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**D 2.1 Literature review of energy use and potential
 for heat recovery in the EU28 Report**

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Introduction

Primary energy consumption in industry is in the form of electricity, natural gas, gas oil, liquid fuel, coal and renewables. A preliminary assessment using EINSTEIN with a sample of 67 audits in 10 countries has shown that at least 17% of primary energy savings is possible. Given that the sample used in the audit was relatively small it is necessary to study this aspect further.

It is desirable, through a literature review, to

- (a) identify and quantify primary energy consumption in the major industrial sectors,
- (b) consider waste streams and the temperature level of these,
- (c) identify and, using EINSTEIN where possible, consider in detail conventional candidate technologies for energy recovery from waste streams, including their advantages, disadvantages and limitations.

The review is based on scientific journal papers as well as reports and ensembles of data from EU official authorities and organizations. This is realized by (i) online search, (ii) direct communication between the partners of the consortium and the corresponding local authorities, (iii) direct communication between the leader of this WP and authorities/organizations in countries non-participating in the consortium. The result is a detailed report that includes comparative tables with regard to country, type of industry, technology used, energy waste stream type and potential.

Part I:
EU28 Countries energy analysis

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Austria

Capital City: Vienna

Geographical Size: 83,879 km²

Population: 8,507,786 (2014 est.)

Population as % of EU population: 1.7% (2014 est.)

GDP: €329.296 billion

Official Languages: German

Currency: Euro €

Industries: construction, machinery, vehicles and parts, food, metals, chemicals, lumber and wood, paper and paperboard, communications equipment, tourism.



Austria is an EU member state since 1st January 1958 and a member of the Eurozone since 1st of January 1999. Austria is located at the Eastern end of the Alps and covers an area of 83,879 km². The main language in Austria is German and the capital of the country is Vienna (“EUROPA - EU member countries,” 2016).

The most significant segments of the Austrian economy, in 2014, were wholesale and retail trade, transport, accommodation and food services, industry and public administration, defense, education, human health and social work activities (“EUROPA - EU member countries,” 2016).

The population and GDP were 8,507,786 and €329.296 billion, in 2014, respectively. One of the most important sectors in Austria is the industrial sector, which corresponds to the 22.1% of the Austrian economy (“EUROPA - EU member countries,” 2016).

Energy Consumption of Country

Austria’s total final energy consumption, in 2013, was 318.75 TWh. Table 1 shows the final energy consumption by sector in Austria from 2009 up to 2013. As can be seen in the table, industry consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the above table it can be concluded that the percentage share of the final energy consumption for each sector is 31.91% for industry, 32.26% for transport, 24.24% for residential, 9.71 % for tertiary and 2.06% for agriculture, in 2013.

Table 1 Energy Consumption by Sector – Austria.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	93.9	100.27	101.58	101.33	101.7
FINAL CONSUMPTION OF TRANSPORT	TWh	98.98	101.82	99.34	98.28	102.83
FINAL CONSUMPTION OF RESIDENTIAL	TWh	73.09	79.65	73.94	76.6	77.26
FINAL CONSUMPTION OF AGRICULTURE	TWh	6.19	6.53	6.16	6.56	6.58
FINAL CONSUMPTION OF TERTIARY	TWh	32.5	35.61	32.17	31.26	30.95
TOTAL FINAL CONSUMPTION	TWh	306.52	324.96	314.36	314.18	318.75

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Austria has a variety of industries each of them playing an important role to the economy of the country. The most important ones are construction, machinery, vehicles and parts, food, metals, chemicals, lumber and wood, paper and paperboard, communications equipment, tourism (“CIA - The World Factbook,” 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively (“SPF Economie,” 2016).

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 2 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the most consumed source is electricity and the most consumed fuel is gas. The less consumed energy in industry is heat and then renewables.

