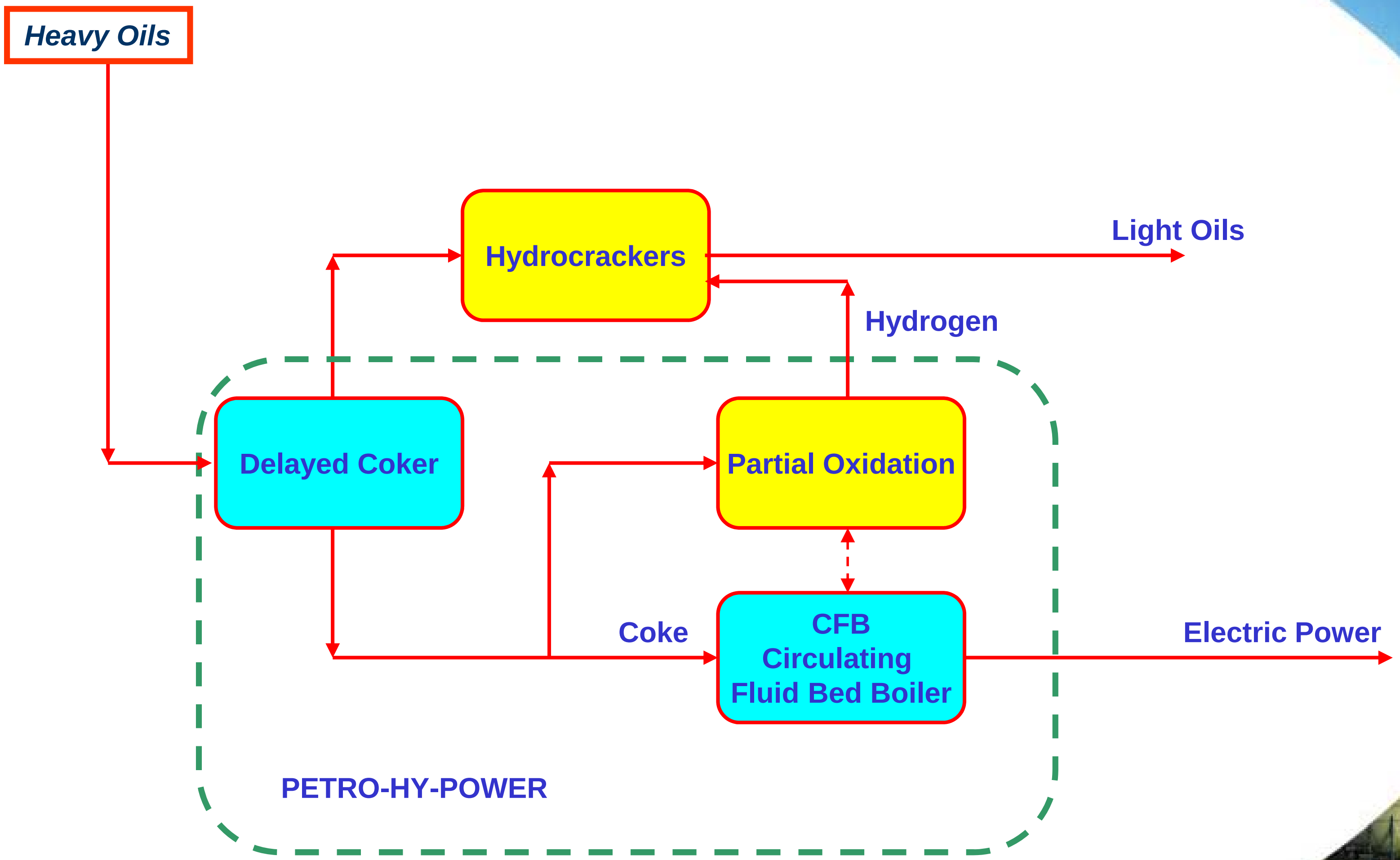
- Hydrogen and electric power production
  - excellent efficiency
- Plant configuration and size
  - easily adjusted to fulfil different requirements of electric power and hydrogen production
- The cost of electricity (assuming hydrogen price of 9 cent € / Nm^3)
  - attractive including cases with the $C0_2$ capture
- The partial capture of the $C0_2$
  - higher investment cost and to a small loss of efficiency

- Improvements in the main areas like the gasifiers and ASU are expected in the near future, making the proposed plant configuration more and more attractive

Conclusions



Conclusions



Clean chemicals from gasification of petroleum coke

Agenda

- Introduction
- Methanol
- SNG (Substitute Natural Gas)
- Distillates
- Ammonia / Urea

