PRESENTATION TO WtE INDUSTRY EVENT IN PERTH, AUSTRALIA

December 5th 2012
Perth Zoo

Dr Kevin Whiting

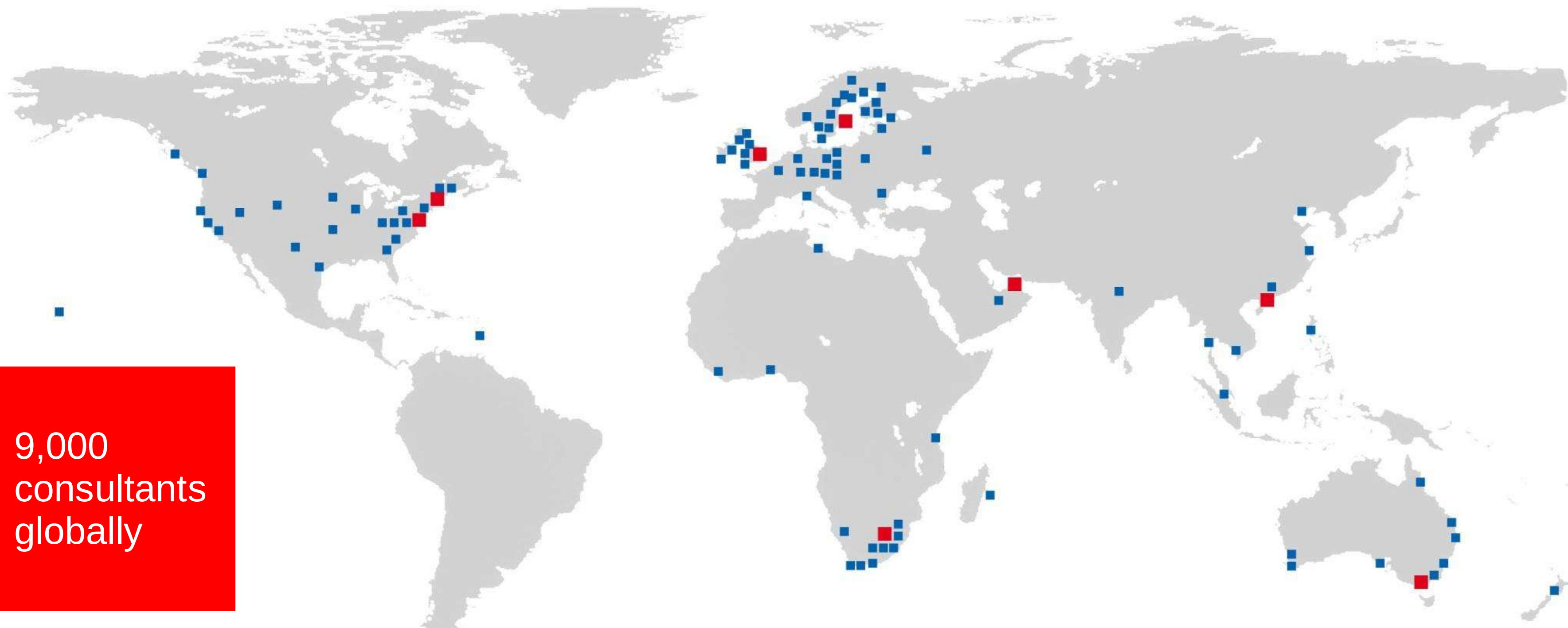
A review of state-of-the-art for WtE technologies in relation to the study just completed for the Department of Environment & Conservation, Government of Western Australia.

UNITED BY OUR DIFFERENCE WSP

We are WSP

WSP is one of the world's fastest-growing design, engineering and management consultancies, specialising in projects for the property, transport and environment and energy sectors.

Delivering services in 35 countries



9,000 consultants globally

707 M GBP turnover 2010

UK Divisions
Property (£325m)
Management and Industry (203m)
Environment and Energy (£93m)
Transport and Infrastructure (£86m)

Who we Advise

- Lenders
- Investors
- Project developers
- Corporates
- D&B Contractors
- Local Government
- Government

- Lenders Engineer
- Owners Engineer
- Technical Advisor
- Technical due diligence

STATEMENT OF COMPETENCE

- Dr Kevin Whiting, B.Eng, PhD, C.Eng, FIChemE
  - Active for more than 25 years in the field of thermal engineering and recognised worldwide as an expert in combustion, gasification and pyrolysis;
  - Key member of the Juniper Consultancy Services team with a worldwide reputation for techno-business evaluations for the waste industry. Lead author of the Juniper report “Pyrolysis & Gasification of Waste: A Worldwide Technology & Business Review”. Lead Consultant on technical due diligence projects of several plasma gasification and high temperature slagging gasification processes;
  - Technical expert to the UK government – member of an OSTEMS mission to Japan and South Korea in 1995 to assess novel energy generation technologies;
  - Lead speaker at an environmental presentation to 80 Korean businessmen on the Royal Yacht Britannia at Inchon harbour, South Korea in 1997
  - Delivered papers and presentations on thermal treatment of waste at several leading conferences worldwide and lectured on academic courses at the Universities of Leeds, Sheffield and Southampton over an 18 year period.

Objectives of Thermal Waste Treatment

Previously …

- Reduction of waste volume
- Cost effective waste treatment

Currently …

- Recycling and re-use of useful products – including energy
- Production of minimum quantity of inert solid residues
- Minimal environmental impact, particularly the reduction of CO_2 emissions
- Sustainable production of renewable energy
- Fully proven and bankable technology

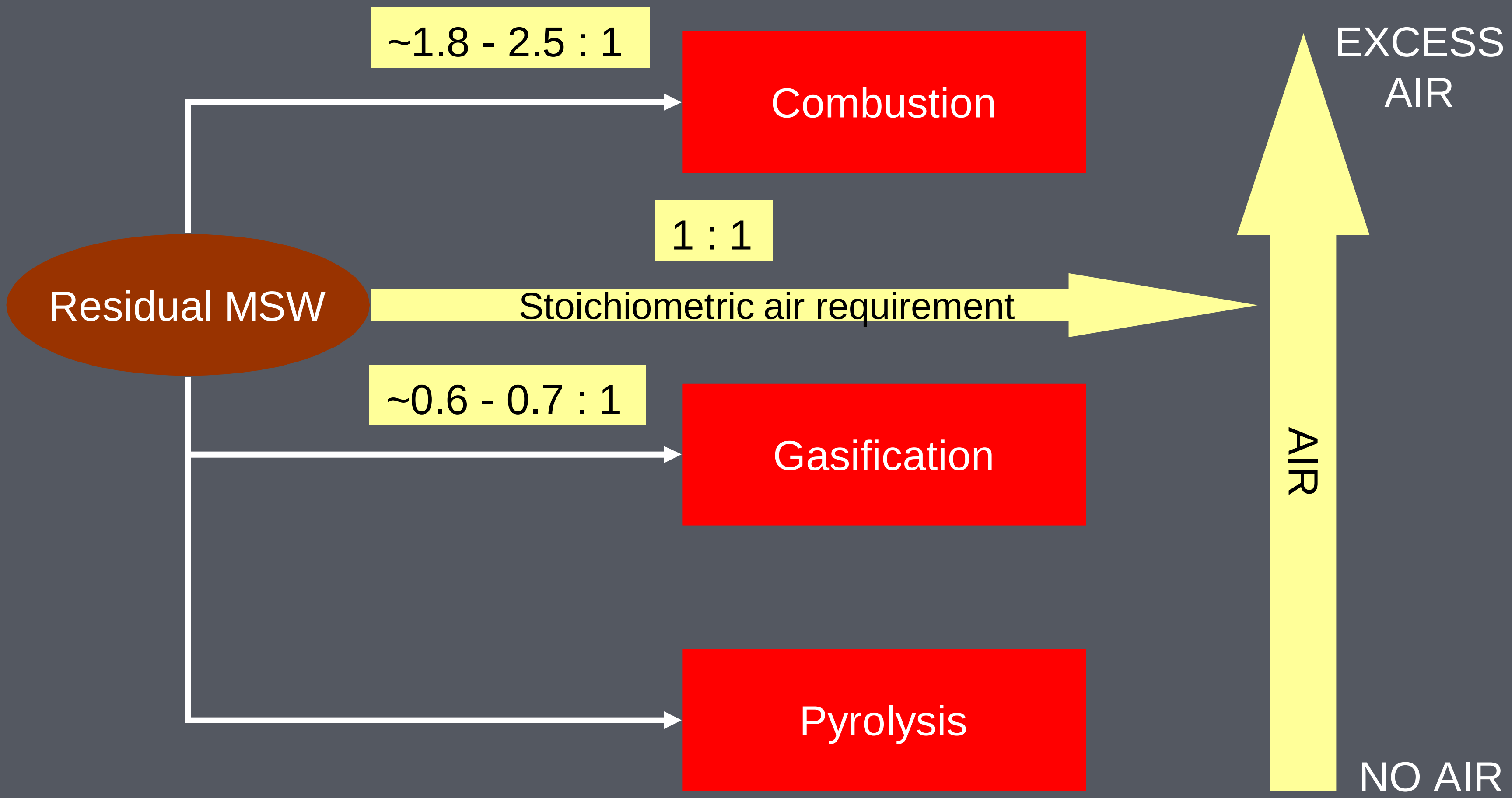
TECHNICAL RISK AREAS FOR WtE PROJECTS - FEEDSTOCK

- where is the feedstock coming from?
- is supply guaranteed for the life of the project?
- what are the contractual relationships?
- is the composition known with any certainty?
- is composition variability anticipated over the life of the project?
- Can the technology mitigate variability of composition?

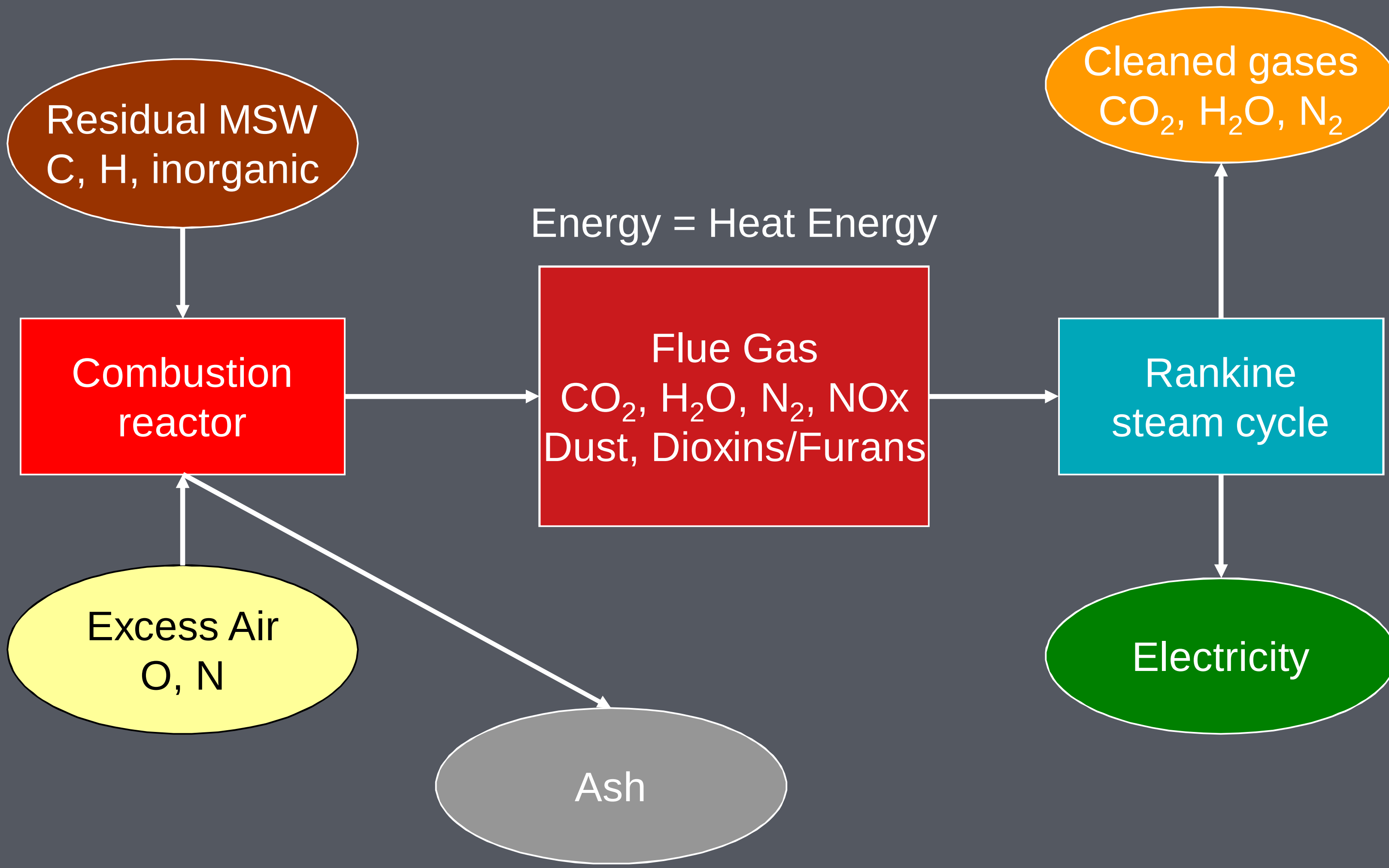
TECHNICAL RISK AREAS FOR WtE PROJECTS - TECHNOLOGY

- is the technology choice right for the feedstock?
- will the technology be capable of meeting all contractual targets and requirements of the client?
- Will the technology meet the limits set for environmental impact by providing proof from similar historical operational facilities?
- Is the technology solution fully proven?
- Does the technology provide sufficient flexibility and ease of switching between operational modes?
- supplier credibility?
- operator credibility?