Table 2 Energy consumption of Industry by fuel/source- Austria.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	12.89	13.75	13.12	13.21	13.56
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	6.5	7.77	7.83	7.67	7.51
GAS CONSUMPTION OF INDUSTRY	TWh	28.49	30.08	31.04	30.93	30.69
HEAT CONSUMPTION OF INDUSTRY	TWh	2.65	2.92	3.07	3.22	3.21
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	17.87	18.65	18.47	18.17	18.54
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	25.5	27.12	28.06	28.12	28.19
FINAL CONSUMPTION OF INDUSTRY	TWh	93.9	100.27	101.58	101.33	101.7

It is also important to see the sectors of industry that the energy is consumed. Table 3 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the iron and steel industry whereas on the other hand, textile and leather consumes the least energy. It can also be concluded that iron & steel, paper, pulp & print and chemical & petrochemical are the most important industries in Austria.

Table 3 Energy Consumption of Industry Sector in 2013 by industry – Austria.

	TWH	%
Industry	151.251	-
Iron & steel industry	40.641	26.87
Chemical and Petrochemical industry	16.589	10.97
Non-ferrous metal industry	3.204	2.12
Non-metallic Minerals (Glass, pottery & building mat. Industry)	14.250	9.42
Transport Equipment	2.133	1.41
Machinery	10.397	6.87
Mining and Quarrying	2.475	1.64
Food and TOBACCO	9.195	6.08
Paper, Pulp and Print	27.705	18.32
Wood and Wood Products	11.142	7.37
Construction	7.967	5.27
Textile and Leather	1.446	0.96
Non-specified (Industry)	4.105	2.71

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Belgium



Capital City: Brussels

Geographical Size: 30,528 km²

Population: 11,203,992 (2014 est.)

Population as% of EU population: 2.2% (2014 est.)

GDP: €402.027 billion

Official Languages: Dutch, French and German

Currency: Euro €

Industries: engineering and metal products, motor vehicle assembly, transport equipment, scientific instruments, processed food and beverages, chemicals, base metals, textiles, glass and petroleum



Kingdom of Belgium is a three regional federal state and a member of the European Union, since 1958. It has joined Eurozone in 1st January 1999. The three regions are divided into the Dutch-speaking Flanders located in the North of the country, the francophone Wallonia located in the south of the country and Brussels, the capital, where French and Dutch people live ("EUROPA - EU member countries," 2016)

Belgium is located in the Western Europe next to Germany (West), Netherlands (North) and France (South). The recorded population and GDP in 2014 were 11,203,992 and €402,027 billion, respectively. Its total area coverage is 30,528 km² and the 16.8 % of the Belgian economy corresponds to the industrial sector ("EUROPA - EU member countries," 2016).

Energy Consumption of Country

Belgium's total final energy consumption, in 2013, was 397.82 TWh. Table 14 shows the final energy consumption by sector in Belgium from 2009 up to 2013. As can be seen in the table, industry consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the above table it can be concluded that the percentage share of the

final energy consumption for each sector is 29.32% for industry, 28.21% for transport, 26.23% for residential, 14.27% for tertiary and 2.14% for agriculture, in 2013.

Table 4 Energy Consumption by Sector – Belgium.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	102.23	122.66	118.96	115.52	116.63
FINAL CONSUMPTION OF TRANSPORT	TWh	125.17	129.75	128.33	114.28	112.21
FINAL CONSUMPTION OF RESIDENTIAL	TWh	97.62	105.74	89.77	97.99	104.33
FINAL CONSUMPTION OF AGRICULTURE	TWh	8.01	8.48	7.28	7.71	8.53
FINAL CONSUMPTION OF TERTIARY	TWh	54.88	58.41	50.99	53.39	56.79
TOTAL FINAL CONSUMPTION	TWh	387.96	424.73	396.26	388.81	397.82

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Belgium has a variety of industries each of them playing an important role to the economy of the country. The most important ones are engineering and metal products, motor vehicle assembly, transport equipment, scientific instruments, processed food and beverages, chemicals, base metals, textiles, glass and petroleum (“CIA - The World Factbook,” 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively (“SPF Economie,” 2016).