Introduction

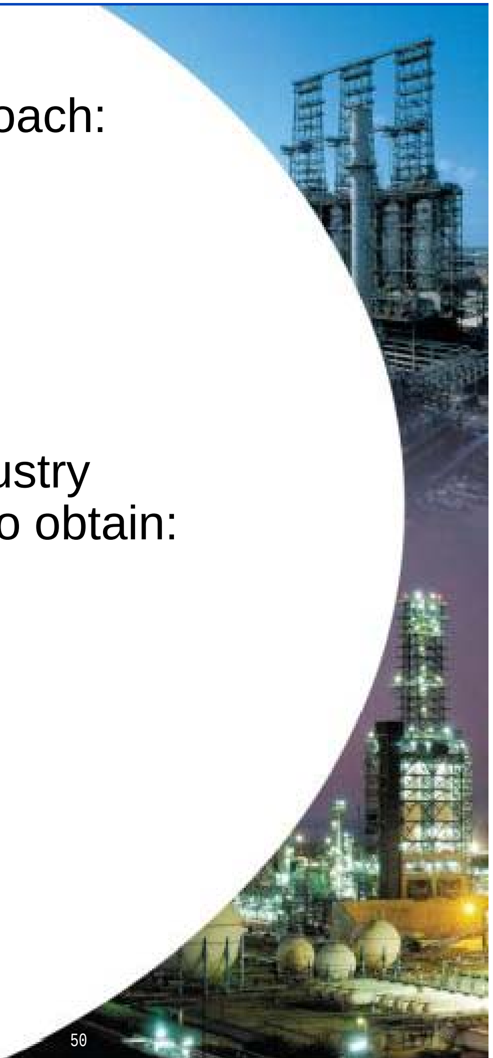
Previous slides presented efficient and economic uses of Petcoke

- Power
- Steam
- Hydrogen

However there are further possibilities

- Valuable chemical products

Introduction



Petroleum coke into chemical products it is a two step approach:

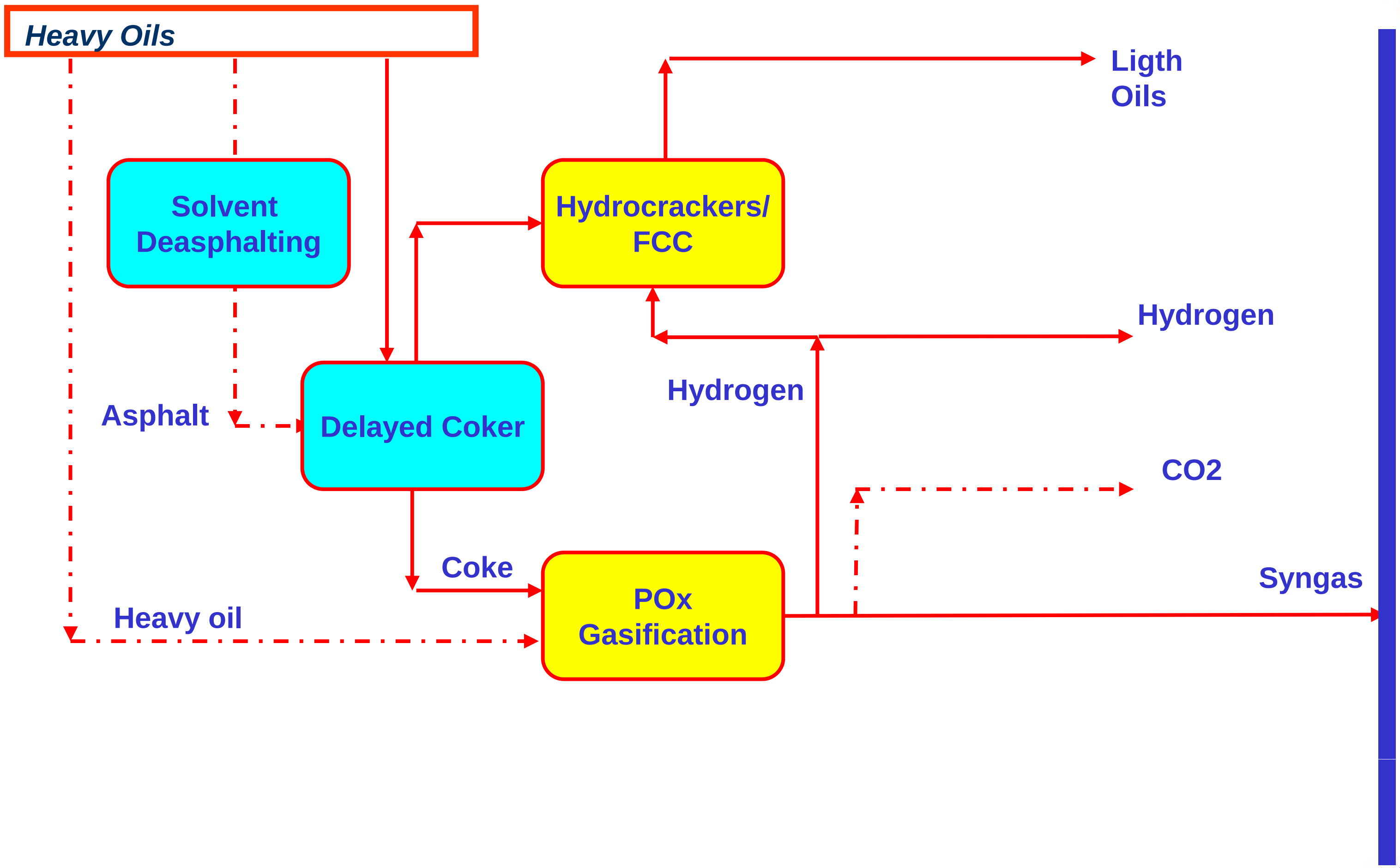
First
Transform petroleum coke into syngas

