IEA TASK WS2

Evolution of Gas Cleaning

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CARBONA BACKGROUND

1978 – 1984 Technical Research Centre of Finland (VTT)

- **Bubbling fluidized bed small gasifiers**
- **Gas wet scrubbing / filtering development**
- **Down draft gasifier with engine (40 kW)**
- **Kemira ammonia plant with 200 MWth HTW gasifier**
- **Updraft gasifier development**

1985 – 1989 Bioneer and Ahlstrom/Pyroflow (now FW)

- **Commercialization of Bioneer updraft gasifiers**
- **Tar decomposition testing with thermal treatment**
- **CFB gasifiers for PP (Pyroflow)**

Conclusion: Tar is Tar

CARBONA BACKGROUND

1989 - 1995 Tampella Power / Enviropower

- **Licenses for U-gas and Renugas from GTI (former IGT)**
- **20 MWth pressurized pilot operation**
- **Hot gas cleanup and catalysts in slip stream**
- **Alkali, ammonia, HCl, heavy metals measurements**

1996 - > Carbona

- **IGCC-development continues**
- **BGGE possible with new catalysts**
- **Cooperation with VTT and Condens**
- **Reforming, filtering, scrubbing**
- **Skive project**

Conclusion: Tar can be handled with catalysts

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GASIFIER TYPES AND CLEANUP

Gasifiers

- downdraft
- updraft
- fluidized bed

Gas cleanup

- none
- filtering hot or cold gas
- scrubbing – tar handling
- tar reforming – filtering - scrubbing

EXPERIENCE ON GAS CLEANUP IN SMALL SCALE

- **Mainly bad experience**
- **Tar the main problem**

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TAR

Light tar

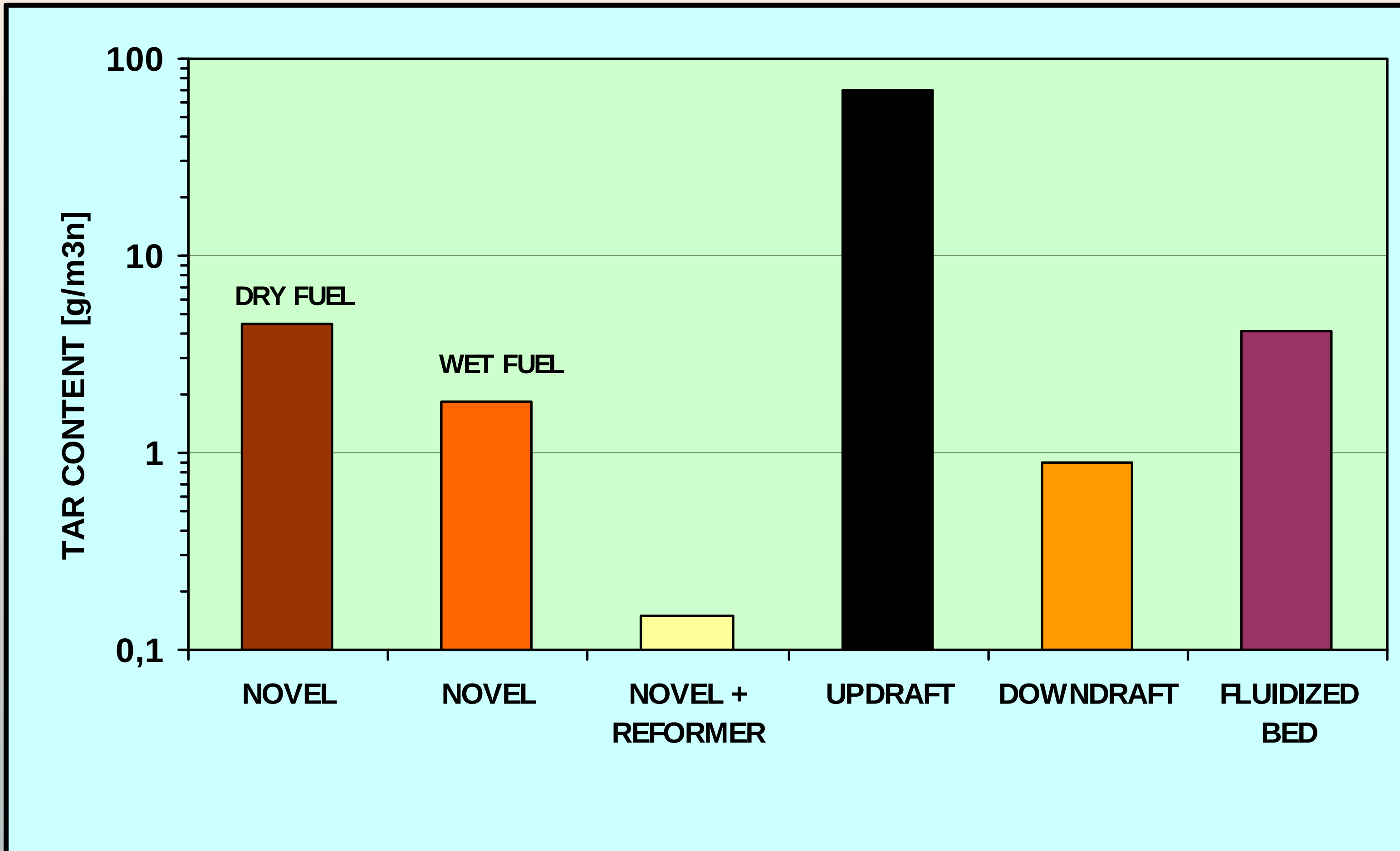
Benzene	**-**	**Pyrene**
78 g/mol	**-**	**202 g /mol**