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 5 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is the electricity and the most consumed fuel is gas. The less consumed energy in industry is heat.

Table 5 Energy consumption of Industry by fuel/source- Belgium.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	9.83	17.3	16.63	14.66	16.54
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	7.6	7.12	4.8	5.56	5.14
GAS CONSUMPTION OF INDUSTRY	TWh	38.44	44.97	44.08	44.2	43.63
HEAT CONSUMPTION OF INDUSTRY	TWh	5.42	6.36	6.06	5.58	5.64
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	7.45	8.5	9.12	8.94	9.63
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	33.48	38.42	38.27	36.59	36.05
FINAL CONSUMPTION OF INDUSTRY	TWh	102.23	122.66	118.96	115.52	116.63

It is also important to see the sectors of industry that the energy is consumed. Table 6 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the iron and steel industry whereas on the other hand, mining and quarrying consumes the least energy. It can also be concluded that iron & steel, chemical & petrochemical and food & TOBACCO are the most important industries in Belgium.

Table 6 Energy Consumption of Industry Sector in 2013 by industry – Belgium.

	TWH	%
Industry	170.499	-
Iron & steel industry	38.722	22.71
Chemical and Petrochemical industry	45.231	26.53
Non-ferrous metal industry	4.935	2.89
Non-metallic Minerals (Glass, pottery & building mat. Industry)	21.214	12.44
Transport Equipment	6.121	3.59
Machinery	2.070	1.21
Mining and Quarrying	0.604	0.35
Food and TOBACCO	21.709	12.73
Paper, Pulp and Print	12.008	7.04
Wood and Wood Products	3.968	2.33
Construction	3.223	1.89
Textile and Leather	3.187	1.87
Non-specified (Industry)	7.507	4.40

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Bulgaria



Capital: Sofia

Geographical size: 111 002 km²

Population: 7 245 677 (2014)

Population as % of EU population: 1.4 % (2014)

GDP: € 42.011 billion (2014)

Official EU language(s): Bulgarian

Currency: Bulgarian lev BGN

Industries: electricity, gas, water, food, beverages, tobacco, machinery and equipment, base metals, chemical products, coke, refined petroleum, nuclear fuel



Bulgaria, officially the Republic of Bulgaria, is a country in the southeastern Europe and the southeast of the Balkans. It is in boarder with Romania to the north, Serbia and FYROM to the west, Greece and Turkey to the south, and the Black sea to the east.

Bulgaria's capital is Sofia and the country's population in 2015 was 7202198 habitats with 30621000 households, GPD at 2014 exchange rate is €42,750.9 million. The country is part of the EU since 1st of January 2007 (Eurostat) and is not a member of the Schengen Area.

The economy's most important sectors in 2014 were industry (23.5%), wholesale and retail trade, transport, accommodation and food services (21.3%), defense, education, human and health social work activities (13.2%).

Energy Consumption of Country

Bulgaria consumed 99.98 TWh of energy in 2013 which is lower than the previous 3 years. The energy consumption for each sector from 2009 to 2013 for Bulgaria is shown in Table 7. It can be noticed that the highest energy consumed sector in 2013 is the transport, followed by the industry and the residential sector. The agriculture sector is observed to be the lowest consuming sector where the tertiary sector is second to lowest.

Table 7 Energy Consumption by Sector –Bulgaria.