Second
Transform syngas into chemical product

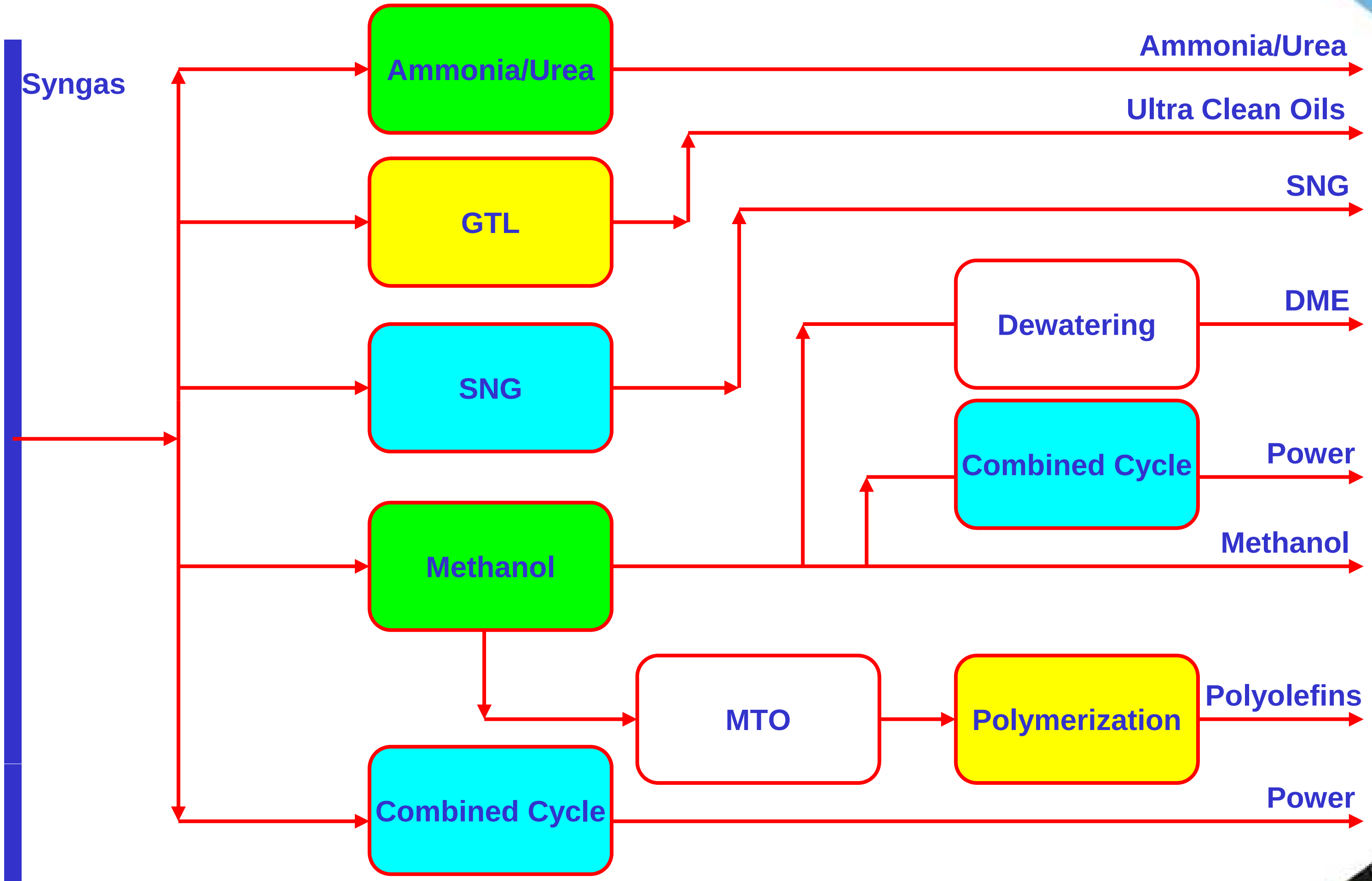
Syngas is a mixture of basic chemical components (the industry chemical “bricks”) that can be processed in different ratios to obtain:

- Hydrogen
- Methanol
- SNG (Substitute Natural Gas)
- Distillates through Fischer-Tropsch reaction
- Ammonia and Urea

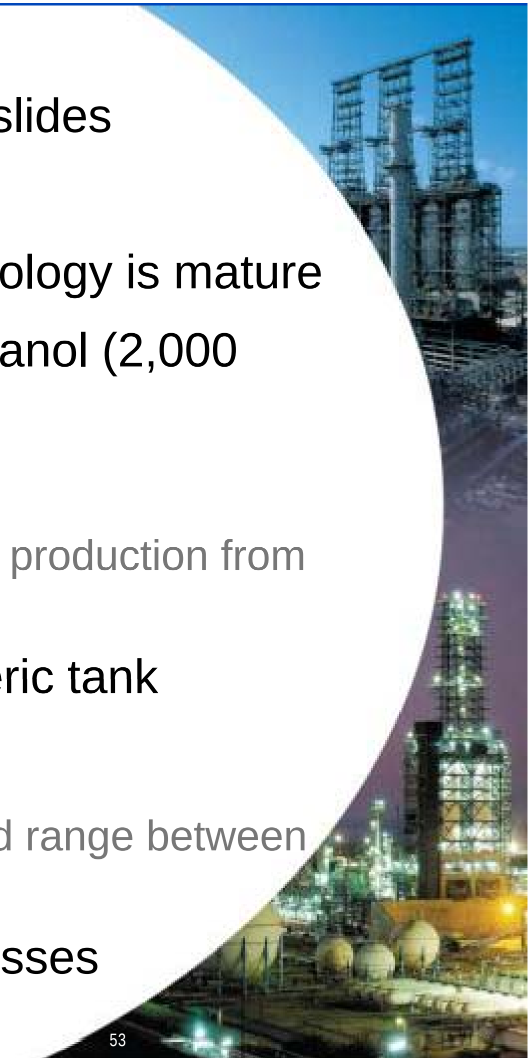
Introduction



Introduction



Methanol



Hydrogen production has been covered in previous slides

Methanol

- Syngas can be easily converted to methanol; the technology is mature
- 100 t/h of petroleum coke produces approx 83 t/h methanol (2,000 MTPD)
- Several proven technologies are available
  - FW has an agreement with Casale and can provide overall production from DCU to petroleum coke gasification to methanol
- Methanol can be accumulated as liquid in an atmospheric tank
- Methanol market price is very volatile
  - range from 150 $/t to 800$/t while the production cost could range between 200 to 250 $/t
- Methanol is an interesting starting point for many processes

SNG (Substitute Natural Gas)

SNG (Substitute Natural Gas)