Heavy tar

Heavier than fluoranthene	**> 202 g/mol**
Condensing	**> 150^{o}C**

TYPICAL TAR CONTENTS

Wood Gasification



Source: VTT

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TAR-COMPOSITION: FLUIDIZED BED GASIFIER

Treatment conditions and component		Wheat, straw	Pine sawdust	Peat A	Peat B	Brown coal	Polish coal
Temperature, °C		850	940	930	940	910	1 000
Residence time in freeboard, s		5	4	5	4	4	5
Pressure, MPa		0.5	0.5	0.5	0.5	0.5	0.5
Benzene and its derivatives							
Benzene	C_6H_6	9 876	7 059	1 699	1 989	962	364
Toluene	C_7H_8	1 275	134	17	15	6	-
Styrene	C_8H_{10}	578	113	3	6	-	-
m- and p-Xylene	C_9H_{10}	68	1	-	-	1	-
4-Methylstyrene	C_9H_{10}	114	4	1	-	-	-
Polycyclic hydrocarbons							
Indene	C_9H_8	602	141	7	-	-	-
Naphthalene	$C_{10}H_8$	3 300	1 866	246	212	29	57
2-Methylnaphthalene	$C_{11}H_{10}$	192	27	2	2	1	-
1-Methylnaphthalene	$C_{11}H_{10}$	113	14	1	1	-	-
Acenaphthylene	$C_{12}H_8$	975	647	20	15	-	-
Biphenyl	$C_{12}H_{10}$	178	52	4	3	-	-
Acenaphthene	$C_{12}H_{12}$	50	30	24	9	-	-
Fluorene	$C_{13}H_{10}$	209	55	5	3	-	-
Phenanthrene	$C_{14}H_{10}$	687	446	38	19	-	-
Anthracene	$C_{14}H_{10}$	194	61	5	2	-	6
Fluoranthene	$C_{16}H_{10}$	275	296	25	1	-	-
Pyrene	$C_{16}H_{10}$	330	307	27	-	1	-
Hydrocarbons with heteroatoms							
Pyridine	C_5H_5N	169	4	88	28	1	-
Phenol	C_6H_6O	159	13	1	1	-	-
Isoquinolene	C_9H_7N	21	-	1	1	-	-
Quinazoline	$C_8H_6N_2$	-	4	3	-	-	-
Dibenzofurane	$C_{12}H_8O$	91	78	7	4	-	-
Total concentration mg/m3n		19 456	11 352	2 224	2 311	1 001	427