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	28.23	29.73	31.41	29.97	29.99
Final consumption of transport	TWh	32.26	31.84	31.65	33.38	30.28
Final consumption of residential	TWh	24.99	26.3	27.8	27.87	26.24
Final consumption of agriculture	TWh	2.14	2.14	2.4	2.31	2.26
Final consumption of tertiary	TWh	10.93	11.48	12.08	11.63	11.21
Total final consumption	TWh	98.55	101.49	105.34	105.16	99.98

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Bulgaria's main industry sectors are energy, tourism, transportation, IT and telecommunications, food and beverage, pharmaceuticals, and textile and clothing. In the past, few of the main industries were metallurgy, machine manufacture and chemicals where due to technology advancement these sectors have reduced in the recent years.

Bulgaria exports Refined Petroleum, Refined Copper, Raw Copper, Wheat and Packaged Medicaments, and the country's top imports are Crude Petroleum, Copper Ore, Refined Petroleum, Petroleum Gas and Packaged Medicaments. The top export destinations of Bulgaria are Germany, Italy, Turkey, Romania and Greece and the import origins are Russia, Germany, Italy, Romania and Turkey.

Energy Consumption of the Country's Industry

The industrial sector plays an important role on the country's energy consumption and it can be further analyzed by source/fuel. The energy consumption of the industrial sector by fuel from 2009 to 2013 is presented in Table 8. It can be observed that the most consumed source is the Gas followed by electricity. The coal and the oil products consumption are the least consumed sources and the renewable consumption is showing an increase in the last 5 years.

Table 8 Energy consumption of Industry by fuel/source- Bulgaria.

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	2.36	2.5	2.38	1.98	1.87
Oil products consumption of industry	TWh	4.24	3.72	2.48	2.4	2.38
Gas consumption of industry	TWh	6.97	8.09	9.84	8.83	8.79
Heat consumption of industry	TWh	5.29	5.58	6.05	6.02	5.52
Renewable consumption of industry	TWh	0.94	2.01	2.22	2.51	2.9
Electricity consumption of industry	TWh	8.43	7.83	8.44	8.23	8.52
Final consumption of industry	TWh	28.23	29.73	31.41	29.97	29.99
	Unit	2009	2010	2011	2012	2013

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

A further analysis of the country's industry sectors is presented in Table 9 where the highest consumption is observed in the chemical and petrochemical industry followed by the non-metallic minerals (glass, pottery and building materials). The transport equipment and the wood and wood products are consuming the least amount of energy.

Table 9 Energy Consumption of Industry Sector in 2013 by industry – Bulgaria.

	TWh	%
Industry	30.11	-
Iron & steel industry	1.15	3.83
Chemical and Petrochemical industry	9.09	30.20
Non-ferrous metal industry	1.70	5.63
Non-metallic Minerals (Glass, pottery & building mat. Industry)	5.76	19.13
Transport Equipment	0.19	0.64
Machinery	1.38	4.57
Mining and Quarrying	1.07	3.55
Food and TOBACCO	2.79	9.26
Paper, Pulp and Print	2.92	9.69
Wood and Wood Products	0.67	2.23
Construction	0.81	2.69
Textile and Leather	0.78	2.58
Non-specified (Industry)	1.80	5.98

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Croatia



Capital: Zagreb

Geographical size: 56 594 km²

Population: 4 246 700 (2014)

Population as % of EU population: 0.8 % (2014)

GDP: € 43.085 billion (2014)

Official EU language(s): Croatian

Currency: Croatian Kuna HRK

Industries: chemicals and plastics, machine tools, fabricated metal, electronics, pig iron and rolled steel products, aluminum, paper, wood products, construction materials, textiles, shipbuilding, petroleum and petroleum refining, food and beverages, tourism



Croatia, officially the Republic of Croatia, is a sovereign state in central Europe. It is in border with Bosnia and Herzegovina and Montenegro in the south, Serbia and Hungary on the east, Slovenia on the north and the Adriatic Sea in the west.

Croatia's capital is Zagreb and the country's population in 2014 was 4,246,700. The country's GDP was € 43.085 billion in 2014, it has been an EU member since 1st of July 2013 and is not a member of the Schengen area.