Advanced Conversion Technologies



COMBUSTION


Residual MSW
C, H, inorganic
Combustion reactor
Excess Air
O, N
Ash
Energy = Heat Energy
Flue Gas
CO_2, H_2O, N_2, NOx
Dust, Dioxins/Furans
Cleaned gases
CO_2, H_2O, N_2
Rankine steam cycle
Electricity

THERMAL WASTE TREATMENT

Conventional Energy from Waste processes dependent on scale

- Moving grate
- Fluidised bed
- Oscillating kiln - Cyclerval

Novel thermal treatment processes

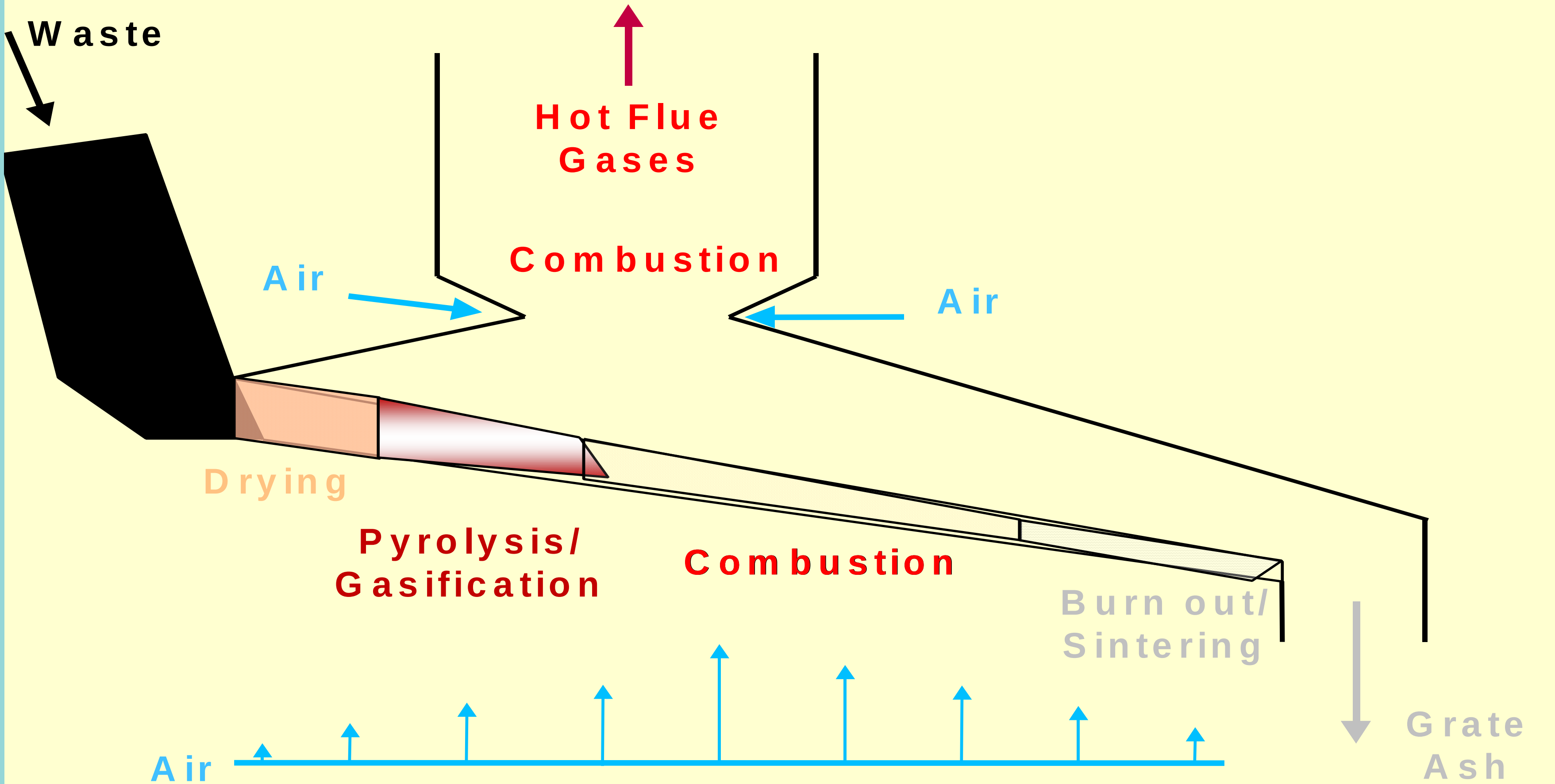
- Gasification
- Pyrolysis
- Plasma gasification

MOVING GRATE COMBUSTORS

Grate moves burning solid waste through combustion chamber

- Typically divided into three zones:
  - drying and preheating
  - ignition and combustion
  - burnout and ash removal
- Four main designs:
  - forward reciprocating
  - reverse reciprocating
  - roller
  - horizontal

PROCESSES OCCURING WITHIN A MOVING GRATE



WSP

MOVING GRATE COMBUSTORS

Moving grate types:

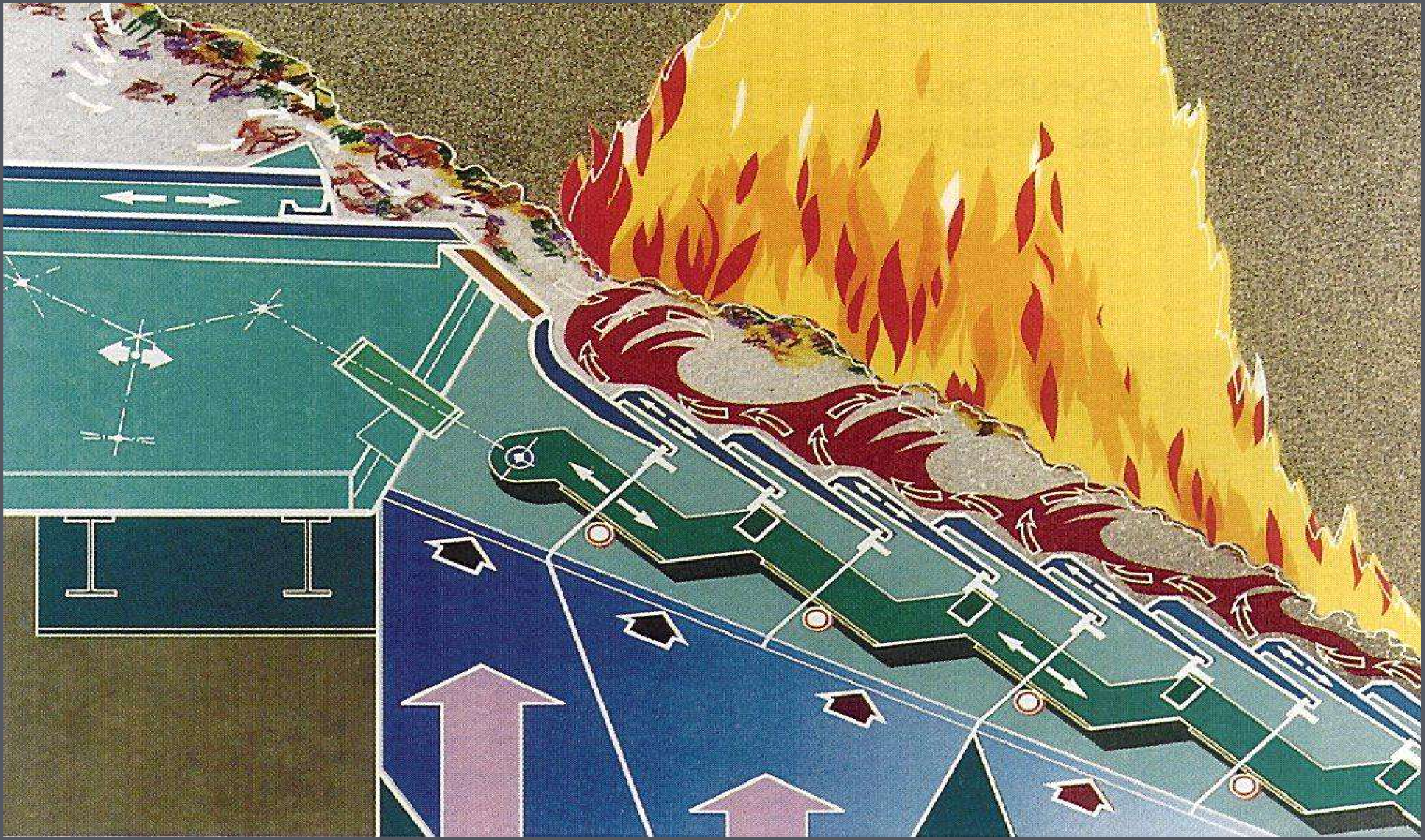
- Forward reciprocating
  - Vølund (now Babcock & Wilcox), Steinmüller (now Fisia Babcock), Von Roll Inova (now Hitachi Zosen Inova), Noell (now Fisia Babcock), Takuma
- Reverse reciprocating
  - Martin (including Covanta and MHI as licensees), Stein Industrie (now CNIM)
- Roller
  - Deutsche Babcock (now Fisia Babcock)
- Horizontal
  - ABB Enertech (now CNIM and Martin), JFE (NKK)

WSP

REVERSE RECIPROCATING

Source: Martin

REVERSE RECIPROCATING GRATE - MARTIN



Source: Martin

FLUIDISED BED COMBUSTORS

- Technology known for most of this century
- Rapid developments during 1970's
- Today well established and proven process for energy conversion
- Technology has been applied to:
  - coal (worldwide)
  - biomass (Scandinavia and Canada)
  - MSW/RDF (Japan, USA and Europe)

FLUIDISED BED COMBUSTORS

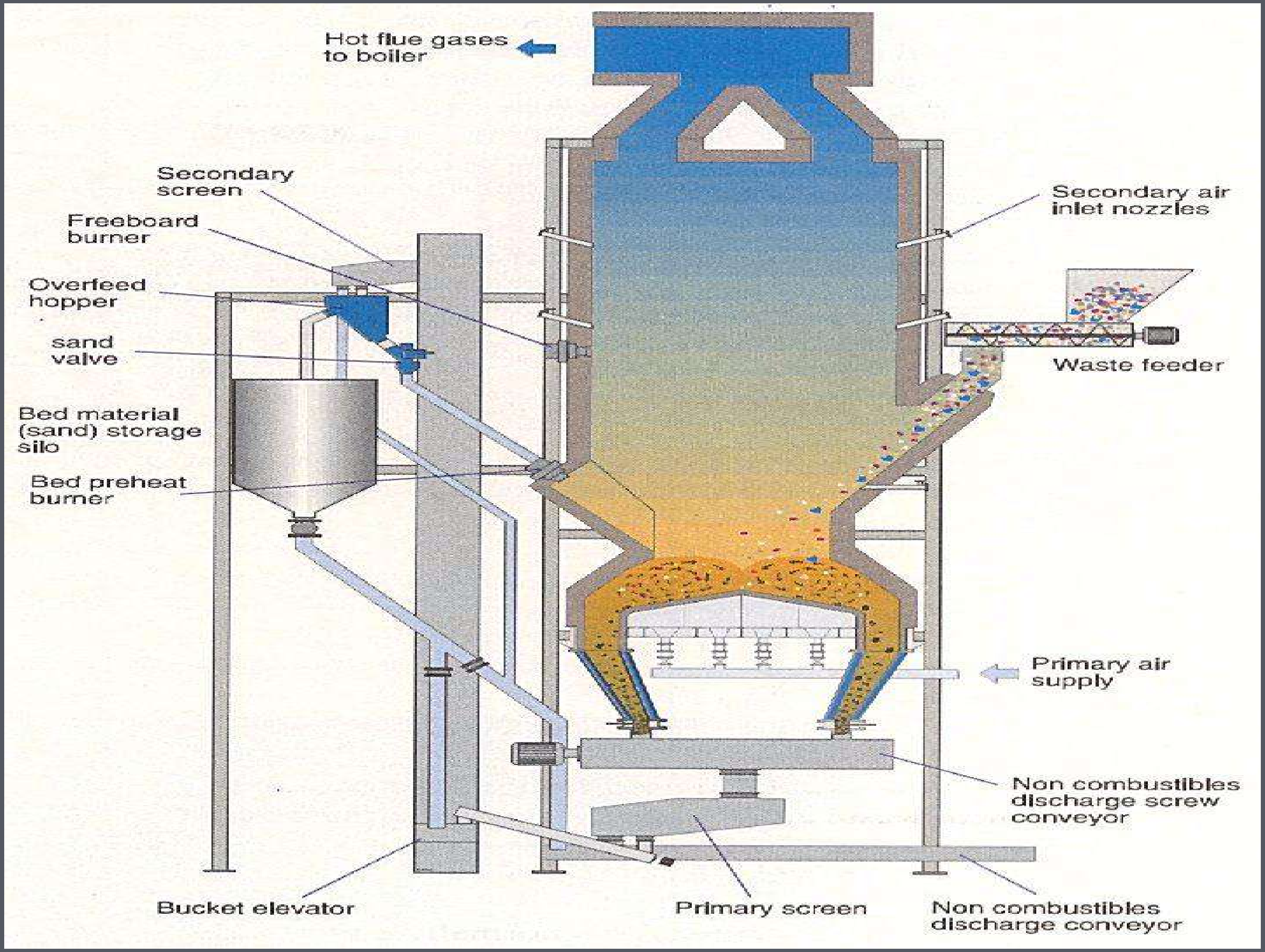
Country	BFB/TIF	CFB
Scandinavia	7	5
Other Europe	14	1
Japan	150+	0
USA	7	2

Source: Juniper

- Japanese plants are all operating on 100% MSW
- US plants on RDF and RDF + Coal mixtures
- Some European plants operate on mixtures of fuels, including MSW, RDF, wood wastes, paper mill sludges, plastics

WSP

REVOLVING FLUIDISED BED (TIF)



FLUIDISED BED COMBUSTORS

CHARACTERISTICS

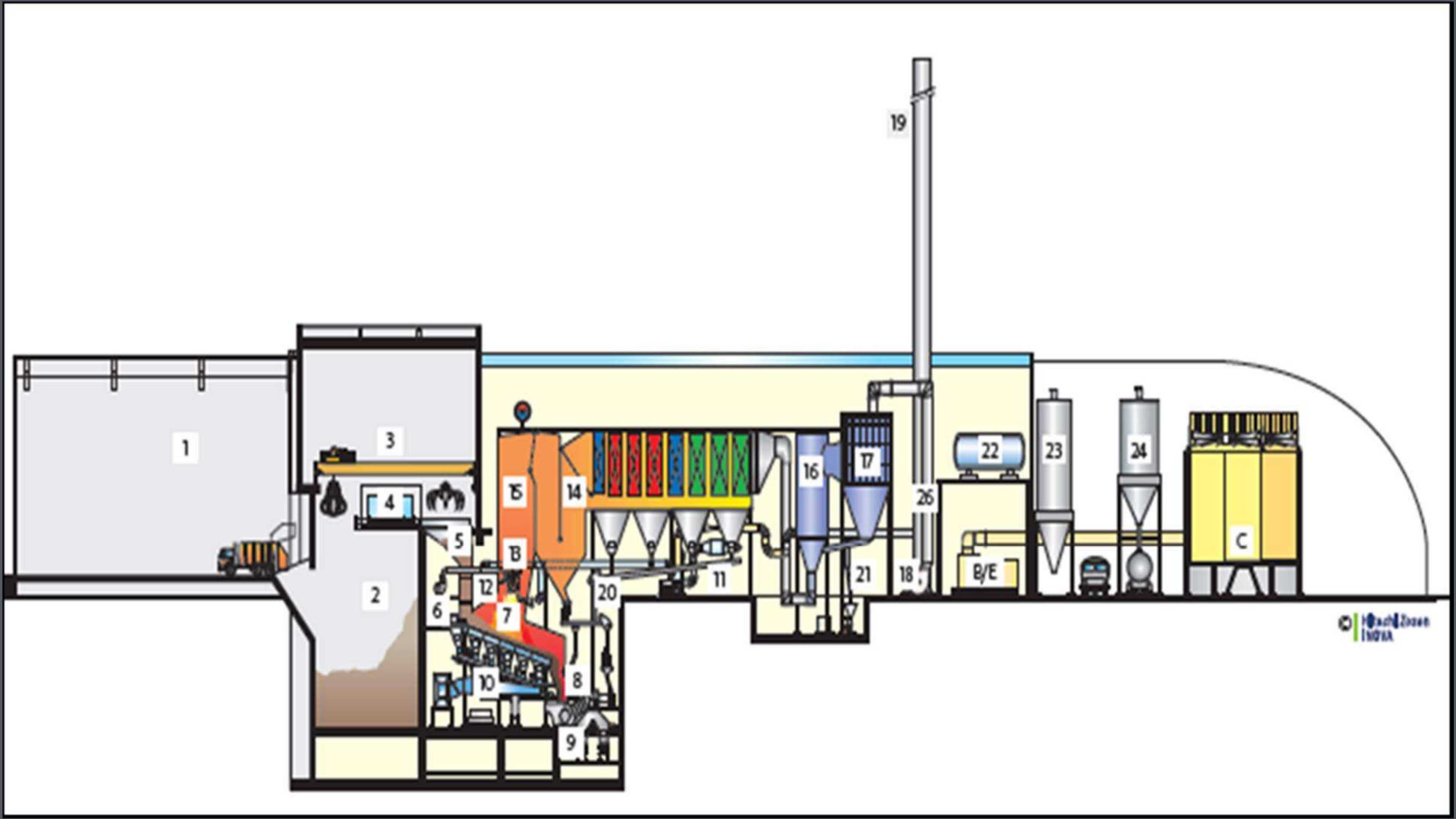
- Rapid mixing of solids creates isothermal conditions throughout the reactor
- Thermal flywheel effect limits temperature variations
- Minimisation of "hot spots" when combusting high CV materials
- Heat and mass transfer between gas and solids is very high
- Rate of heat transfer between a FB and an immersed object is high causing solid waste particles to combust and oxidise rapidly
- In-situ removal of acid gases by addition of limestone
- Reduced corrosion risk allows for higher steam temperatures giving increased thermal efficiency
- Typical operating temperature creates low level of NOx