Source: VTT

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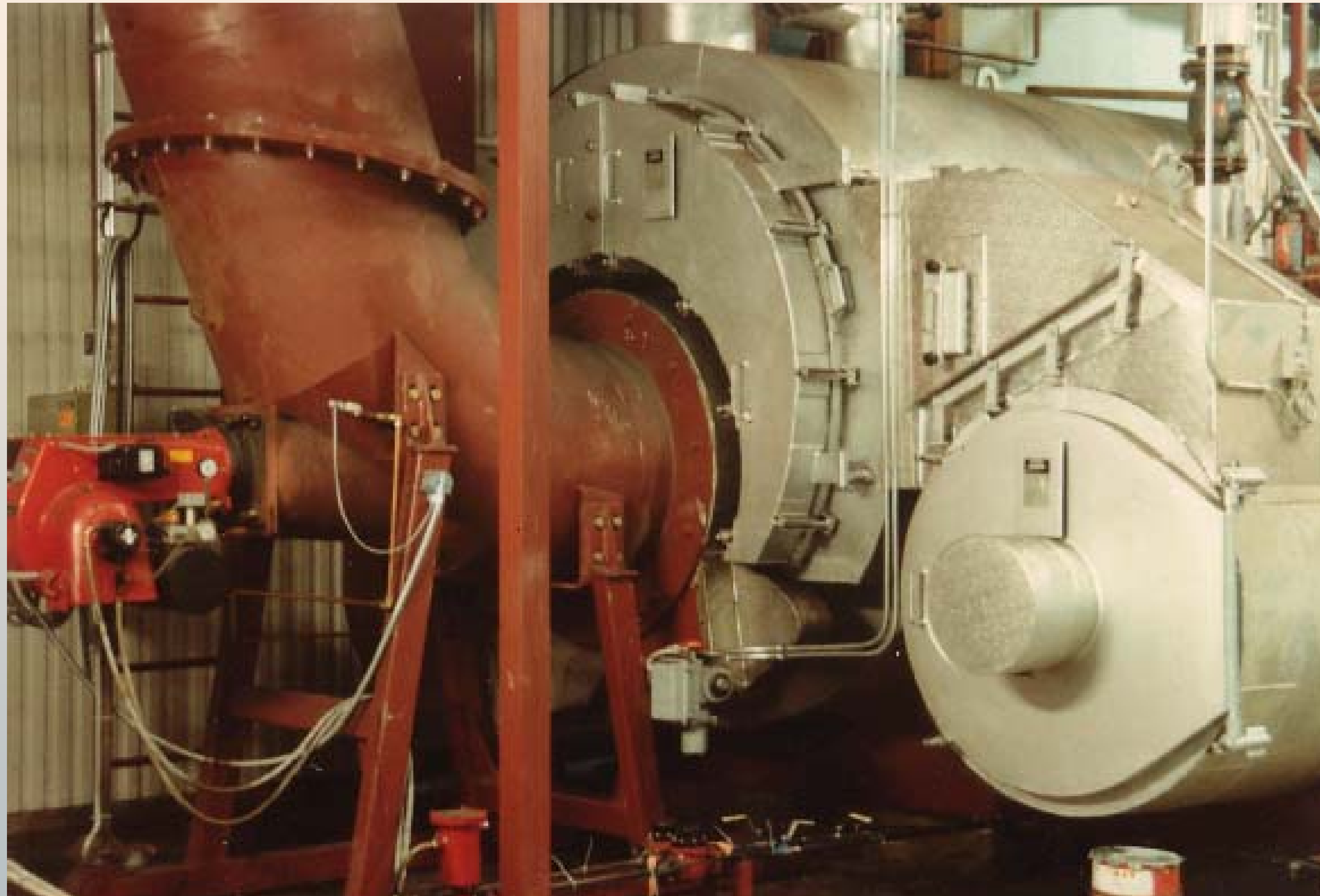
GAS BOILER AND BURNER