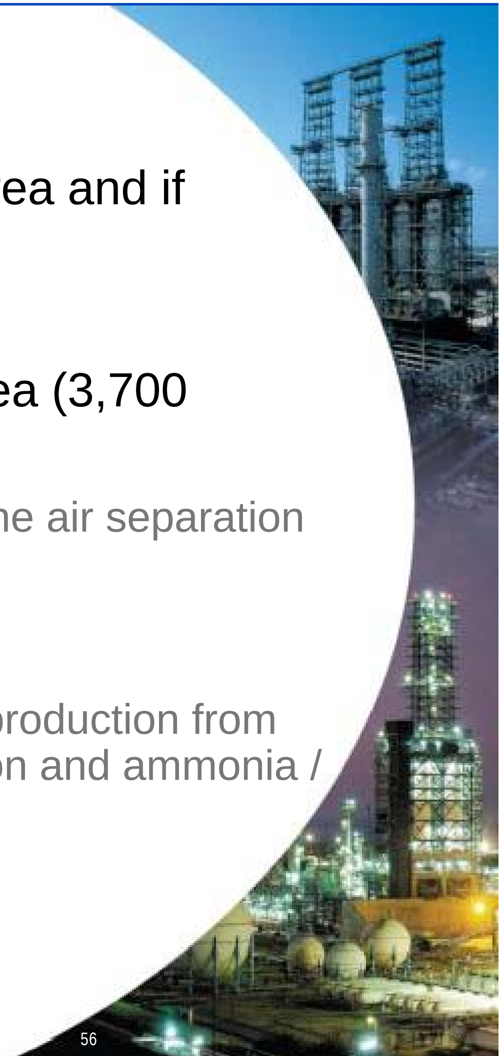
- Syngas can be easily converted to SNG
  - the technology is proven even if there are not many commercial installations
- 100 t/h of petroleum coke produces approx 62,000 Nm^3/h of SNG (500 MM Nm^3/y)
- Several technologies are available
  - FW has developed its own technology which offers several advantages over the competition (simplicity, no recirc compressor, mild temperatures)
  - FW technology is supported by a catalyst which is SudChemie property
  - FW can provide overall production from heavy refinery residues through delayed coker, gasification to SNG production
- SNG can be easily sold to the natural gas grid
- SNG production plant is simple with relatively low cost unit

Distillates

Distillates through Fischer-Tropsch reaction

- Syngas can be converted to oil distillates via Fischer-Tropsch reaction
  - the technology is mature but few references are on the market
- 100 t/h of petroleum coke produces approx 36 t/h of distillates (equivalent to 7,400 BPSD of LPG/Naphtha/Diesel)
- Few proven technologies are on the market
  - availability is subject to specific agreements with the technology providers
  - FW has excellent relations both with Sasol and Shell which are the most experienced technology providers
  - FW can provide to its customers overall production from refinery heavy residues through delayed coking to gasification and finally to distillates
- Distillates can be further processed and injected in the refinery blending pools contributing to the production of clean fuels
- High investment cost unit