Croatia's sectors with the highest impact factor on economy in 2014 were wholesale and retail trade, transport, accommodation and food services (21.2 %), industry (21.1 %) and public administration, defense, education, human health and social work activities (15.4 %). The general touristic sector plays an important factor on the country's economy with approximately 10 million foreign visitors per year.

Energy Consumption of Country

Croatia's total energy consumption in 2013 was reported at 76.43 TWh and is presented in Table 10 with the energy consumption of the country's different sectors from 2009 to 2013. The highest energy consumption is observed is the residential sector followed by the transport sector. The sector with the least amount of energy consumed is the agriculture where the industry sector is noticed close to the average of the country's sectors. The total energy consumption has been reduced in the in the past 5 years.

Table 10 Energy Consumption by Sector –Croatia.

	Unit	2009	2010	2011	2012	2013
<i>Final consumption of industry</i>	TWh	16.69	16.18	15.07	13.38	13.06
<i>Final consumption of transport</i>	TWh	24.91	24.06	23.67	23.3	23.68
<i>Final consumption of residential</i>	TWh	30.62	32.03	30.57	29.61	28.82
<i>Final consumption of agriculture</i>	TWh	2.91	2.85	2.91	2.67	2.64
<i>Final consumption of tertiary</i>	TWh	8.35	8.8	8.75	8.42	8.23
<i>Total final consumption</i>	TWh	83.47	83.93	80.97	77.37	76.43

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Croatia's leading industrial branches consist of the production of food, drinks and tobacco, followed by the chemical and oil industries. Croatia's export partners consist of Italy, Bosnia & Herzegovina and Slovenia. The country's export activities are related to the processing of oil products, motor vehicles, chemical products, food production, electrical equipment, machinery, finished metal products, pharmaceutical products, clothing, and timber and wood products (Miroslav Krleža, 2015). The main import partners consist of Germany, Italy and Slovenia.

Energy Consumption of the Country's Industry

Croatia's industry consumption by source/fuel is presented in Table 11 from 2009 to 2013. The gas as fuel has the highest consumption while electricity follows. The least consumption by fuel is reported to be the coal and the renewable sources. The energy consumed from electricity is relatively steady in the last 5 years (as seen in the figure) but the consumption from the gas fuel has been reduced.

Table 11 Energy consumption of Industry by fuel/source- Estonia.

	Unit	2009	2010	2011	2012	2013
<i>Coal consumption of industry</i>	TWh	1.48	1.73	1.62	1.46	1.3
<i>Oil products consumption of industry</i>	TWh	4.49	3.6	3.3	2.97	3.27
<i>Gas consumption of industry</i>	TWh	5.89	5.96	5.62	4.56	4.09
<i>Heat consumption of industry</i>	TWh	0.5	0.53	0.55	0.59	0.6
<i>Renewable consumption of industry</i>	TWh	0.71	0.68	0.57	0.69	0.63
<i>Electricity consumption of industry</i>	TWh	3.61	3.67	3.41	3.1	3.19
<i>Final consumption of industry</i>	TWh	16.69	16.18	15.07	13.38	13.06

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

The country's industry sectors are presented in Table 12. The highest consumption is observed in the Non-metallic Minerals (Glass, pottery & building mat. Industry) sector followed by the Food and TOBACCO. In addition, the Chemical and Petrochemical industry is consuming a high percentage energy. The least amount of energy is being consumed by the transport equipment industry and the non-ferrous metal industry.

Table 12 Energy Consumption of Industry Sector in 2013 by industry – Croatia.