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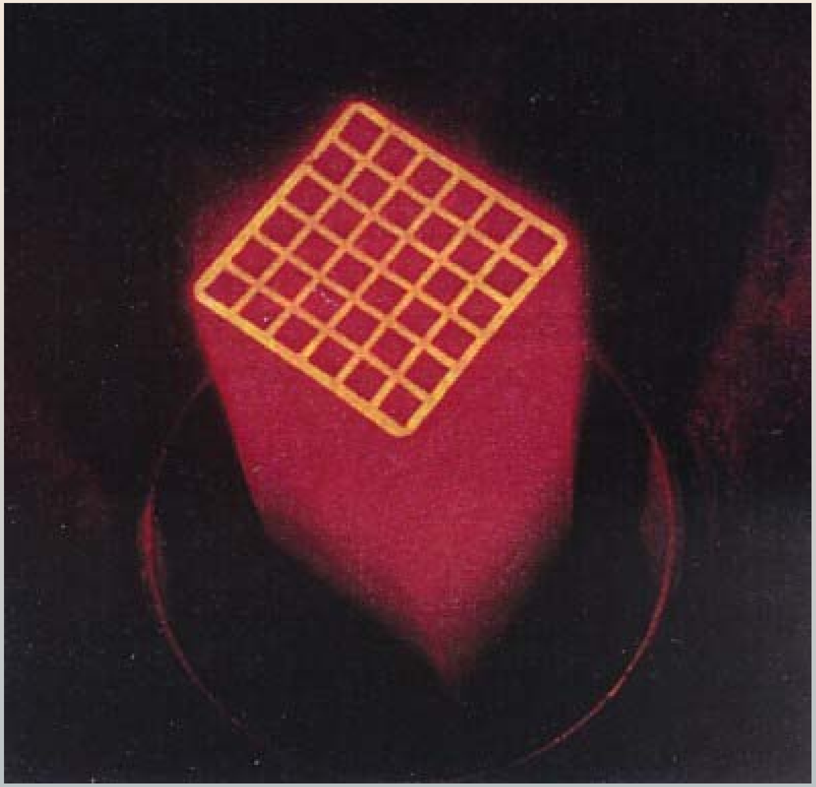
REFORMER

Catalyst



Source: VTT

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REFORMER
Performance

		GAS FROM GASIFIER	GAS FROM REFORMER
Temperature	°C	850	835
Mass flow	kg/s	1,087	1,151
CO	%-vol	17,17	19,13
CO2	%-vol	12,17	10,47
H2	%-vol	15,18	18,52
H2O	%-vol	12,41	11,52
CH4	%-vol	3,35	0,82
C2H4	%-vol	0,04	0,00
C3H8	%-vol	0,00	0,00
C6H6	%-vol	0,11	0,00
N2	%-vol	39,50	39,52
H2S	ppmv	75	68
NH3	ppmv	574	42
HCl	ppmv	59	54
TOTAL	%-vol	100,0	100,0
LHV	kJ/kg	4769	4473

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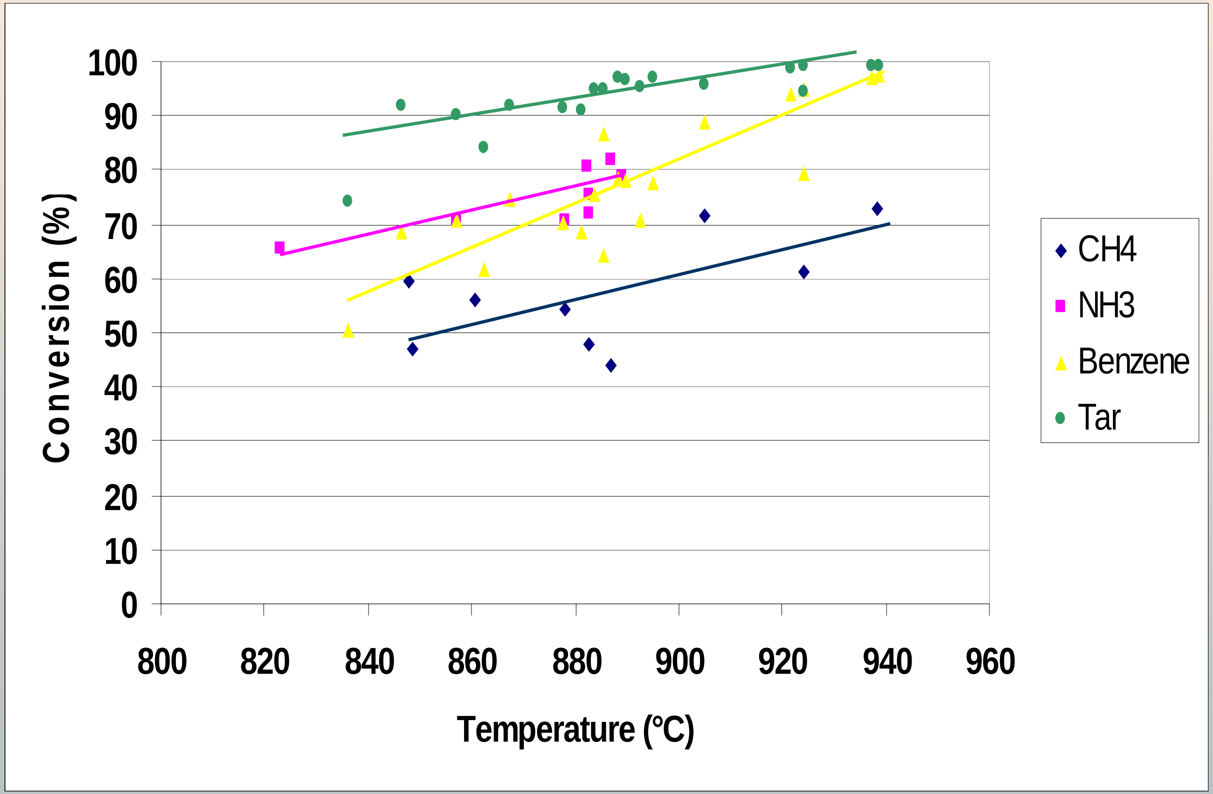
TAR REFORMER