Ammonia / Urea



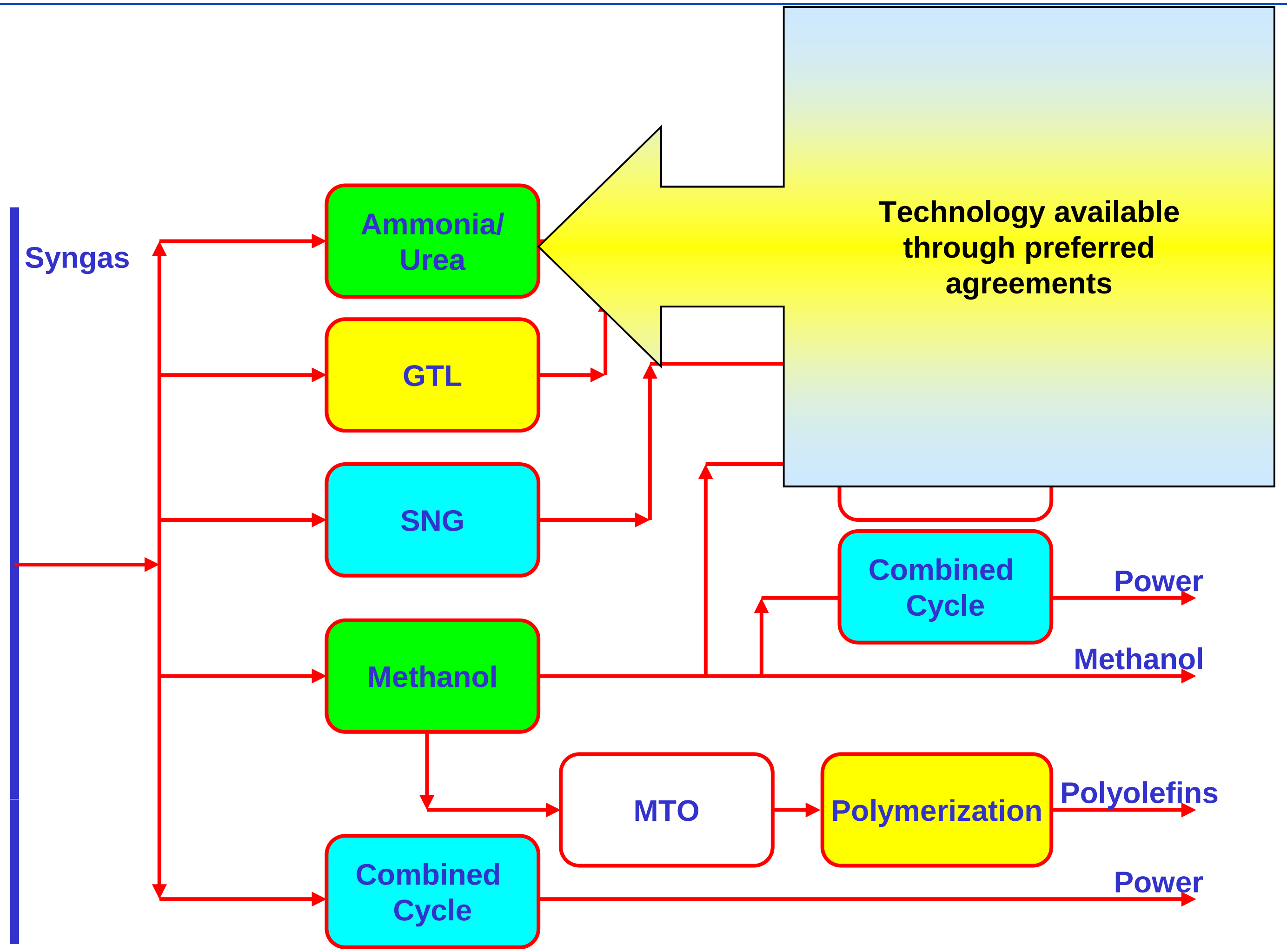
Ammonia / Urea / UAN

- Syngas can be easily converted to Ammonia , then to Urea and if required to UAN (Urea Ammonium Nitrate solution)
  - The technology is mature
- 100 t/h of petroleum coke produces approx 159 t/h of urea (3,700 MTPD equivalent plant)
  - nitrogen necessary for the ammonia reaction is taken from the air separation unit provided to supply oxygen to the gasification step
- Several proven technologies are available
  - FW has an agreement with Casale and can provide overall production from refinery heavy residues through delayed coking to gasification and ammonia / urea synthesis.
- Urea is a solid while UAN is a liquid solution
- Urea market price can range from 260 $/t to 300 $/t