	TWh	%
<i>Iron & steel industry</i>	0.29	2.24
<i>Chemical and Petrochemical industry</i>	1.60	12.29
<i>Non-ferrous metal industry</i>	0.17	1.33
<i>Non-metallic Minerals (Glass, pottery & building mat. Industry)</i>	3.89	29.94
<i>Transport Equipment</i>	0.16	1.26
<i>Machinery</i>	0.67	5.17
<i>Mining and Quarrying</i>	0.25	1.93
<i>Food and TOBACCO</i>	2.54	19.59
<i>Paper, Pulp and Print</i>	0.66	5.10
<i>Wood and Wood Products</i>	0.41	3.12
<i>Construction</i>	1.29	9.92
<i>Textile and Leather</i>	0.33	2.50

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Cyprus



Capital City: Nicosia

Geographical Size: 9,251 km²

Population: 858,000 (2014 est.)
(not including Turkish occupied area)

Population as % of EU population:
0.2% (2014 est.)

GDP: €17.506 billion (2014 est.)
(not including Turkish occupied area)

Official Languages: Greek, Turkish

Currency: Euro €

Industries: tourism, food and beverage processing, cement and gypsum, ship repair and refurbishment, textiles, light chemicals, metal products, wood, paper, stone and clay products, copper, furniture.



Cyprus is an EU member state since 1st of May 2004. The island covers an area of 9,251 km² and is the third largest island in the Mediterranean Sea after the Italian islands of Sicily and Sardinia. It is also the world's 81st largest island by area and world's 51st largest by population. The neighboring territories are Turkey within 57 km to the north, Syria 105 km to the east, Lebanon 108 km to the east, Israel 200 km southeast, Egypt 380 km to the south and Greece 280 km to the north (europa.eu, 2015).

The Republic of Cyprus is divided into six districts: Nicosia, Famagusta, Kyrenia, Larnaca, Limassol and Paphos. Geopolitically, the island is subdivided into four main segments. The Republic of Cyprus occupies the southern two-thirds of the island (59.74%). The Turkish Occupied Area covers the northern one third (34.85%) of the island. Lastly, two bases under British sovereignty are located on the island: Akrotiri and Dhekelia, covering the remaining 2.74%.

Energy Consumption of Country

Cyprus consumed 18.54 TWh of primary energy in 2013 which is lower than the previous 4 years. Table 13 shows the energy consumption by sector for Cyprus from 2009 to 2013. As can be observed, the transport sector is the biggest consumer of energy, the second bigger is the tertiary sector and third the industry.

Table 13 Energy Consumption by Sector –Cyprus.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	3.11	2.89	2.43	1.95	2.04
FINAL CONSUMPTION OF TRANSPORT	TWh	12.32	12.37	12.45	11.51	10.34
FINAL CONSUMPTION OF RESIDENTIAL	TWh	3.98	3.73	3.84	3.79	3.32
FINAL CONSUMPTION OF AGRICULTURE	TWh	0.45	0.46	0.43	0.48	0.43
FINAL CONSUMPTION OF TERTIARY	TWh	2.62	2.66	2.79	2.59	2.42
TOTAL FINAL CONSUMPTION	TWh	22.47	22.11	21.94	20.32	18.54

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Cyprus main industries are tourism, food and beverage processing, cement and gypsum, ship repair and refurbishment, textiles, light chemicals, metal products, wood, paper, stone and clay products (CIA, 2015). Industries are numerous and small in scale, 95% of them employing fewer than 10 workers. Working owners make up a large part of the industrial labor force. Manufacturing, which accounts for about 10.6% of GDP, and employs 9.1% of the labor force, is dominated by small enterprises. The manufacturing sector of industrial production has declined in absolute value over 10% from its peak in 1992, reflecting declines in the traditional leaders, textiles and food processing. Textiles, the leading manufacturing industry since 1974, has declined in output value about 50% since a peak reached in 1988, whereas food processing (food, beverages and cigarettes) has declined about 15% from a peak reached in 1992. The manufacture of non-metallic mineral products has also declined, about 7% from peak levels in 1994–1995. Growth has occurred among nontraditional manufactures in the areas of chemicals, petroleum, rubber and plastics, up over 25% in the decade. Other industrial sectors have increased strongly: mining and quarrying is up nearly 60% since 1990 and the production of electricity, gas, and water treatment, increased nearly 80%. According to CIA estimates, overall industrial production grew 2.2% in 1999 in the Greek Cypriot area, but was declined an estimated 0.3% in the Turkish area. The leading products are textiles, shoes, cement mosaic tiles and cigarettes. Major plants include modern flour mills, tire-treading factories, knitting mills, preprocessing facilities, and a petroleum refinery. Furniture and carts are also manufactured.