Performance



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CONTAMINANTS IN BIOMASS FUEL

Contaminants originating from the fuel

	Woody biomass	Agricultural biomass	Other waste
Typical biomass fuel	Wood chips, forest residue, paper mill waste	Willow, straw, alfalfa	Sewage sludge, RDF
Ash content	1-5%w	4-11%w	10-45%w
Sulfur content	<0.1%w	0.1-0.3%w	0.1-1%w
Nitrogen content	0.4-07%w	0.5-3.0%w	0.5-6%w
Chlorine content	<0.1%w	0.1-0.25%w	0.1-1%w
Alkalines (Na+K)	0.05-0.4 %w	0.3-3%w	n/a

PRODUCT GAS CONTAMINANTS

Typical contaminants in product gas:

- **nitrogen gases (NH_3, HCN)**
- **sulfur gases (H_2S, COS)**
- **other gases (HCl)**
- **vapor phase alkali metals (Na, K)**
- **vapor phase trace elements**
- **dust**

NITROGEN COMPOUNDS

- Fuel nitrogen forms ammonia (NH_3) and hydrogen cyanide (HCN).
- NH_3 and HCN burn to NOx in the power generating equipment and are emitted with the flue gas.
- The higher the fuel bound nitrogen, the higher product gas NH_3 (between 1000 and 30000 ppm).
- Fuel bound nitrogen to ammonia conversion between 40-85%.
- Formation of ammonia can not be controlled in the gasifier.
- NH_3 and HCN are not harmful for power generation equipment.
- Removed in catalyst and wet scrubber.

CHLORINE COMPOUNDS

- Chlorine in fuel forms HCl in the gasification process.
- Typical HCl content in biomass derived gas is 20 - 500 ppmv.
- HCl can pass the power generating equipment and are emitted with the flue gas.
- HCl can cause corrosion in power generation equipment.
- HCl forms chlorides with calcium based gasifier bed material and alkalis.
- Vapor phase chlorides can condense in power generation equipment after oxidation.
- Chlorides are mainly removed with the filter ash and in scrubber.

ALKALI METALS

- **Alkali metals (Na and K) in fuel mainly stay in gasifier and filter ash.**
- **A small portion volatilize (below 1 ppmw in the product gas).**
- **Volatile alkalis form chlorides, hydroxides and sulfides.**
- **Alkali compounds are removed in the filter and scrubber.**

TRACE ELEMENTS

- Vapor phase trace elements are mainly:
  As, Cd, Co, Cu, Cr, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Sn, Zn, V
- Vapor phase trace elements are emitted with the flue gas (Cd, Hg) and may contaminate catalysts (As)
- Removal occurs in filter when vapor phase trace elements condense on particle surface or in wet scrubber

TRACE ELEMENT CONTENT OF PRODUCT GAS AFTER CERAMIC FILTER UNIT (µg/m^{3}n)

Hg	BDL
Cd	0.7-2.0
Pb	2.3-2.4
Se	BDL
Sb	BDL
Co	BDL
Mn	NA
Be	BDL
As	BDL
Cr	NA
Ni	NA