FLUIDISED BED COMBUSTORS

ADVANTAGES

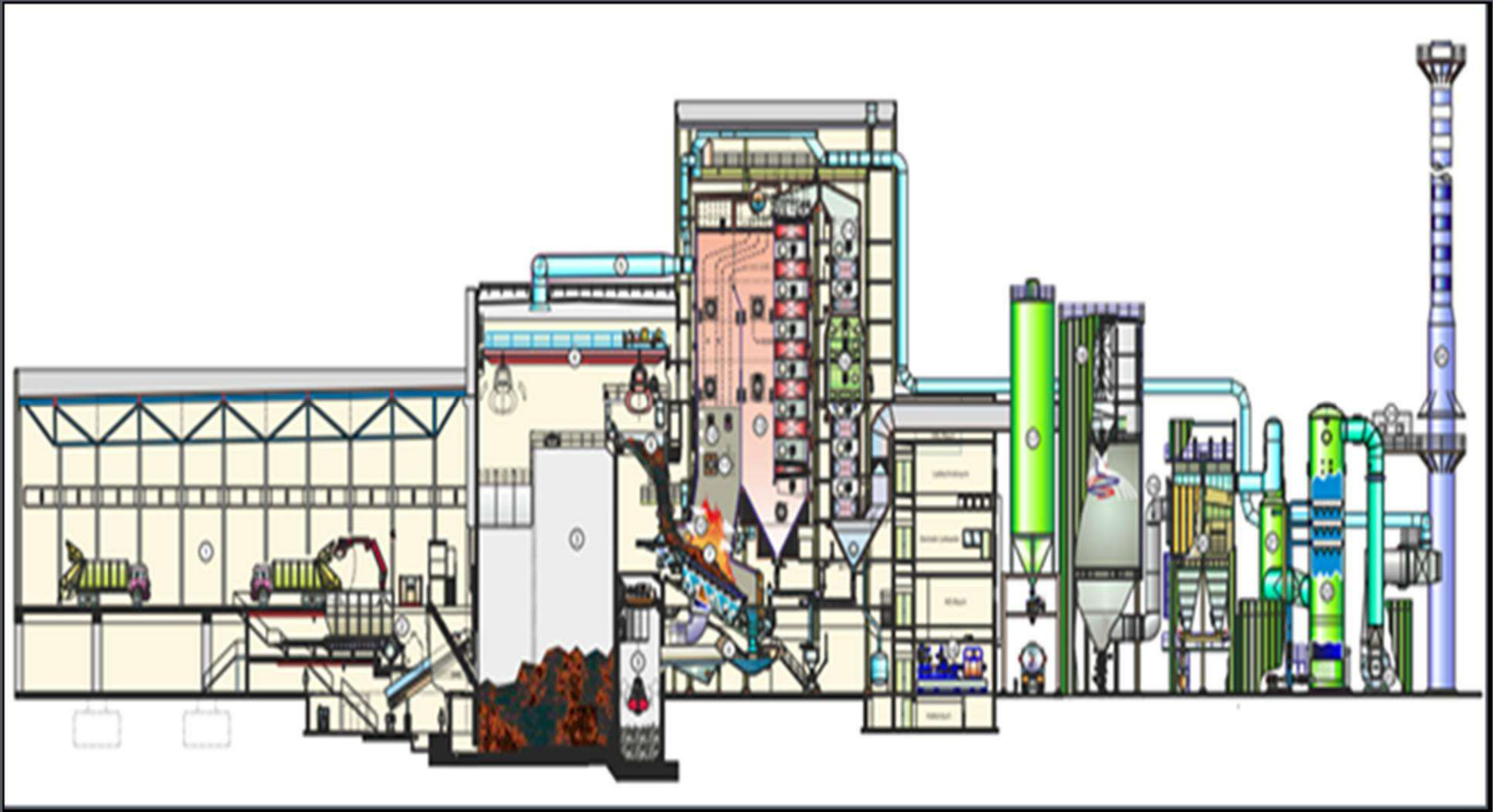
- FB's are proven in applications of:
  - pure MSW streams and
  - variable mixtures of solid wastes and fuels
- More than 150 bubbling FB's are operating on MSW worldwide
- Flexibility of waste switching
- Can handle low CV and high CV fuels
- In-bed scrubbing reduces acid gas loading
- Can handle high moisture and high ash fuels
- Can respond very well to rapid load changes
- Can 'turndown' to 25% of normal capacity

WtE BOILER CONFIGURATIONS - HORIZONTAL



Source: Hitachi Zosen Inova

WtE BOILER CONFIGURATIONS - VERTICAL



Source: Martin GmbH

PROS & CONS OF BOILER COFIGURATION IN WtE PLANTS

Horizontal boiler arrangement	Vertical boiler arrangement
■ Meets current state-of-the-art design ■ Many reference plants worldwide ■ Meets all current guarantees ■ Employs mechanical rapping tube cleaning methods therefore lowers internal steam consumption ■ Requires more land take	■ Meets current state-of-the-art design ■ Many reference plants worldwide ■ Meets all current guarantees ■ Employs soot blowers therefore steam consumption higher ■ Requires taller building ■ Lower investment cost

THERMAL CAPACITY AND THERMAL EFFICIENCY

Thermal capacity of an EfW plant governed by:

- Mechanical load
- Fuel CV
- Thermal capacity of boiler
- Firing Diagram

Thermal efficiency of an EfW plant constrained by:

- Rankine steam cycle
- Steam pressure and temperature
- Chlorine corrosion
- Fouling by alkali metals

EU Waste Framework Directive R1 Efficiency Factor

- EfW plant determined as Resource Recovery process …
- … and not a Disposal process (D10)
- New plants must meet an R1 value > 0.65

WSP

RESOURCE RECOVERY – R1 EFFICIENCY INDEX

$$R1 = \text{Energy Efficiency} = (Ep - Ei)/(0.97 \times (Ew + Ef))$$

Ep = annual energy produced (exported + utilised on-site) as heat and/or electricity

Ew = annual energy input to the system as waste (net calorific value)

Ef = annual energy input to the system from fuels that contribute to the production of steam

Ei = annual energy imported (excluding Ew and Ef) – includes electricity, heat and fuels used for plant start-up

All electrical values are multiplied by 2.6 and heat values by 1.1

MEASURES FOR INCREASING THERMAL EFFICIENCY

- Increased steam parameters
  - pressure/temperature of superheated steam

- Reduced flue gas heat losses
  - lower temperature at boiler outlet
  - reduce excess air rate

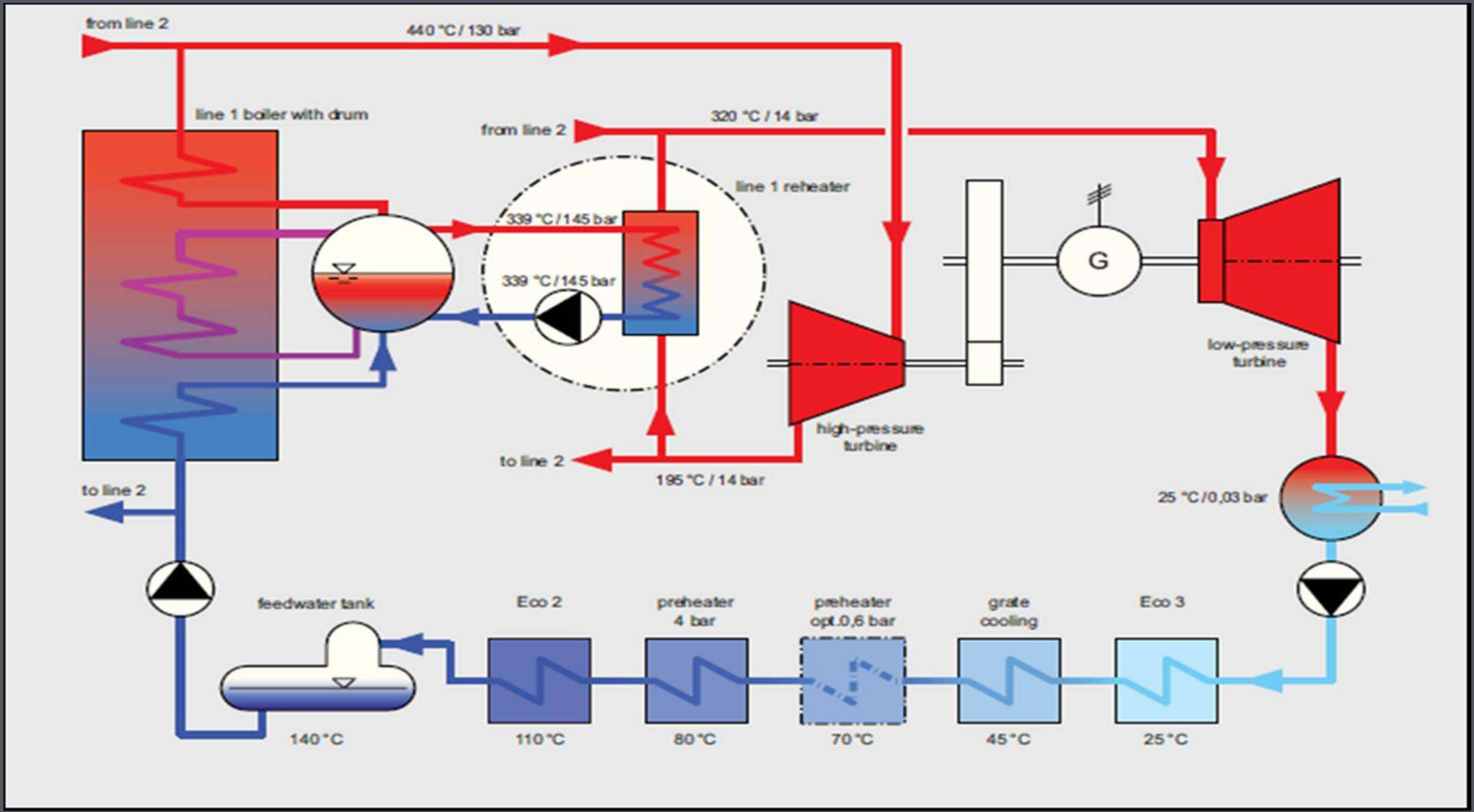
- Improved steam condensation conditions
  - use water instead of air condensers

- Optimised thermal cycles
  - intermediate superheating (reheat cycle)
  - external superheating

HIGH THERMAL EFFICIENCY – STEAM CONDITIONS

PLANT	STEAM PRESSURE (bar)	STEAM TEMPERATURE (ºC)
Typical WtE Plant	40	400
Amsterdam	130	440
Reno Nord	50	425
Bilbao	100	540
Brescia	72	450
Riverside UK	72	427
Mainz	42.3	420
Lahti II	121	540
Montgomery County	59.6	443

HIGH THERMAL EFFICIENCY - AMSTERDAM

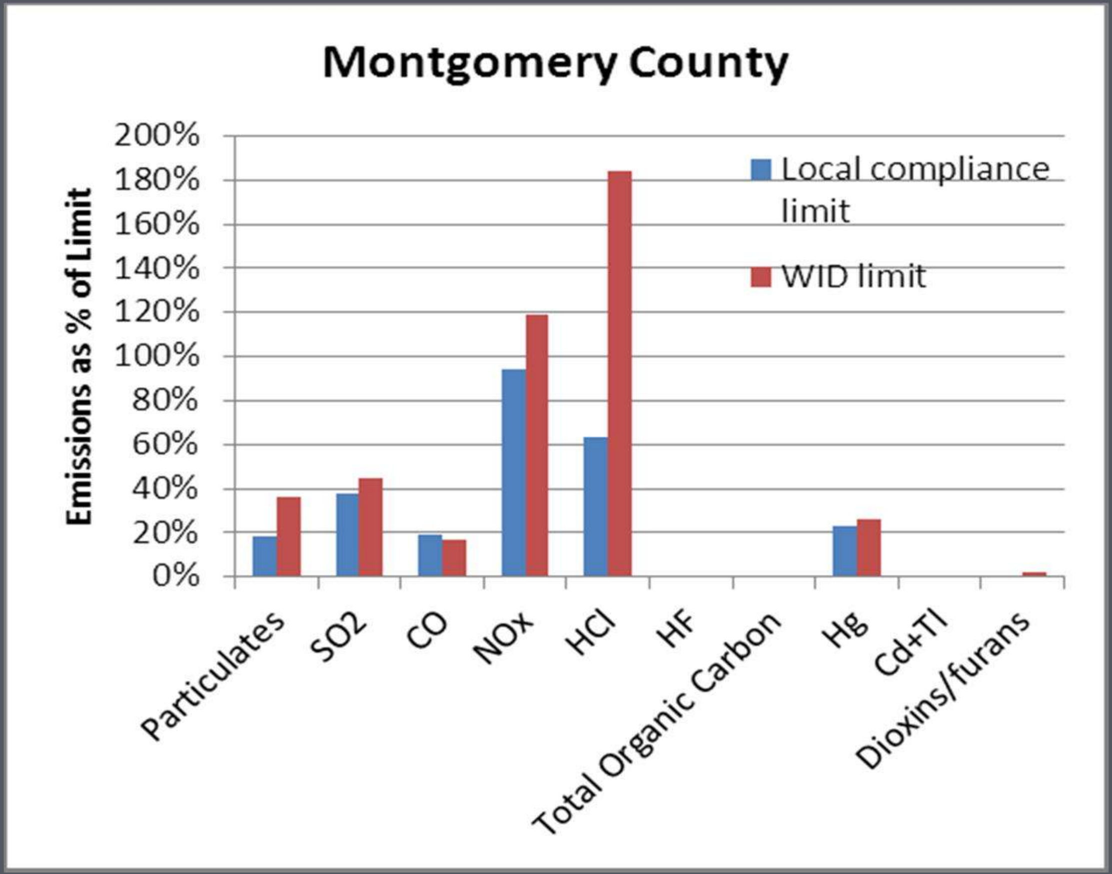


Source: AEB

FLUE GAS CLEANING

Pollutant	Typical Abatement Techniques
Particulates	Fabric filters, Electrostatic precipitators, Cyclones
Oxides of Nitrogen (NOx)	Flue gas recirculation, SNCR and SCR
Acid Gases (Sulphur Dioxide, Hydrogen Chloride, Hydrogen Fluoride)	Wet, Semi-dry or Dry scrubbers, Fabric filters
Heavy Metals (Mercury, Cadmium, Lead, Copper etc)	Fabric filters, Activated carbon injection
Dioxins and Furans	Flue gas recirculation, Fabric filters, Activated carbon injection