Nine industrial estates have been established. In both the Greek and Turkish areas of Cyprus, industry accounts for about 20% of GDP and employs about 22% of the labor force.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 14 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the most consumed source is the electricity and then the renewables. The consumption of coal, oil and gas in the industrial sector is zero for the last years.

Table 14 Energy consumption of Industry by fuel/source- Cyprus.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	0.21	0.26	0.1	0	0
TOTAL PRIMARY CONSUMPTION	TWh	2	1.69	1.44	1.27	1.44
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	0	0	0	0	0
GAS CONSUMPTION OF INDUSTRY	TWh	0	0	0	0	0
HEAT CONSUMPTION OF INDUSTRY	TWh	0.07	0.09	0.08	0.04	0.01
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	0.83	0.85	0.8	0.64	0.59
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	3.11	2.89	2.43	1.95	2.04
FINAL CONSUMPTION OF INDUSTRY	TWh	0.21	0.26	0.1	0	0

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 15 shows the consumption of industrial sector by each industry. As can be observed, the biggest consumer is the non-metallic minerals (glass, pottery and building materials) and the second bigger consumer the food and TOBACCO industry.

Table 15 Energy Consumption of Industry Sector in 2013 by industry – Cyprus.

	TWH	%
Industry	2.170	-
Iron & steel industry	0.002	0.09%
Chemical and Petrochemical industry	0.047	2.16%
Non-ferrous metal industry	0.000	0.00%

Non-metallic Minerals (Glass, pottery & building mat. Industry)	1.550	71.42%
Transport Equipment	0.002	0.09%
Machinery	0.020	0.92%
Mining and Quarrying	0.077	3.53%
Food and TOBACCO	0.324	14.94%
Paper, Pulp and Print	0.016	0.74%
Wood and Wood Products	0.005	0.23%
Construction	0.042	1.93%
Textile and Leather	0.006	0.28%
Non-specified (Industry)	0.079	3.66%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Czech Republic



Capital City: Prague

Geographical Size: 78,867 km²

Population: 10,512,419 (2014 est.)

Population as % of EU population: 2.1% (2014 est.)

GDP: €154.739 billion

Official Languages: Czech

Currency: Czech koruna (CZK)

Industries: motor vehicles, metallurgy, machinery and equipment, glass, armaments



Czech Republic is located in Central Europe and is a member of the European Union, since 1st May 2004. Czech Republic has not joined the Eurozone and runs its own currency which is known as Czech koruna (CZK). Since 1993 is a separate state once Czechoslovakia was split in two states. The capital of the Czech Republic is Prague and its official language is Czech ("EUROPA - EU member countries," 2016).

The recorded population and GDP in 2014 were 10,512,419 and €154,739 billion, respectively. Its total area coverage is 78,867 km² and the 32.6 % of the Czech economy corresponds to the industrial sector, in 2014 ("EUROPA - EU member countries," 2016).

Energy Consumption of Country

Czech Republic's total final energy consumption, in 2013, was 277.27 TWh. Table 16 shows the final energy consumption by sector in Czech Republic from 2009 up to 2013. As can be seen in the table, industry consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the table it can be concluded that the percentage share of the final energy consumption for each sector is 31.59% for industry, 25.31% for transport, 25.31% for residential, 13.03% for tertiary and 2.56% for agriculture, in 2013.