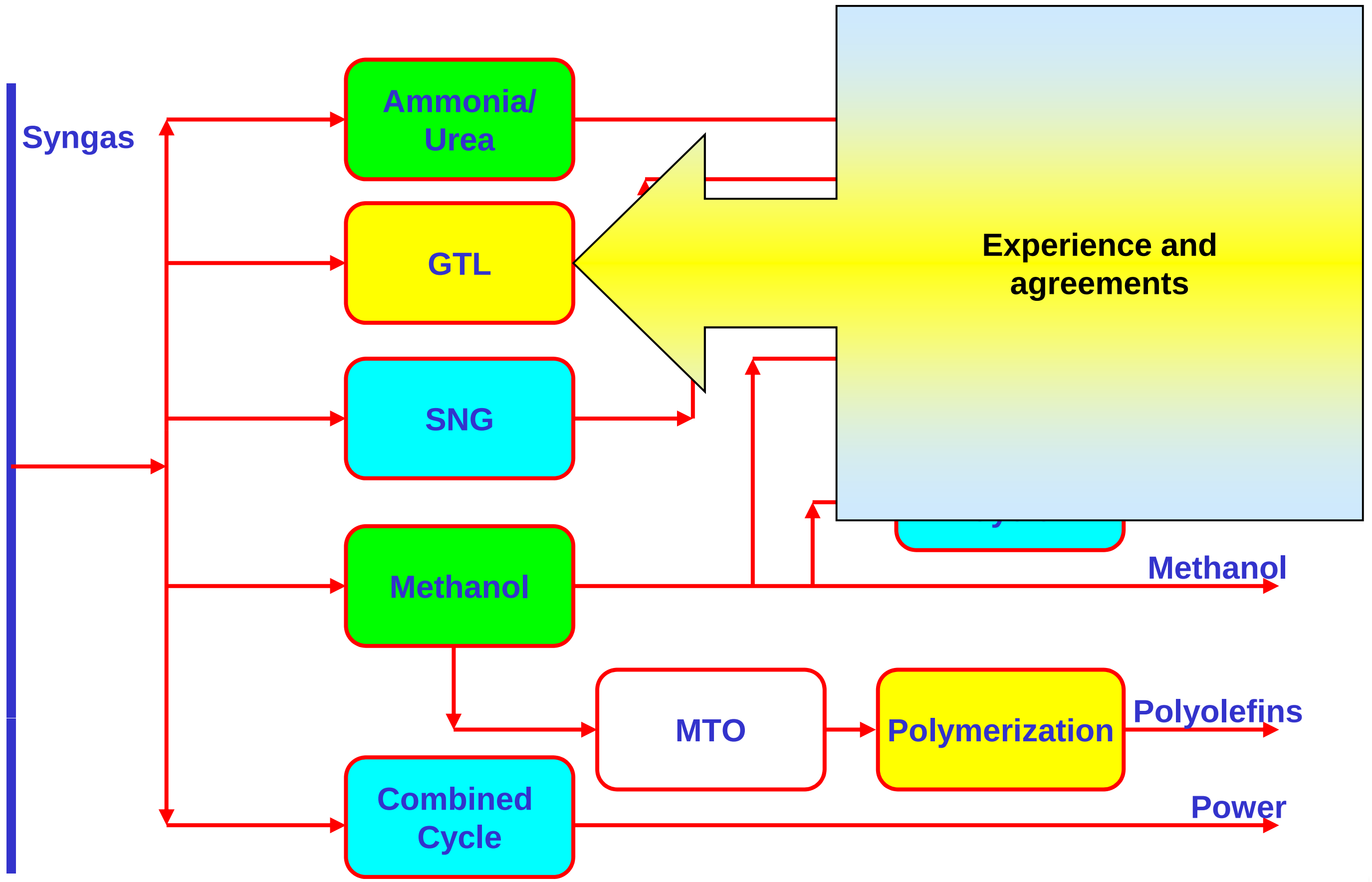
Summary

…… and summarizing

Summary

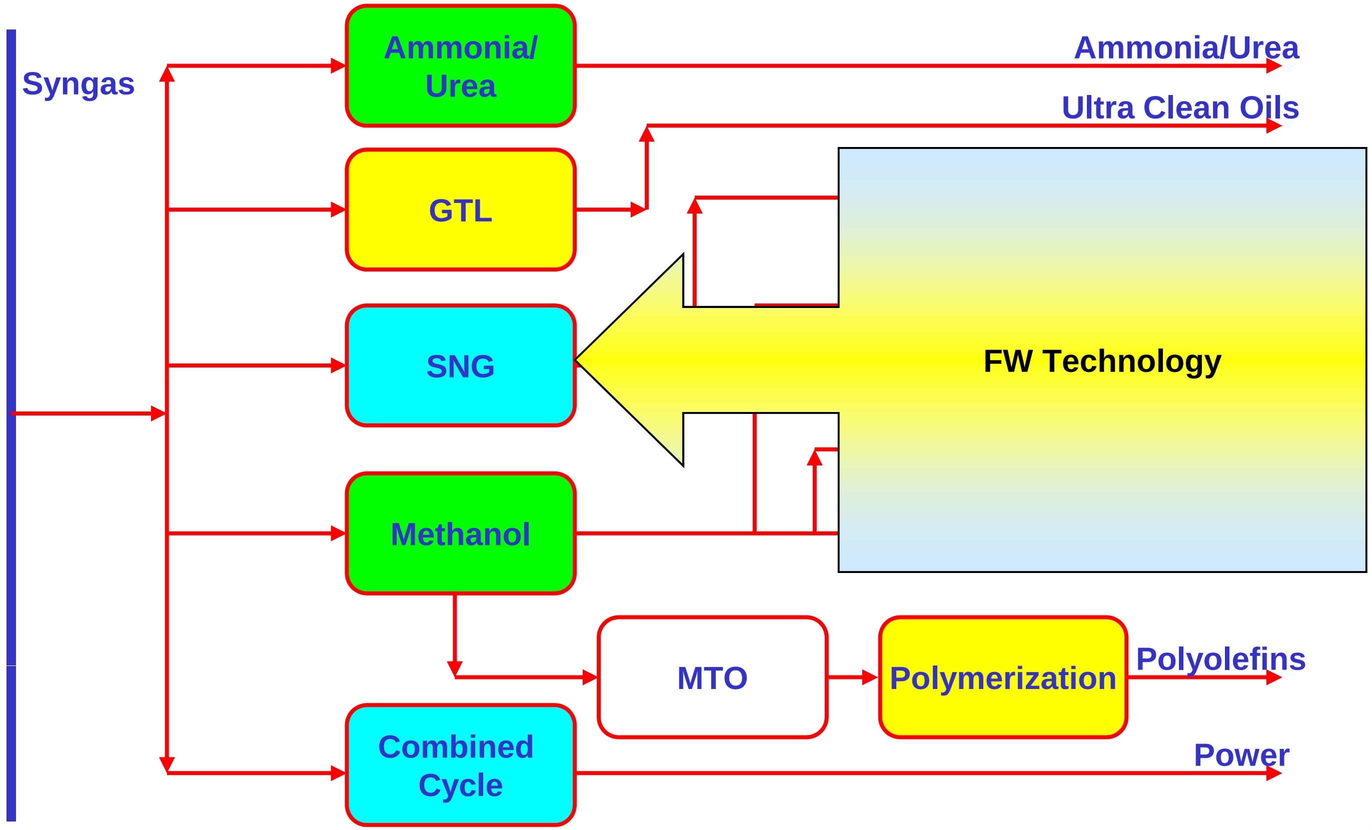

Technology available
through preferred
agreements
Syngas
Ammonia/
Urea
GTL
SNG
Methanol
Combined
Cycle
Power
Methanol
MTO
Polymerization
Polyolefins
Combined
Cycle
Power