LOW EMISSIONS – WID vs. US MACT

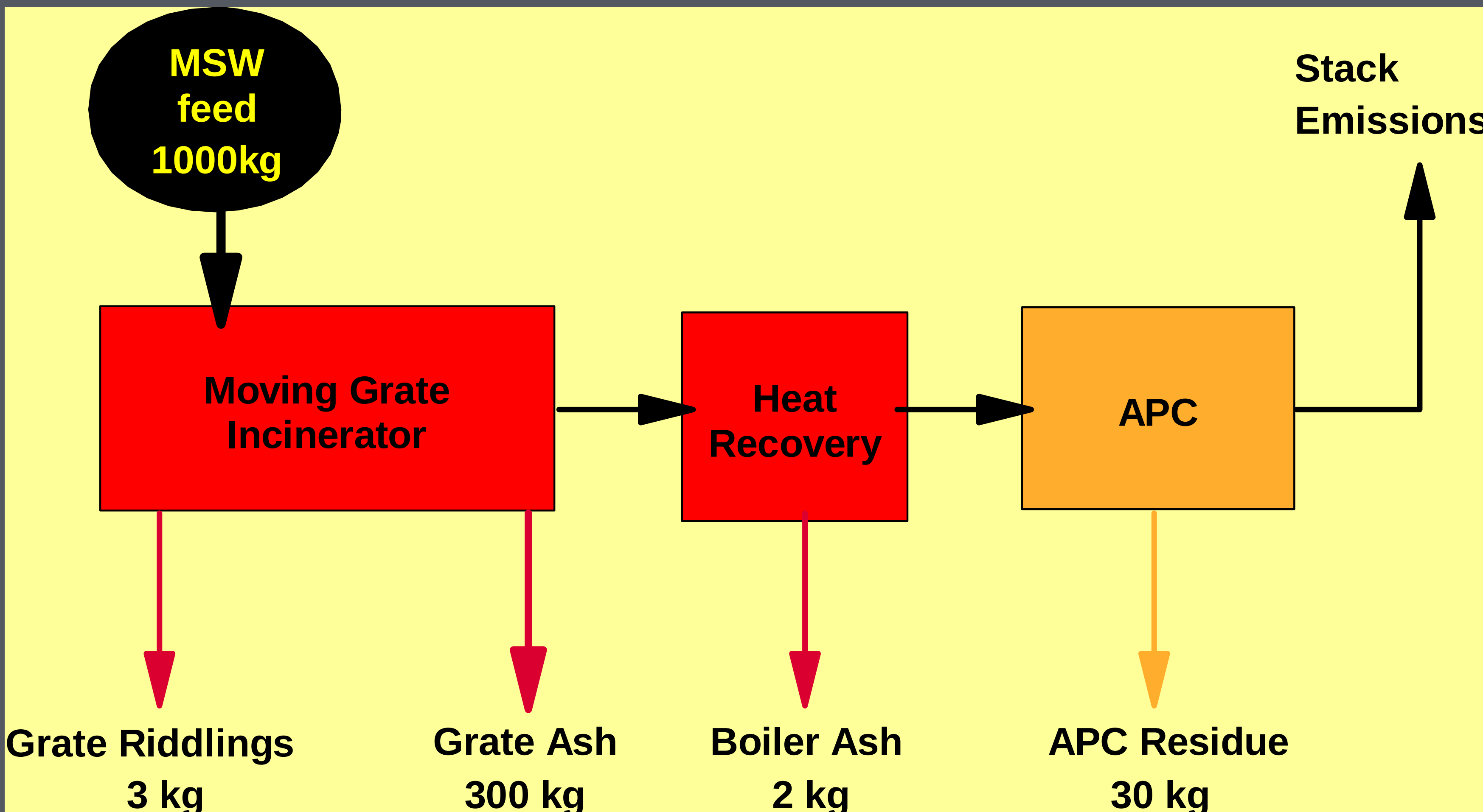


TECHNICAL RISK AREAS FOR WtE PROJECTS

END PRODUCTS

- who will be taking the products?
- will feedstock variability affect product quality?
- Is the product a hazardous waste?
- will the products have positive revenues or negative costs?
- what will the impact be on the project financial model?
- robustness of long term offtake contracts?

QUANTITY OF ASH RESIDUES



Source: International Ash Working Group

THE IMAGE OF INCINERATION …

Energy-from-Waste plants are seen as large industrial facilities

Perception :

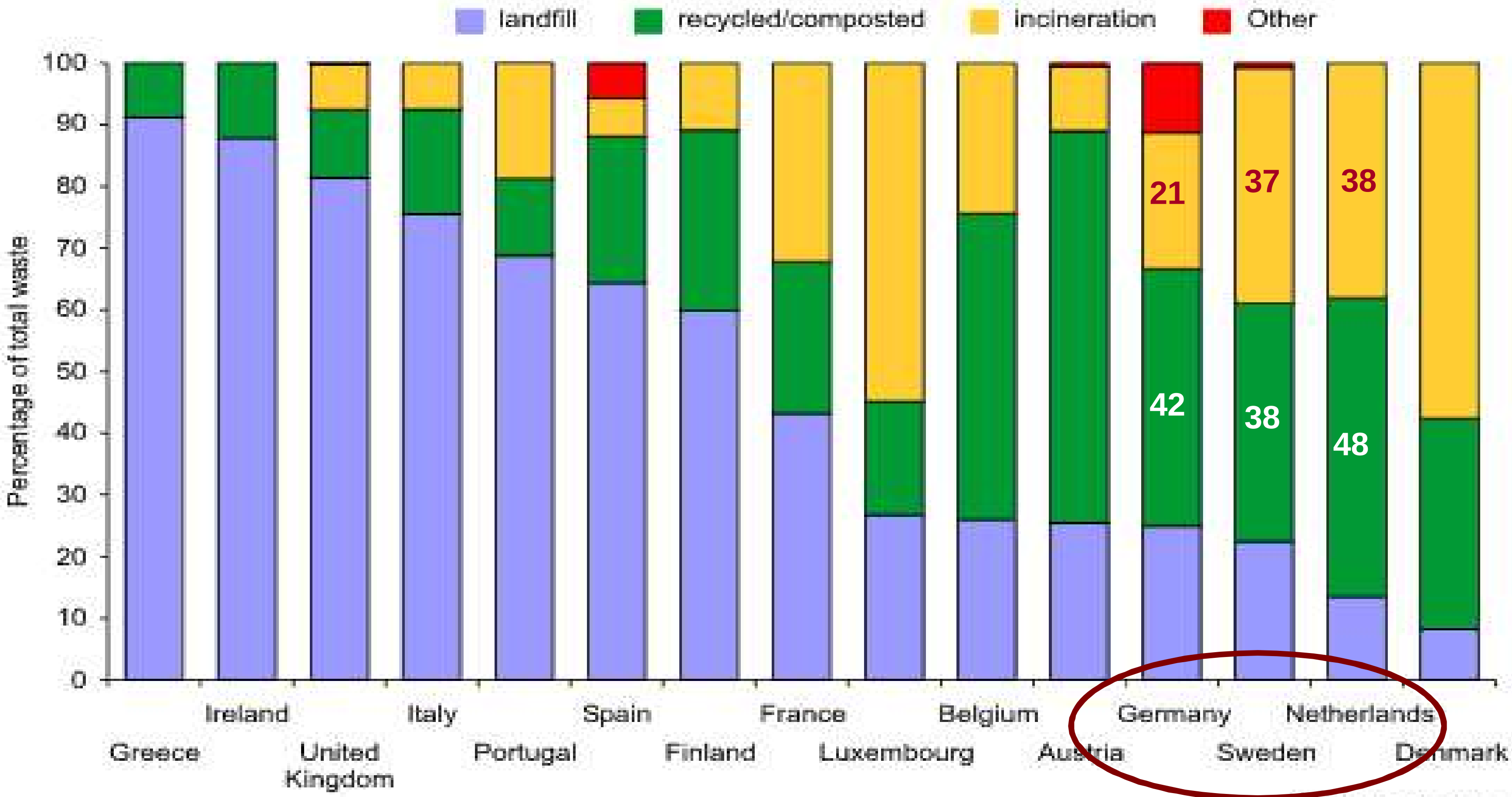
- *health issues*
- *transport movements*
- *pollution*
- *noise*
- *high cost*
- *discourages recycling*

Rotterdam, Netherlands

WSP

MSW TREATMENT INFRASTRUCTURE IN EU 15

Figure 8: Municipal waste management in the European Union



Source: Eurostat

WSP

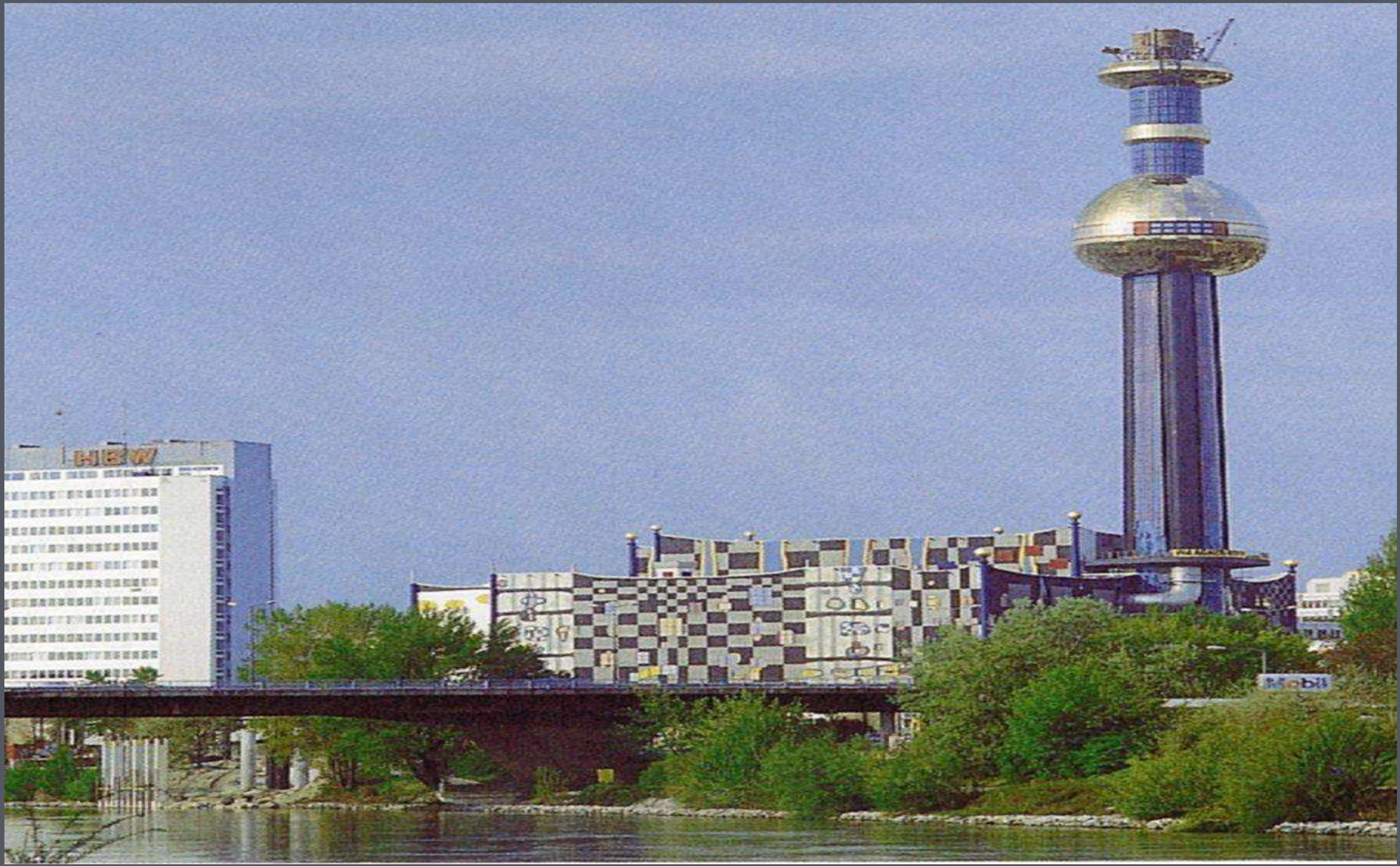
… BUT

Modern incinerators have very low emissions

- *Chimney emissions from the Rotterdam incinerator are cleaner than the ambient air*
- *New incinerators destroy more dioxins than they create*
- *More dioxins from garden bonfires than incinerators*

Rotterdam, Netherlands

SEEKING ACCEPTANCE : INNOVATIVE ARCHITECTURE



Spittelau, Vienna

SEEKING ACCEPTANCE : INNOVATIVE ARCHITECTURE

Marchwood, UK

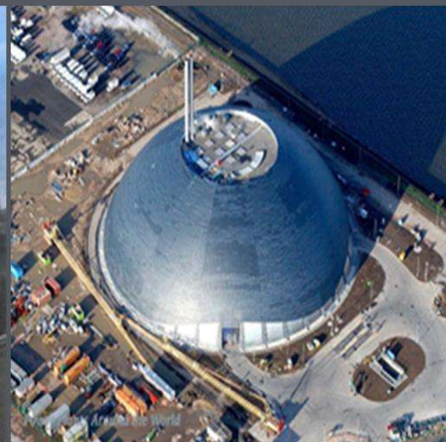
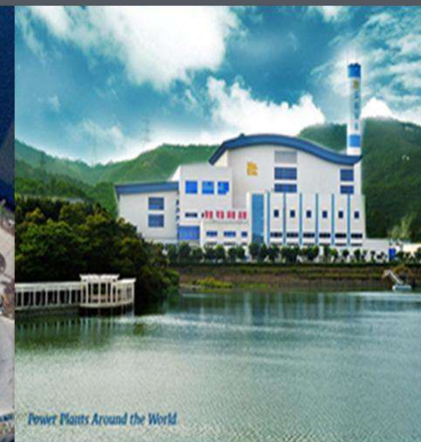
SEEKING ACCEPTANCE : INNOVATIVE ARCHITECTURE