BDL = Below Detection Limit

NA = Not Analyzed

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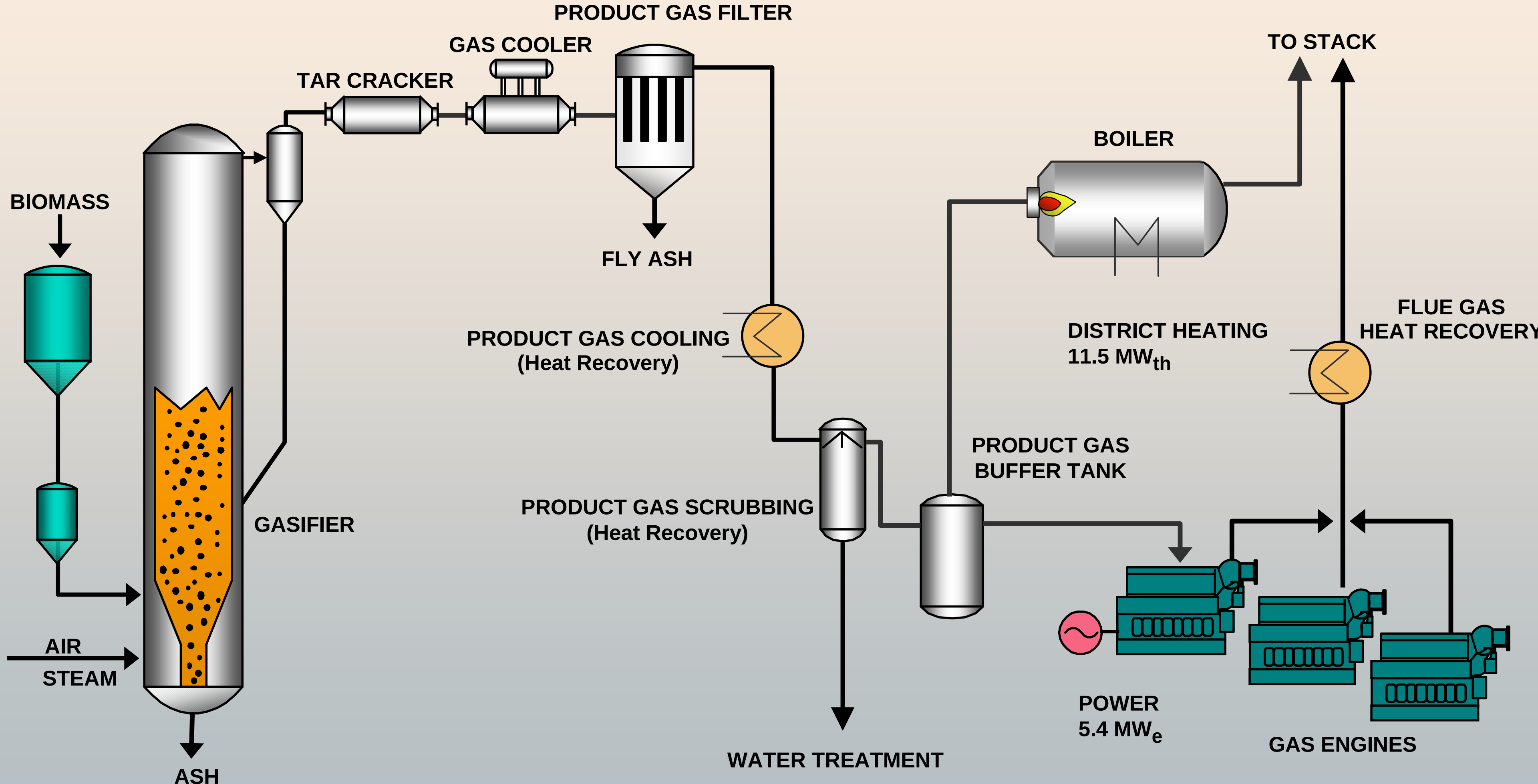
REQUIREMENTS FOR GAS ENGINE FUEL

Temperature	< 40	°C
Pressure	> 150	mbar(g)
Relative moisture content	< 80	%
Particulate content	< 50	mg / 10 kWh
Sulfur content	< 2000	mgH_2S / 10 kWh
Halogen content	< 100-400	mg / 10 kWh
Ammonia content	< 55	mgNH_3 / 10 kWh
Oil (tar) content	< 5	mg / 10 kWh