Summary

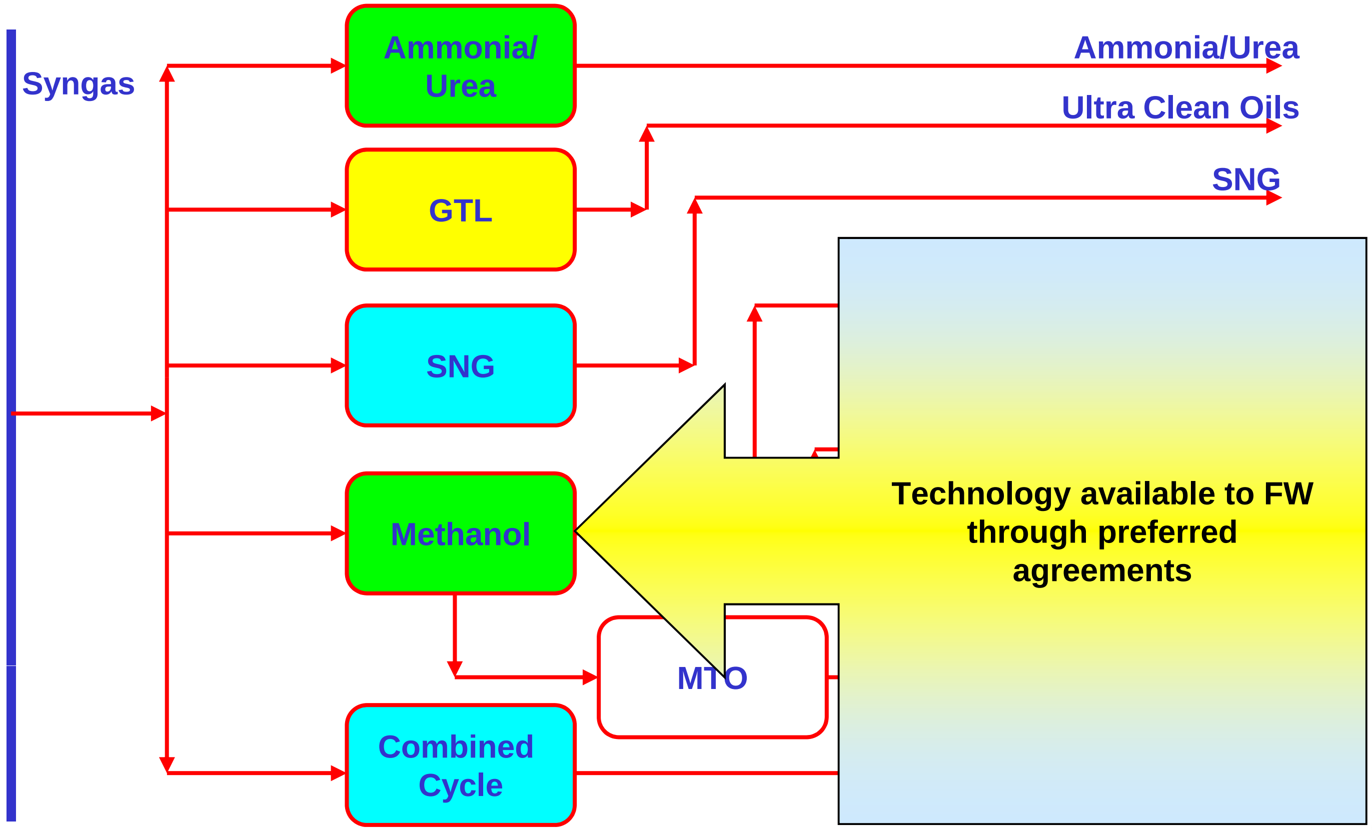

Syngas
Ammonia/ Urea
GTL
SNG
Methanol
MTO
Polymerization
Combined Cycle
Experience and agreements
Methanol
Polyolefins
Power

FOSTER WHEELER

Summary



Summary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