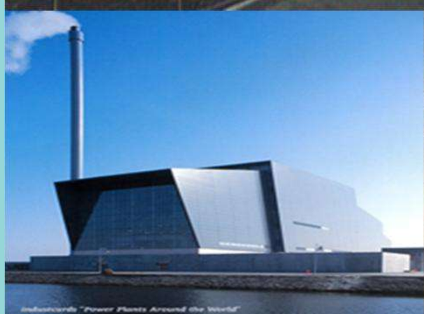
Isle of Man

SEEKING ACCEPTANCE : INNOVATIVE ARCHITECTURE

Issy Les Moulineaux, Paris

ARCHITECTURAL TREATMENT

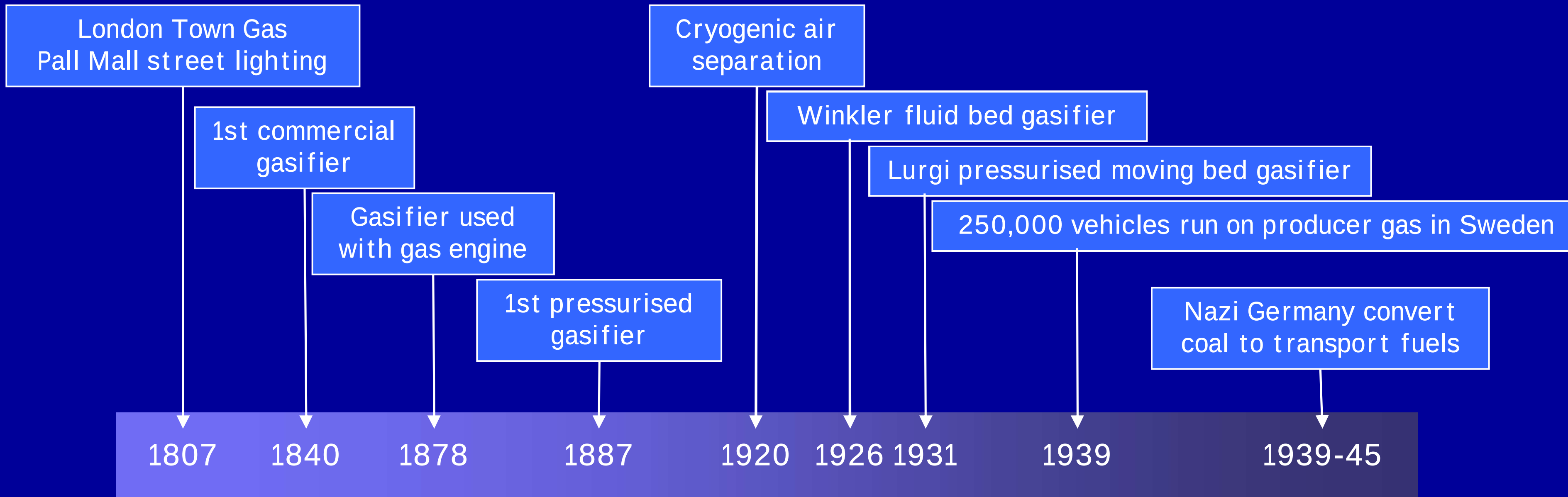






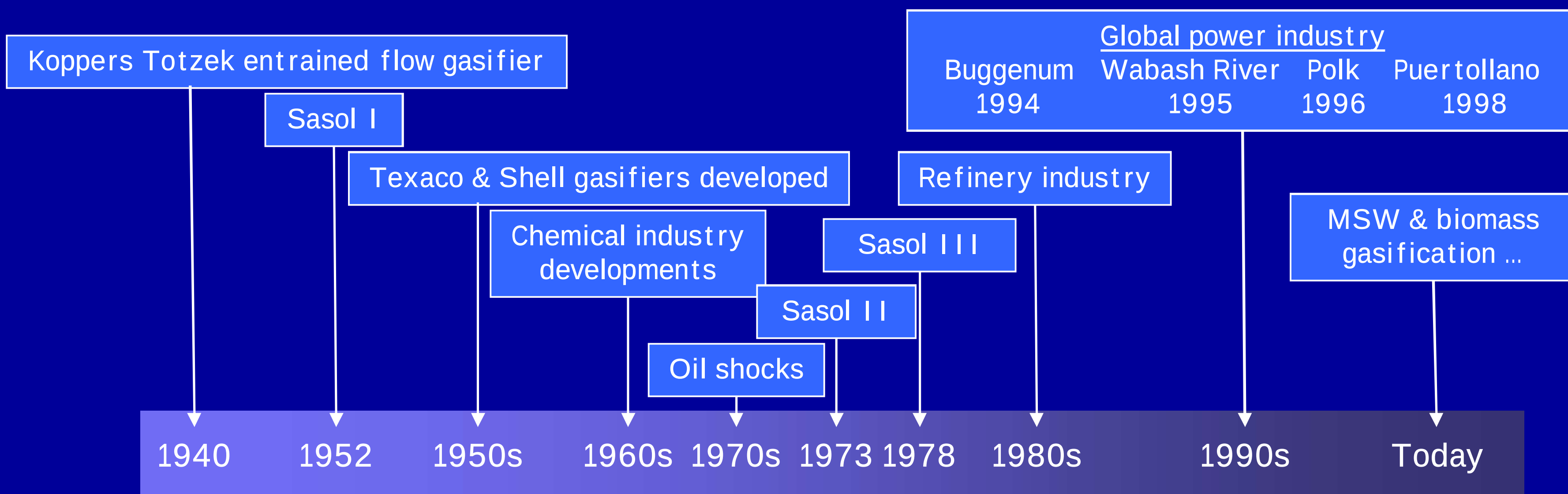



WSP

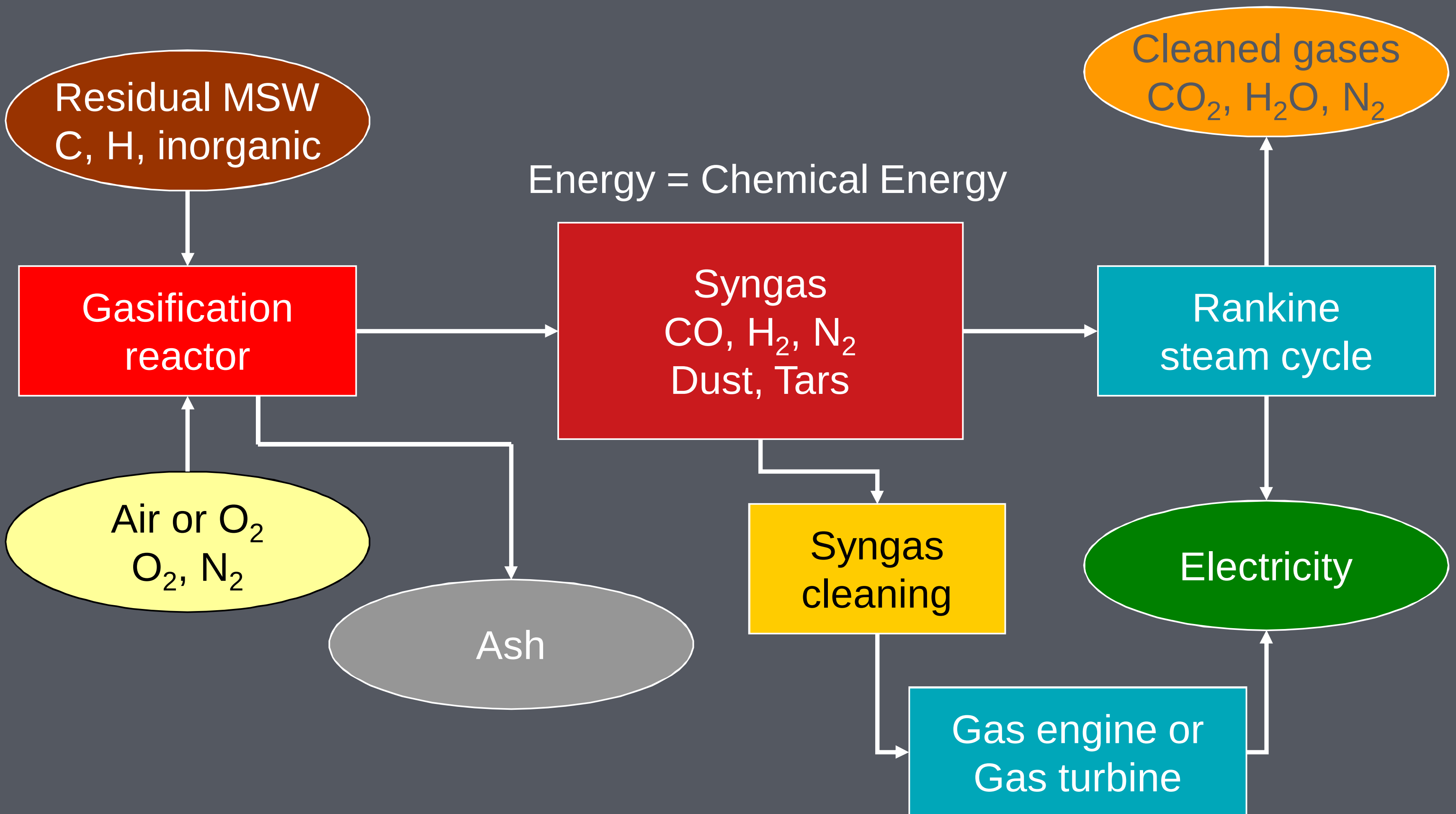
HISTORY OF GASIFICATION



After 1945 plentiful, low cost petrol and diesel arrived. Interest in gasification technology waned.



GASIFICATION



SOLIDS DO NOT BURN!

CHEMICAL EQUILIBRIUM THERMODYNAMICS

Solid-Gas Reactions

$C + \frac{1}{2}O_2 \rightarrow CO$ (partial combustion) [exothermic]

$C + O_2 \rightarrow CO_2$ (combustion) [exothermic]

$C + 2H_2 \rightarrow CH_4$ (hydrogasification) [exothermic]

$C + H_2O \rightarrow CO + H_2$ (water-gas) [endothermic]

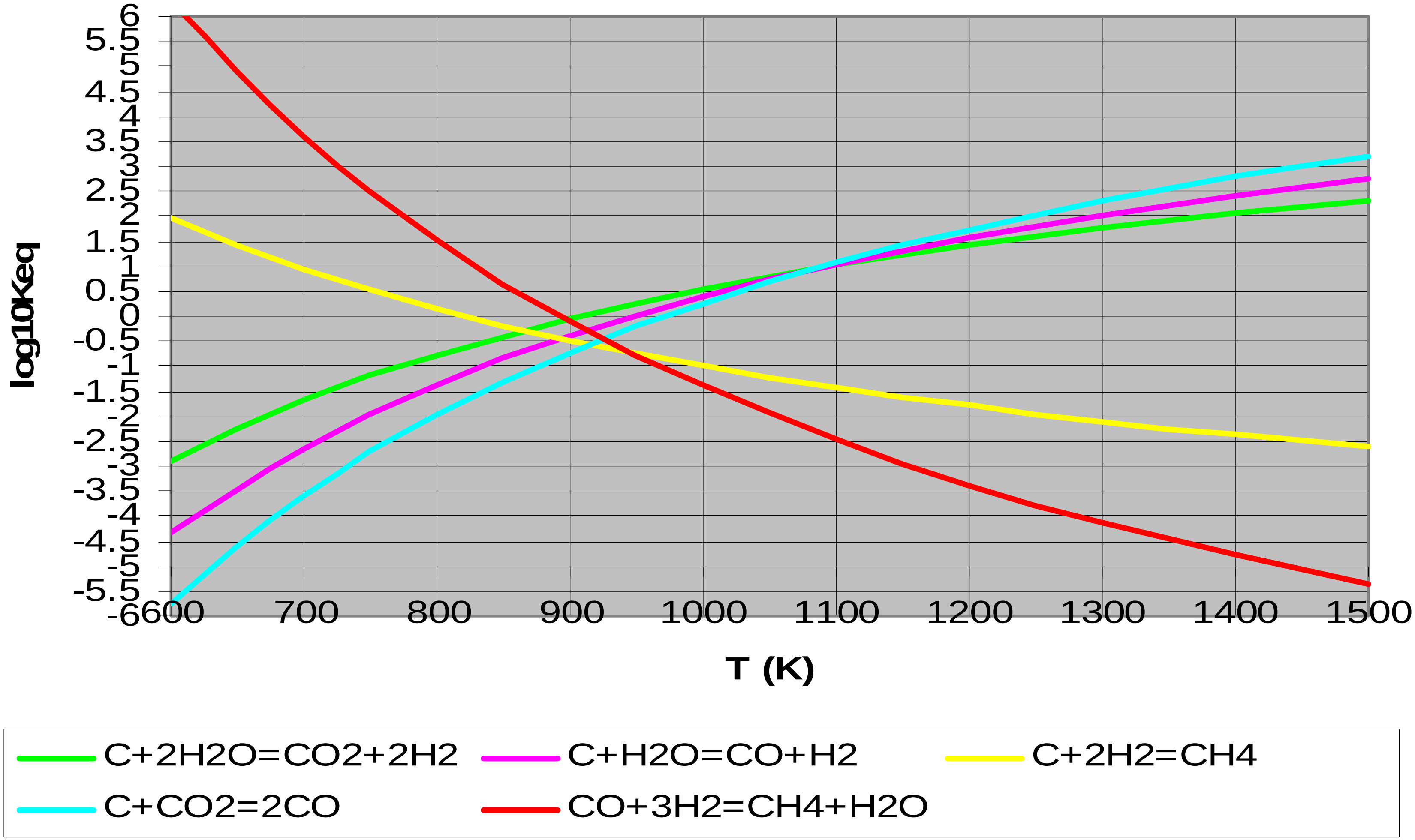
$C + CO_2 \rightarrow 2CO$ (Boudouard) [endothermic]

Gas-Gas Reactions

$CO + H_2O \rightarrow CO_2 + H_2$ (shift) [exothermic]

$CO + 3H_2 \rightarrow CH_4 + H_2O$ [exothermic]

EQUILIBRIUM CONSTANT VS. TEMPERATURE



GASIFICATION REACTOR DESIGNS

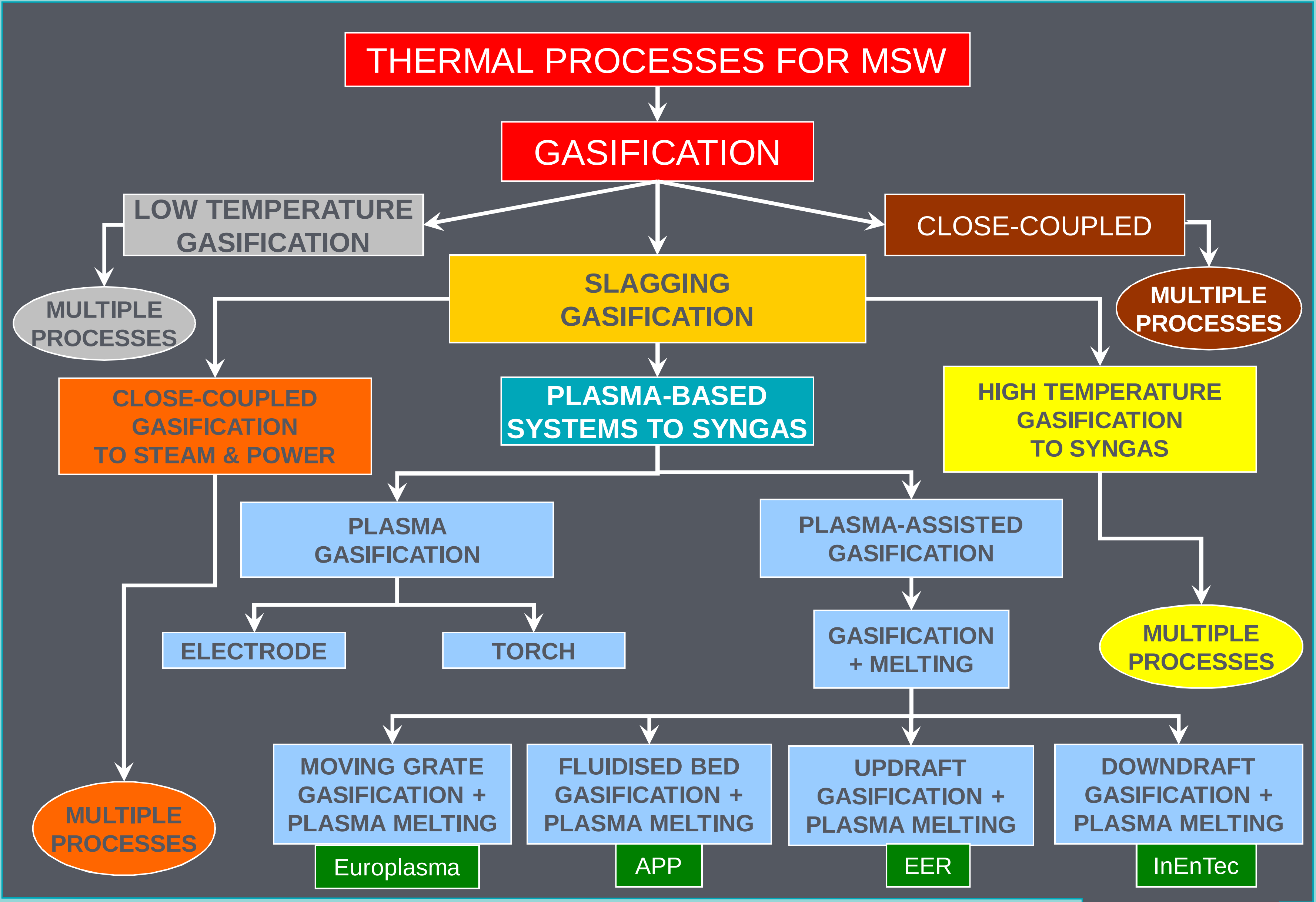
Reactor Type	Mode of contact
Fixed Bed	
Downdraft	Solids move ↓, Gas moves ↓, ie: co-current
Updraft	Solids move ↓, Gas moves ↑, ie: counter-current
Cross-draft	Solids move ↓, Gas moves at right angles ie: ← or →
Variants	*Stirred Bed; Two stage gasifier*
Fluidised Bed	
Bubbling	Relatively low gas velocity, inert solid stays in reactor
Circulating	Much higher gas velocities, inert solid is elutriated, separated and re-circulated
Entrained bed	Usually there is no inert solid, has highest gas velocity of lean phase systems
Twin reactor	1st stage - steam gasification and/or pyrolysis; 2nd stage – char combustion
Moving Bed	Mechanical transport of solid, usually horizontal. Typically used for lower temperature processes, ie: pyrolysis
Variants	*Multiple hearth, Horizontal moving bed, sloping hearth, screw/augur kiln*
Other	
Rotary kiln	Good gas-solid contact
Cyclonic reactor	High particle velocities and turbulence to effect high reaction rates

“ADVANTAGES” OF PYROLYSIS & GASIFICATION

- Not combustion or incineration …
- … therefore better PR image
- Appeals to the proponents of the NIMTOO syndrome …
- … but not necessarily to the proponents of the BANANA syndrome
- Greater flexibility - can produce useful products
  - concentrated syngas (low volume)
  - gaseous fuel
  - transportable fuels
  - feedstock chemicals
- Can produce a melted ash granulate
- Potentially higher thermal efficiency – more energy/tonne
- Lower NOx and toxic organics

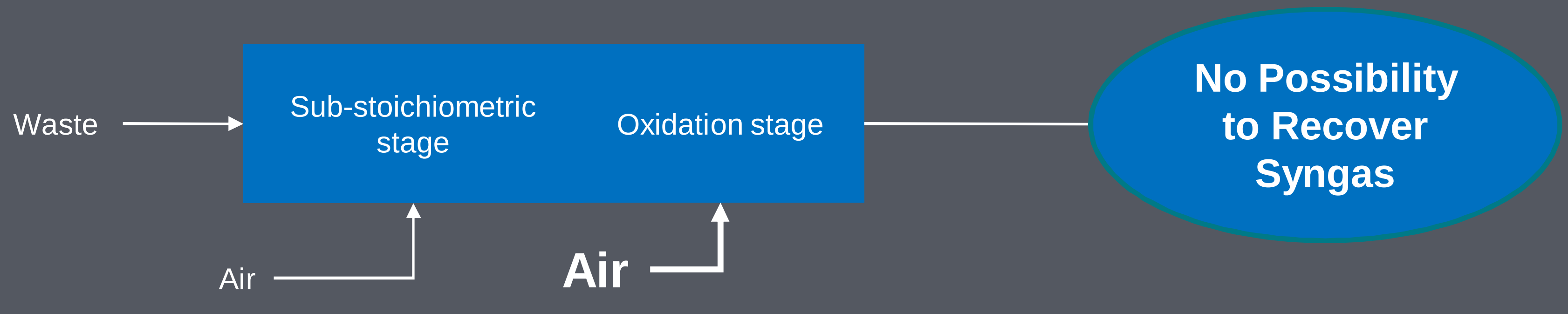
SO YOU WANT TO BUY A GASIFICATION PLANT?