SKIVE PROJECT, DENMARK



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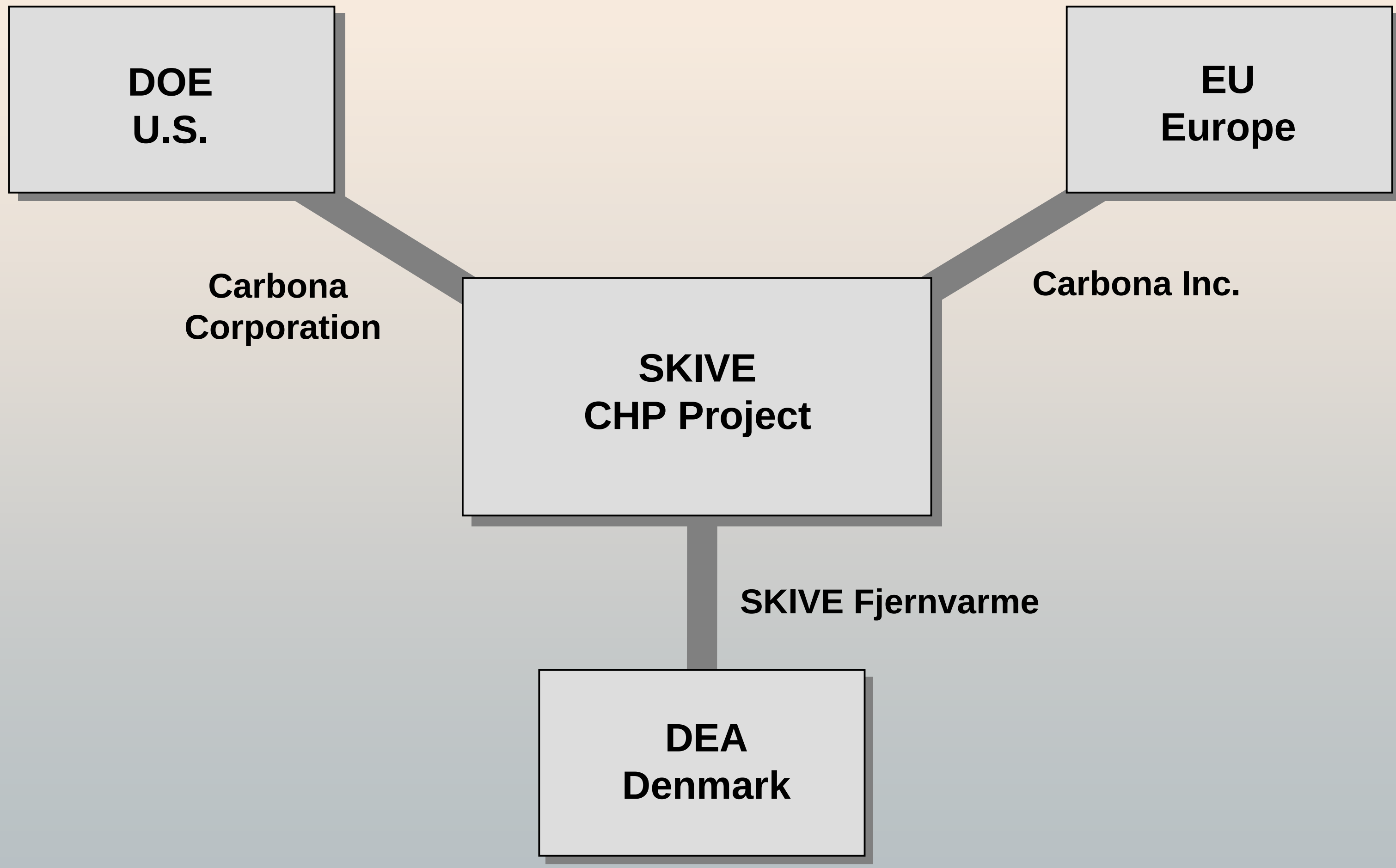
INTERNATIONAL FUNDING COOPERATION