WHICH TYPE OF GASIFICATION PLANT SHOULD YOU CHOOSE?

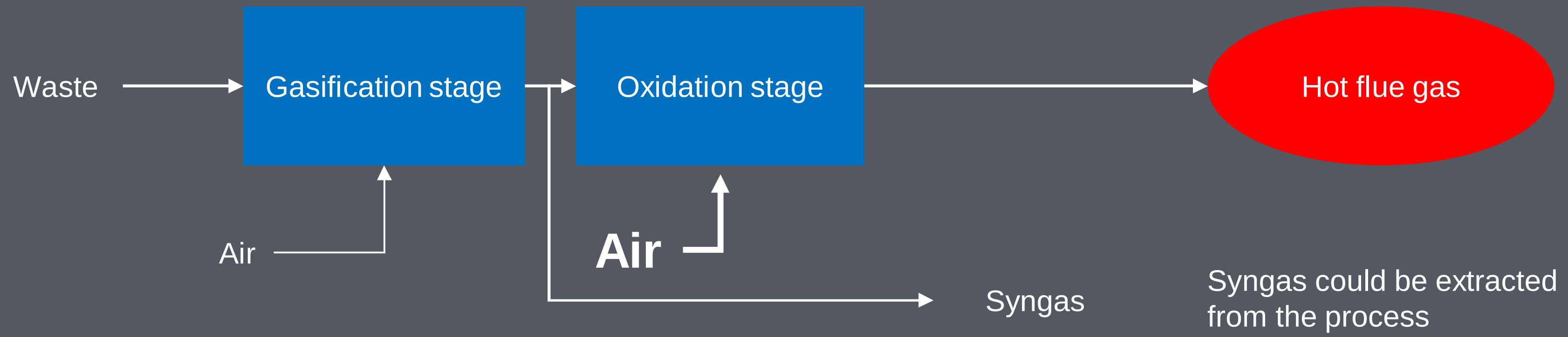

THERMAL PROCESSES FOR MSW
GASIFICATION
LOW TEMPERATURE GASIFICATION
CLOSE-COUPLED
SLAGGING GASIFICATION
MULTIPLE PROCESSES
MULTIPLE PROCESSES
CLOSE-COUPLED GASIFICATION TO STEAM & POWER
PLASMA-BASED SYSTEMS TO SYNGAS
HIGH TEMPERATURE GASIFICATION TO SYNGAS
PLASMA GASIFICATION
PLASMA-ASSISTED GASIFICATION
ELECTRODE
TORCH
GASIFICATION + MELTING
MULTIPLE PROCESSES
MOVING GRATE GASIFICATION + PLASMA MELTING
FLUIDISED BED GASIFICATION + PLASMA MELTING
UPDRAFT GASIFICATION + PLASMA MELTING
DOWNDRAFT GASIFICATION + PLASMA MELTING
MULTIPLE PROCESSES
Europlasma
APP
EER
InEnTec

STARVED AIR COMBUSTION VS. CLOSE-COUPLED GASIFICATION

Starved air combustion



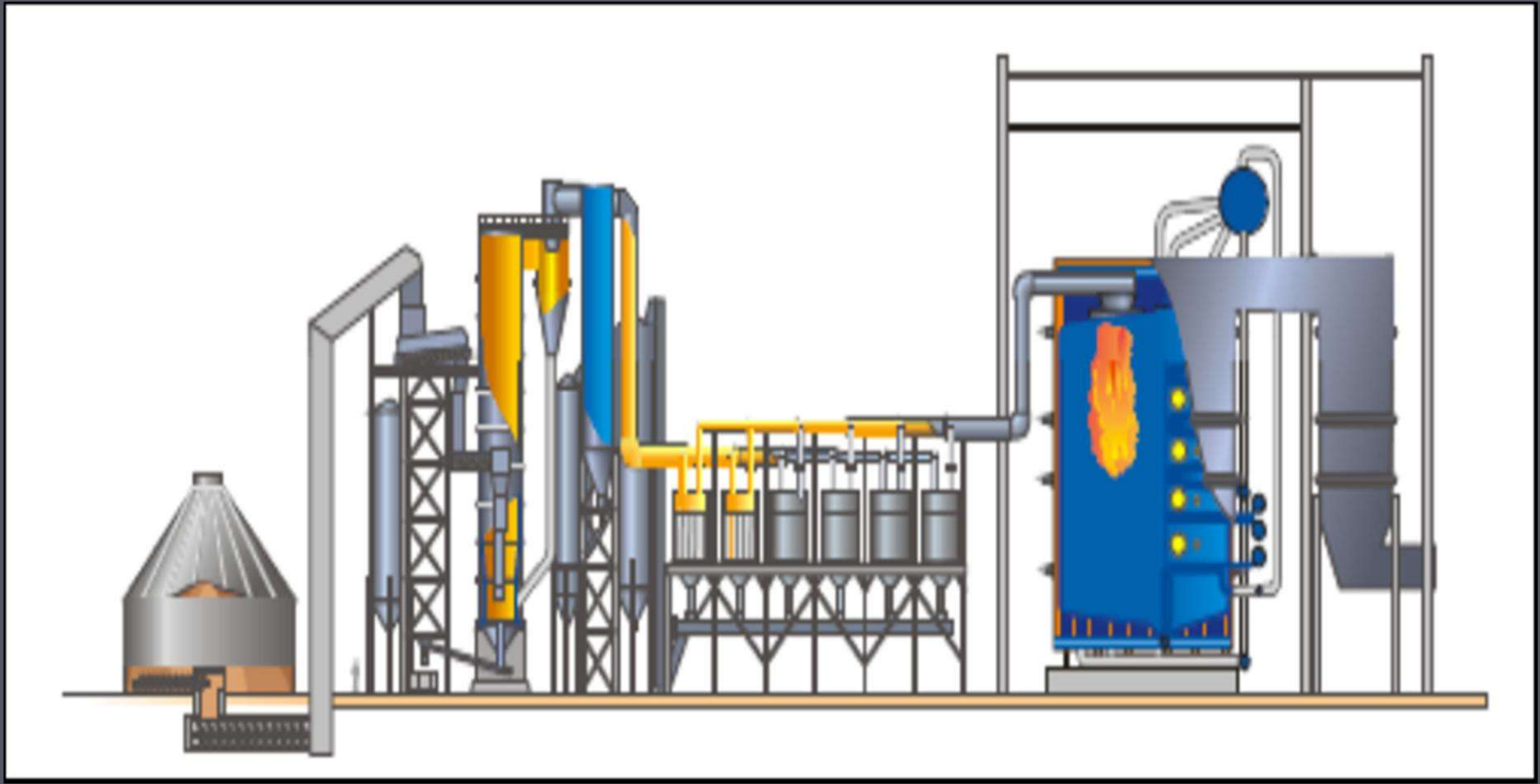
Close-coupled gasification



THE 'TOP 10' WASTE GASIFICATION PLANTS IN THE WORLD

Location	Capacity kTpa	Process	Date	Type
Lahti, Finland	250,000	Metso Power	2012	Gasification
Fukuoka, Japan	215,000	Nippon Steel	2007	Gasification + Melting
Okayama, Japan	170,000	JFE (Tselect)	2005	Gasification + Melting
Sagamihara, Japan	160,000	Kobelco	2010	Gasification + Melting
Narumi, Aichi	160,000	Nippon Steel	2009	Gasification + Melting
Shizuoka, Japan	150,000	Nippon Steel	2010	Gasification + Melting
Ibaraki, Japan	135,000	Nippon Steel	1980	Gasification + Melting
Kawaguchi, Japan	125,000	Ebara	2002	FB gasification + Combustion + Melting
Toyoda, Aichi	122,000	Hitachi Zosen	2007	Gasification + Melting
Toyohashi, Japan	120,000	Mitsui	2002	Pyrolysis + Combustion + Melting

CFB GASIFICATION – LAHTI II

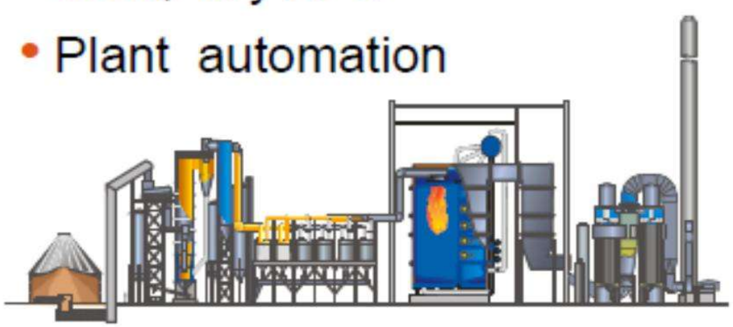


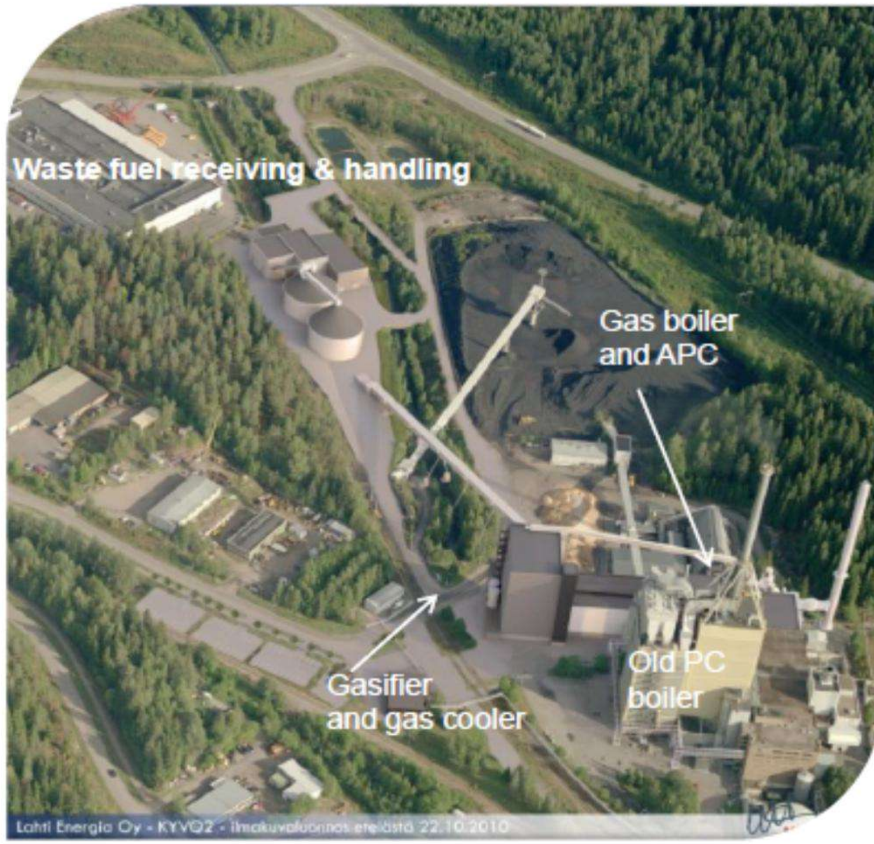
Source: Metso Power

LAHTI II – TECHNICAL DETAILS

METSO DELIVERY

- 2 x 80 MW_{th} gasifiers
  - 250 000 tn SRF/a
- Gas cooling and filtration
- Gas boiler 121 bar, 540 C
- Turbine 50 MW_e & 90 MW_{heat}
  - η_e = 31 % (net)
- SCR, dry APC
- Plant automation

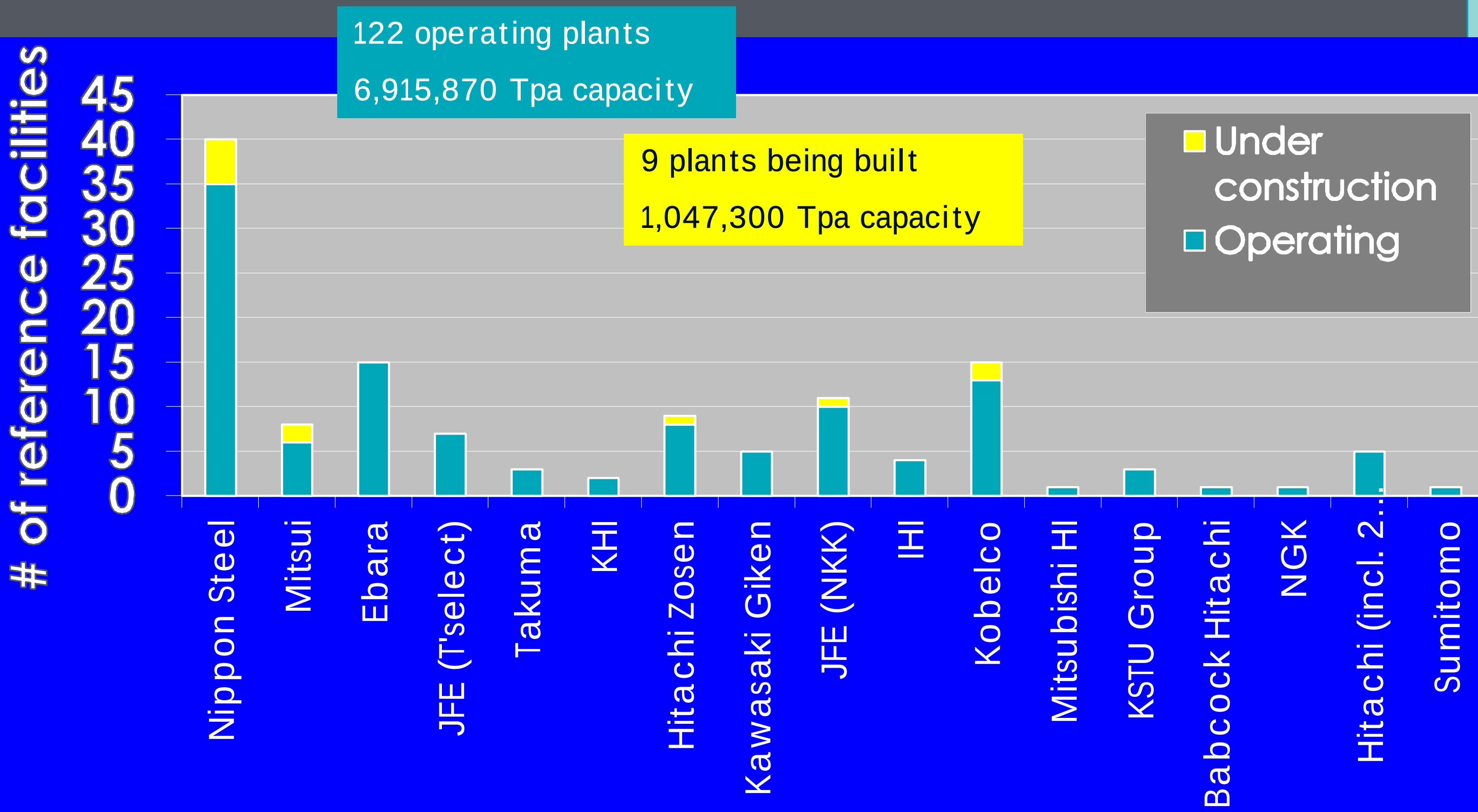




Architecture study of the plant

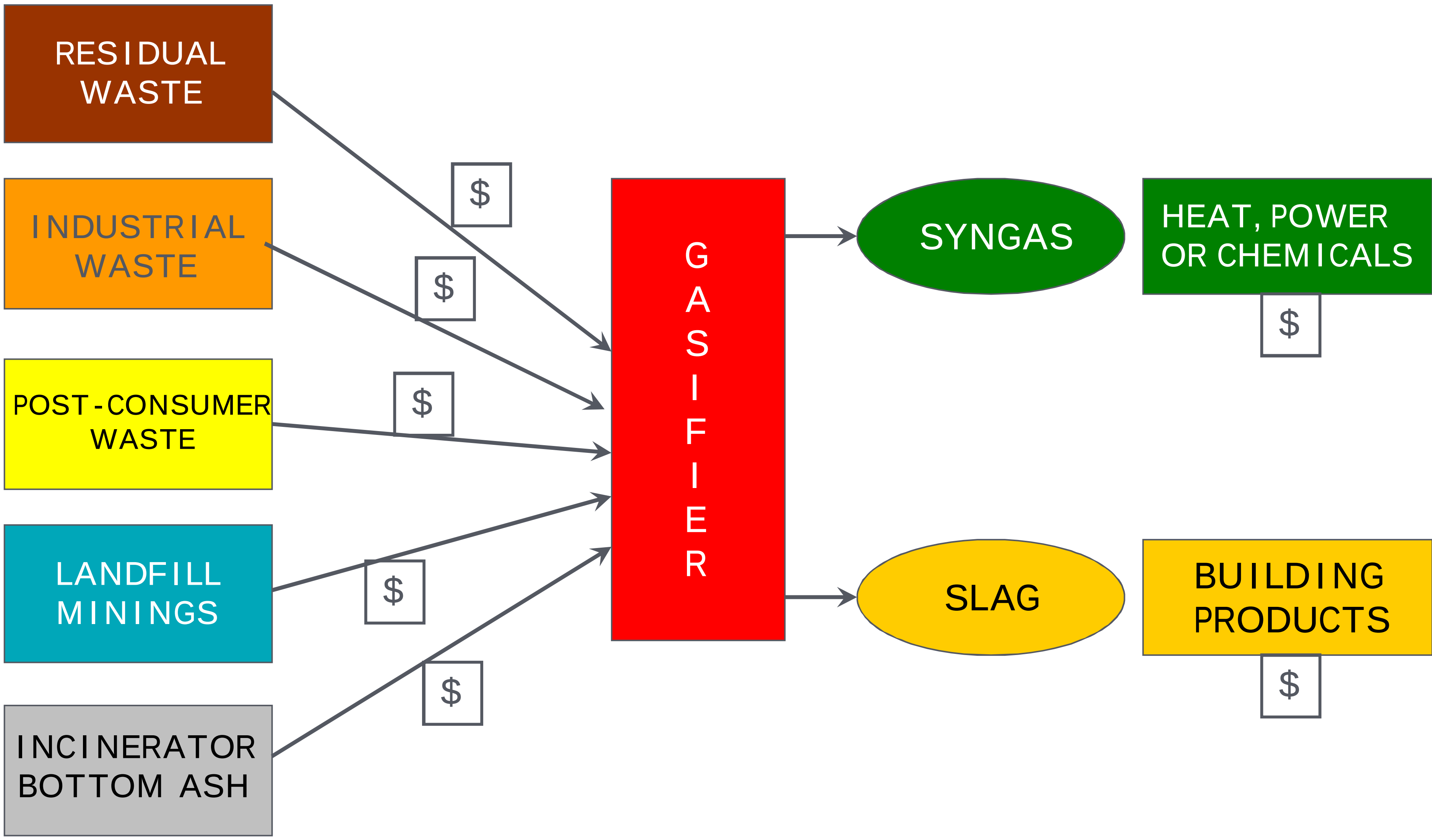
Source: Metso Power

GASIFICATION INFRASTRUCTURE IN JAPAN

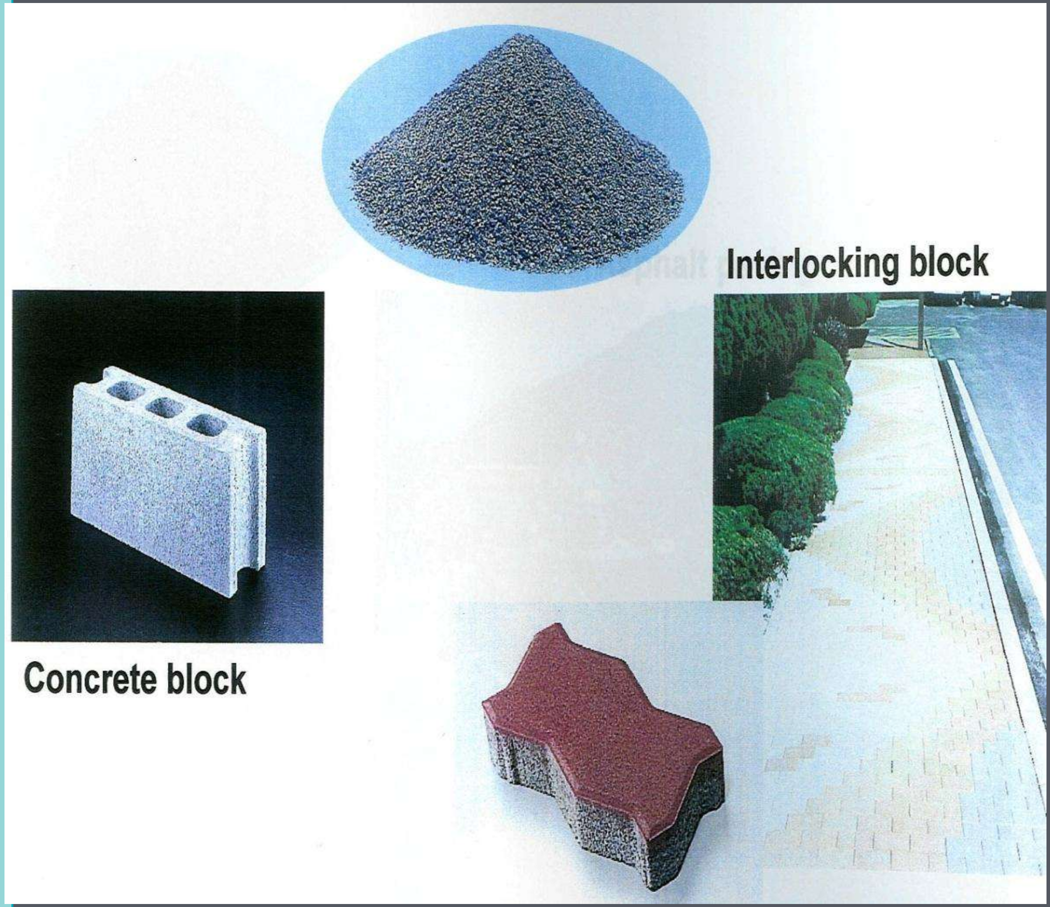


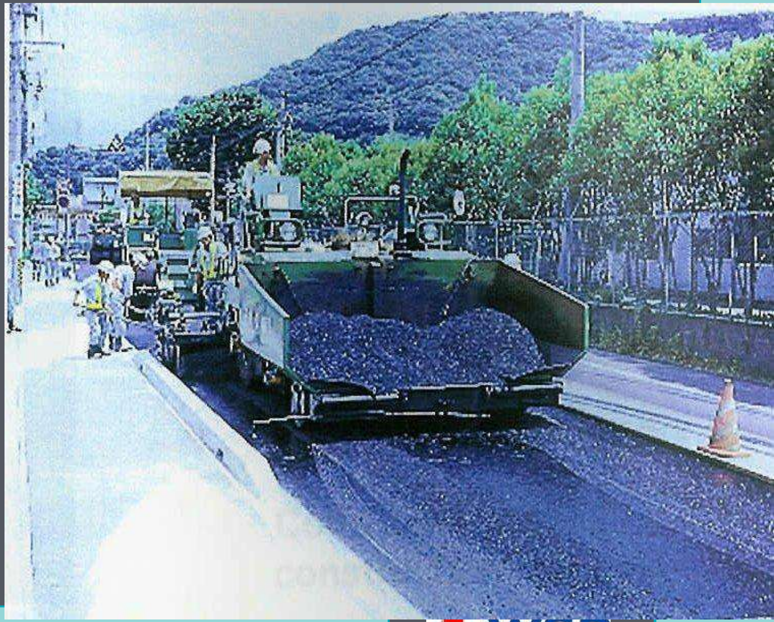
* commercial facilities processing > 30kTpa

RESOURCE RECOVERY – THE JAPANESE MODEL



EXAMPLES OF CONSTRUCTION PRODUCTS MADE FROM WASTE





Source: Nippon Steel

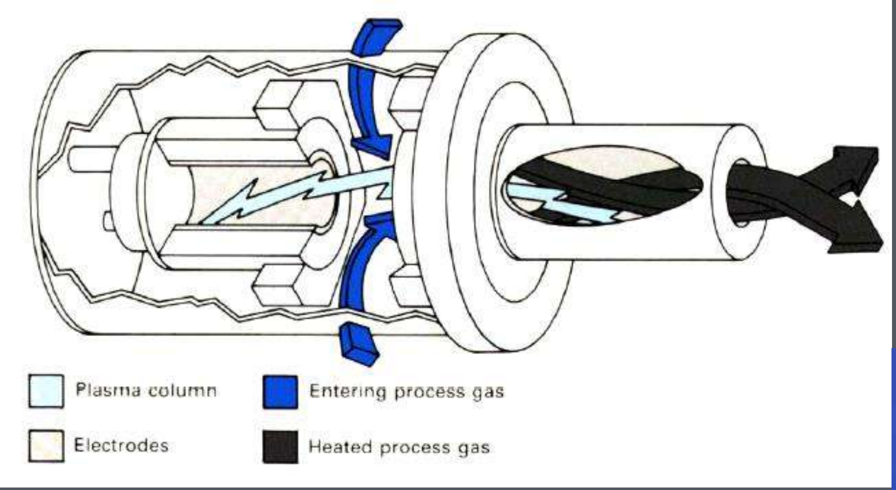
PLASMA TECHNOLOGIES FOR WASTE

Two types of technologies usually offered for waste treatment:

- Plasma Incineration
- Plasma Gasification

Plasma systems are being used in the MSW industry in Japan to vitrify incinerator bottom ash and fly ash residues. These are referred to as *plasma melters*, but they utilise a similar combustion concept as plasma incineration technologies.

PLASMA TORCHES

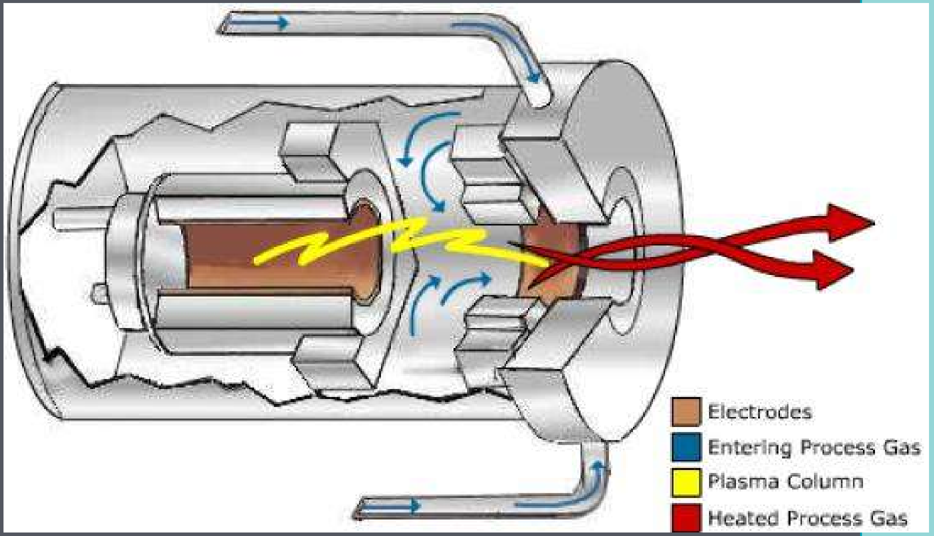


Source: Westinghouse

Source: Pyrogenesis

WHAT IS PLASMA GASIFICATION?

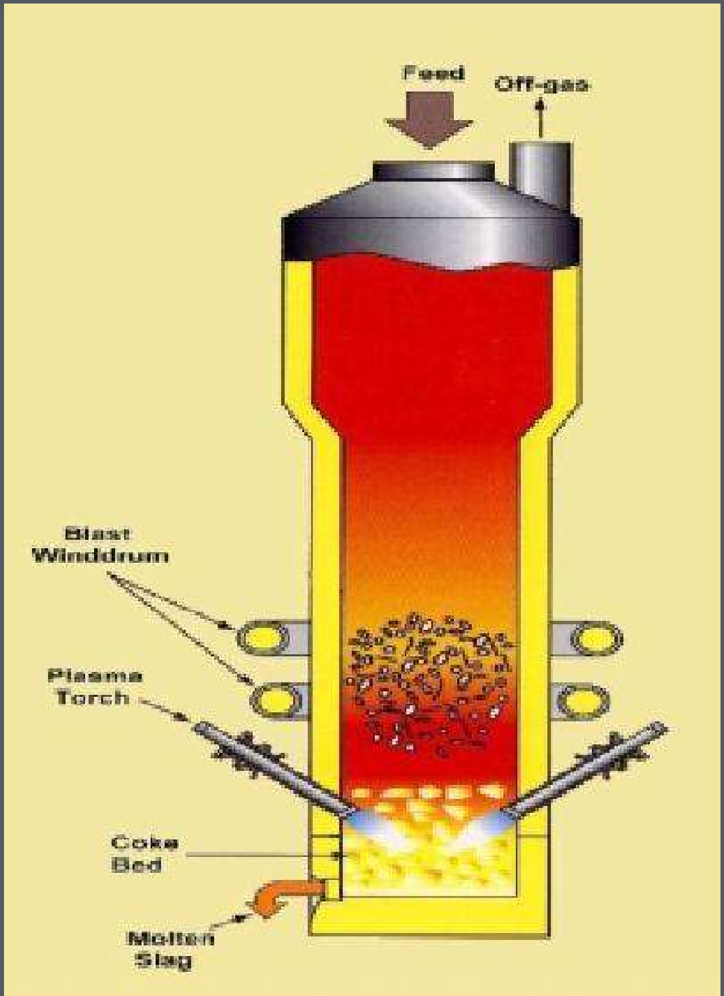
- A Plasma Arc is generated when
  - a 'carrier gas' is exposed to high energy fields between two electrodes, e.g. an electrical discharge;
  - molecules in gas are forced into high energy collisions with charged electrons resulting in the generation of charged particles