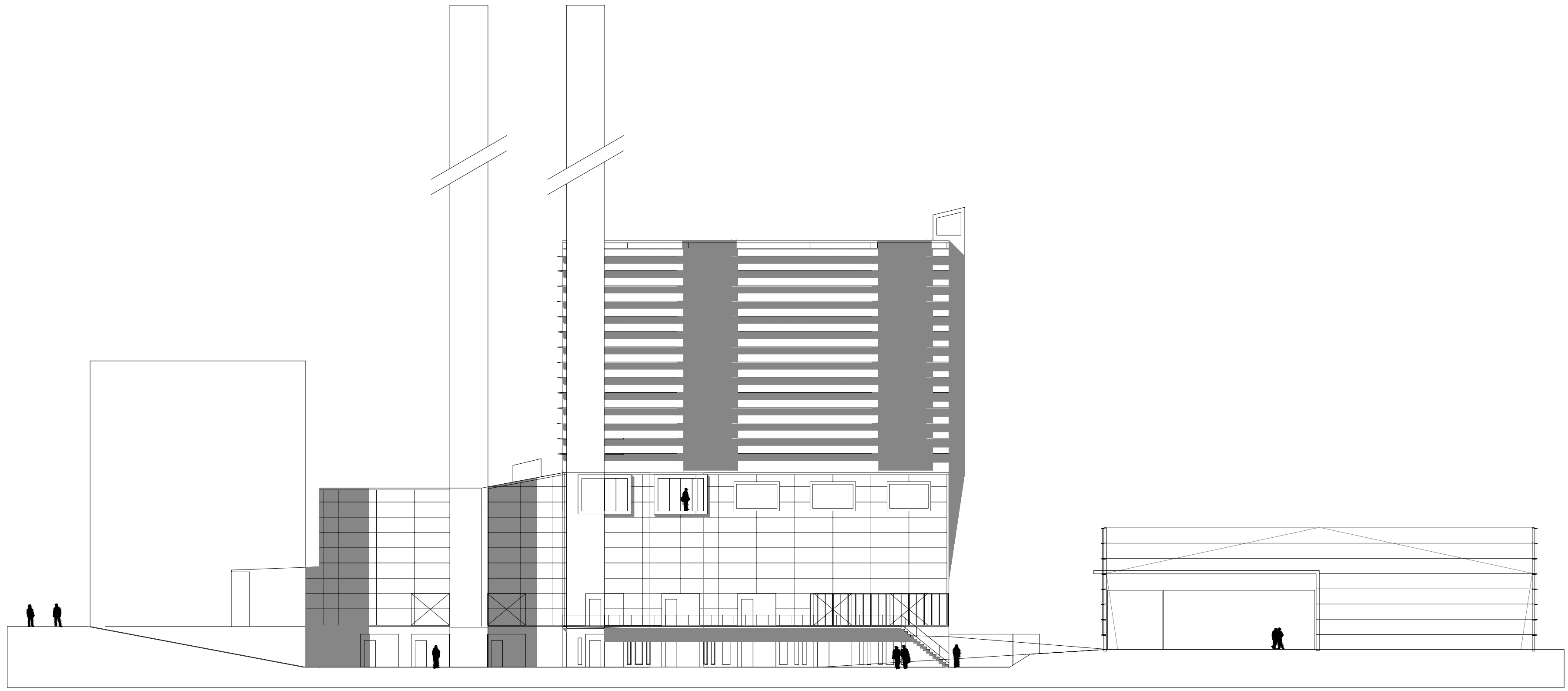


SKIVE PROCESS DESIGN BASIS

- **Plant Configuration:**
  - low pressure fluidized bed gasifier
  - tar cracking
  - gas cooling and scrubbing
  - gas engines
  - district heating system
- **Plant Capacity:**
  - biomass feed 110 tpd
  - power generation max. 5.4 MW
  - 11.5 MW district heat, supply at 94/50 °C
- **Fuel:**
  - wood pellets (20.2 MJ/kg HHV d.b.) of 9.5 % moisture content
- **General:**
  - annual operation 8000 hours
  - technical life time 15 years
- **Plant Efficiency:**
  - electrical efficiency 28 % (LHV)
  - overall efficiency 87 % (LHV)

WOOD PELLETS HANDLING

SKIVE BGGE - BUILDING



Source: Rambøll, Denmark

SKIVE – PROJECT STATUS

- DOE – NREL subsidy enabled the project start.
- EU has accepted to move the project from the former site, Lemvig, to Skive and to change project coordinator and participants. Coordinator is Carbona, partners Skive and GE Jenbacher.
- Danish Energy Agency has also granted a subsidy
- Skive has obtained most approvals from owners and City Council for plant construction & investment.
- Skive, as the main contractor has signed the main contracts.
- Basic engineering and substantial part of detailed engineering has been done by for the entire plant. Construction started 25.10.2004
- Skive BGGE - plant starts operation by the end of 2005.

CONCLUSION ON GAS CLEANUP

- Gas cleanup is still a challenge
- In small scale makes the process complicated and expensive
- to meet “the power plant” standards – tar must be reformed

You do not want to see or smell tar

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