Source: Alter NRG

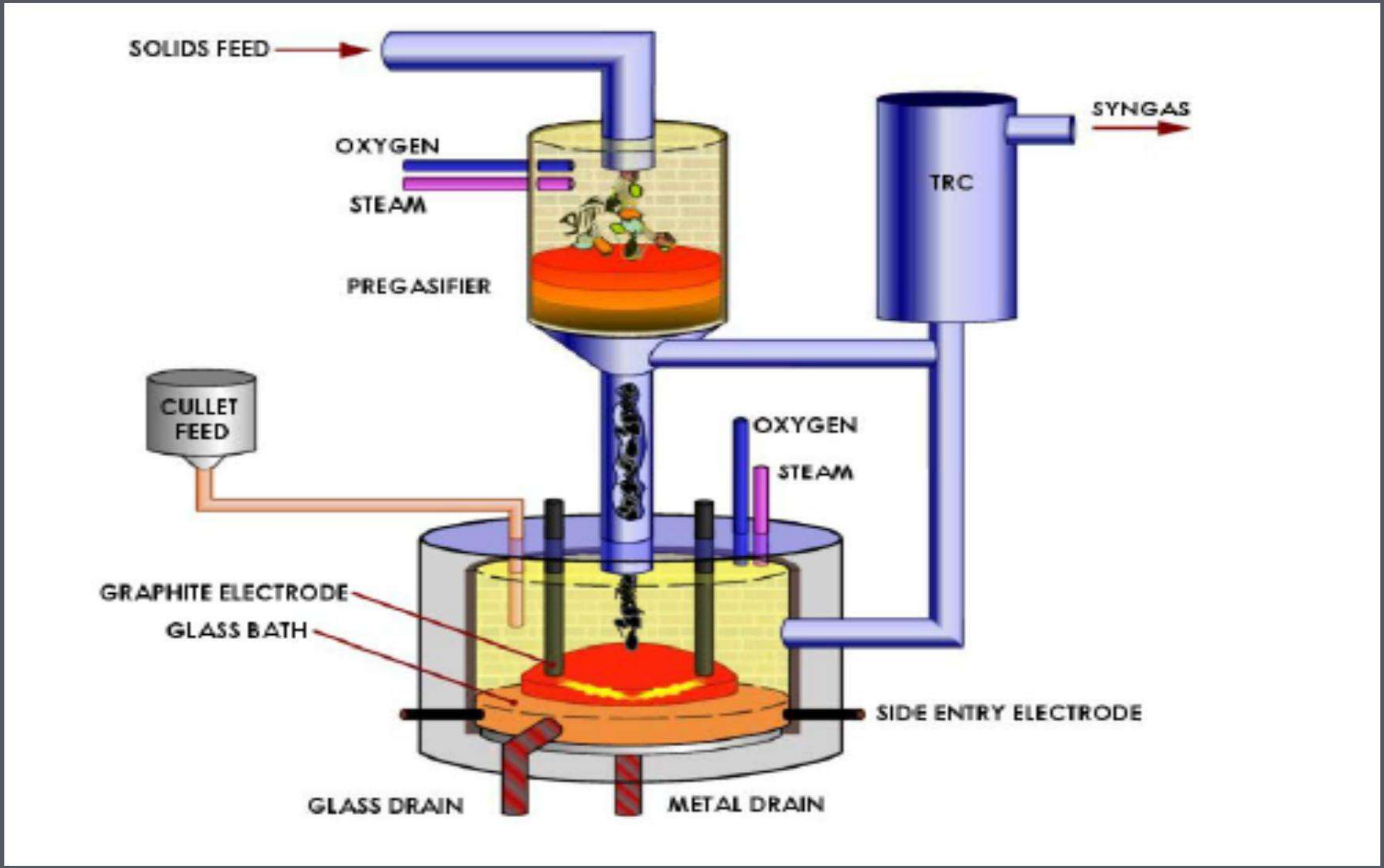
- Although the plasma plume may reach very high temperatures (ca. 20,000 ºC), the bulk temperature of the waste will only reach ~1,800-2,000 °C

WESTINGHOUSE PLASMA GASIFICATION



Utashinai plant

PLASMA ELECTRODE PROCESS



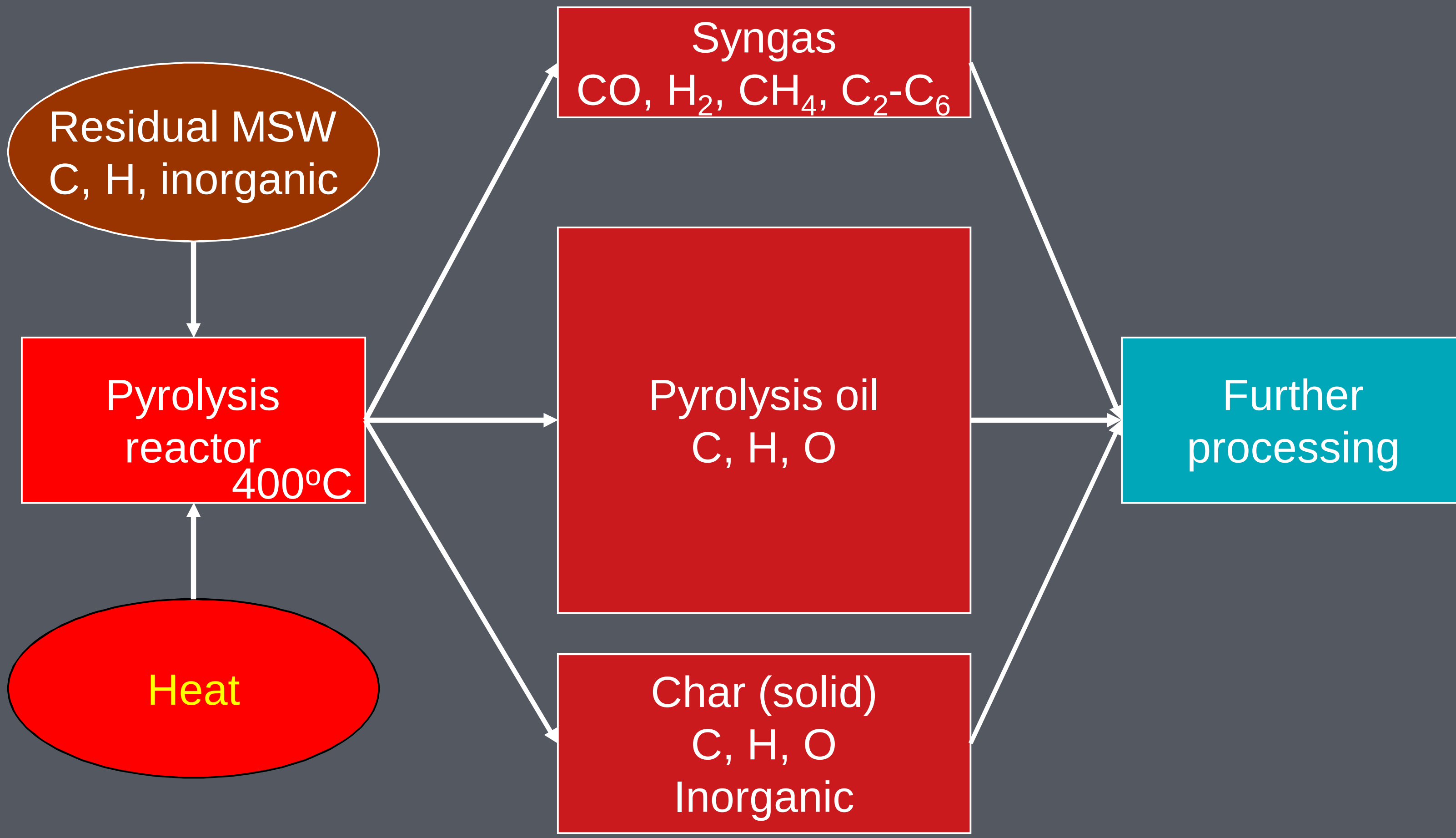
Source: InEnTec LLC

LEADING PLASMA PROCESSES TARGETING MSW

	Process Status	
Company	Hazwaste	MSW/RDF
Advanced Plasma Power (APP)	N/A	Demonstration
AlterNrg (Westinghouse)	N/A	Commercial
EER	N/A	Demonstration
Europlasma	Commercial	Demonstration
InEnTec	Commercial	Demonstration
Plasco	N/A	Demonstration
Pyrogenesis	N/A	Pilot
Solena	N/A	Concept
Startech	Pilot	Concept

WSP

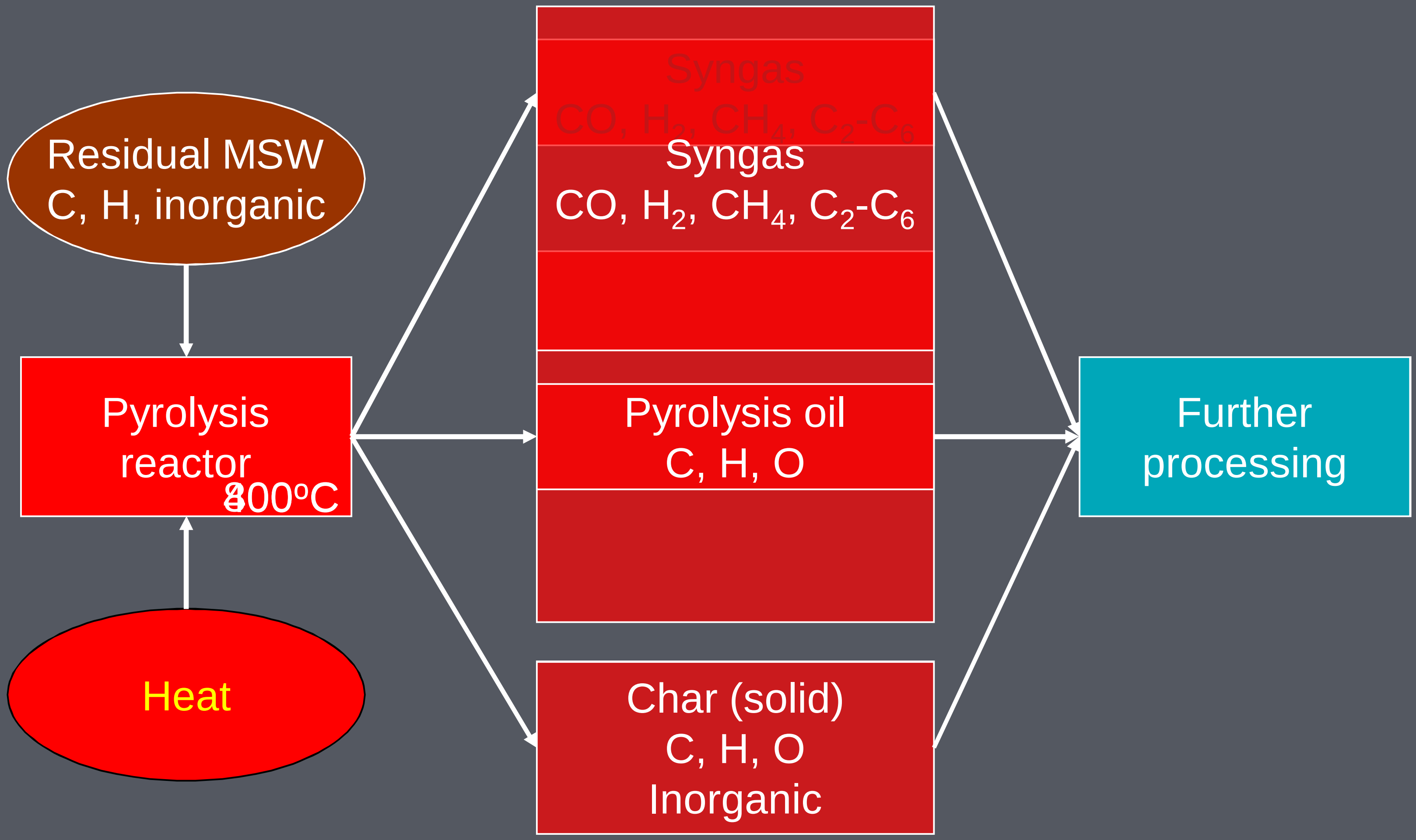
PYROLYSIS



Energy = Chemical Energy

PYROLYSIS (THERMAL GASIFICATION)

PYROLYSIS (



Energy = Chemical Energy

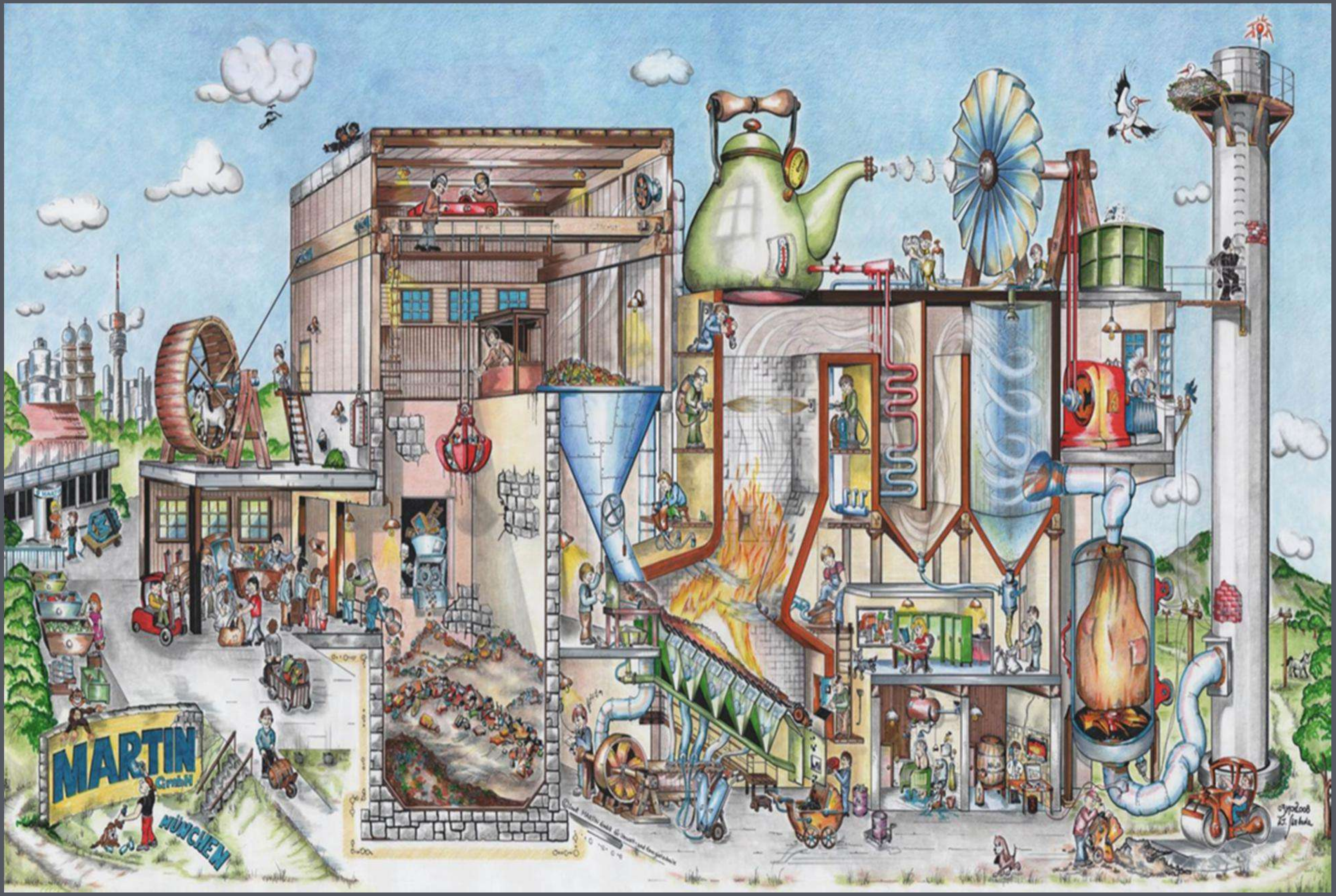
WHAT IS A ‘BANKABLE’ TECHNOLOGY

FUNDER – a technology that is acceptable to senior debt lenders

ENGINEER – a technology that meets the Output Specification

LENDER’S TA – a technology which has a proven track record, with a historic database of performance parameters that can demonstrate minimal risk and economic viability

Key Elements of a Bankable Technology



Source: Martin GmbH