Table 16 Energy Consumption by Sector – Czech Republic.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	94.83	92.25	91.92	88.06	87.6
FINAL CONSUMPTION OF TRANSPORT	TWh	76.69	72.97	73.2	71.15	70.19
FINAL CONSUMPTION OF RESIDENTIAL	TWh	70.92	77.5	69.58	70.8	73.25
FINAL CONSUMPTION OF AGRICULTURE	TWh	5.98	6.45	6.53	6.75	7.09
FINAL CONSUMPTION OF TERTIARY	TWh	34.19	36.49	35.22	35.38	36.13
TOTAL FINAL CONSUMPTION	TWh	285.13	288.82	279.57	275.2	277.27

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Czech Republic has a variety of industries each of them playing an important role to the economy of the country. The most important ones are motor vehicles, metallurgy, machinery and equipment, glass and armaments (“CIA - The World Factbook,” 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively (“SPF Economie,” 2016).

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 17 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is the electricity and the most consumed fuel is gas. The less consumed energy in industry is the energy from renewables. Although that shows upward trend from year to year, it is still the less consumed energy.

Table 17 Energy consumption of Industry by fuel/source- Czech Republic

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	29.08	20.37	21.7	19.76	19.7
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	4.24	4.56	4.06	3.7	2.74
GAS CONSUMPTION OF INDUSTRY	TWh	27.31	31.42	29.59	27.97	28.89
HEAT CONSUMPTION OF INDUSTRY	TWh	6.18	6.99	7.19	7.47	6.54
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	6.19	6.31	6.16	6.47	6.74
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	21.82	22.59	23.21	22.69	23
FINAL CONSUMPTION OF INDUSTRY	TWh	94.83	92.25	91.92	88.06	87.6

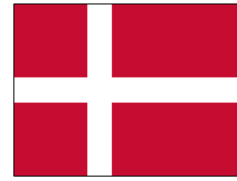
Source: (Odyssee, 2015)

It is also important to see the sectors of industry that the energy is consumed. Table 18 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the iron and steel industry whereas on the other hand, non-ferrous metal industry consumes the least energy. It can also be concluded that iron and steel, chemical and petrochemical and non-metallic minerals (glass, pottery & building mat.) are the most important industries in Czech Republic.

Table 18 Energy Consumption of Industry Sector in 2013 by industry – Czech Republic

	TWH	%
Industry	122.799	-
Iron & steel industry	33.979	27.67
Chemical and Petrochemical industry	16.474	13.42
Non-ferrous metal industry	0.991	0.81
Non-metallic Minerals (Glass, pottery & building mat. Industry)	15.695	12.78
Transport Equipment	7.429	6.05
Machinery	11.852	9.65
Mining and Quarrying	1.332	1.08
Food and TOBACCO	9.032	7.36
Paper, Pulp and Print	9.516	7.75
Wood and Wood Products	3.552	2.89
Construction	3.225	2.63
Textile and Leather	2.175	1.77
Non-specified (Industry)	7.546	6.15

Denmark



Capital: Copenhagen

Geographical size: 42,921 km²

Population: 5,627,235 (2014)

Population as % of EU population: 1.1 % (2014)

GDP: € 257.444 billion (2014)

Official EU language(s): Danish

Currency: Danish krone DKK

Industries: iron, steel, nonferrous metals, chemicals, food processing, machinery and transportation equipment, textiles and clothing, electronics, construction, furniture and other wood products, shipbuilding and refurbishment, windmills, pharmaceuticals, medical equipment.



Denmark is a country in Northern Europe. The southernmost of the Nordic countries, it is southwest of Sweden and south of Norway, and bordered to the south by Germany. Denmark is part of Scandinavia, together with Sweden and Norway. Denmark has an area of 42,921 square kilometres and a population of 5,627,235 (2014)(1.1% of total EU population). Denmark has a high-income economy that ranks 18th in the world in terms of GDP (PPP) per capita and 6th in nominal GDP per capita – As of 2014 (GDP: € 257.444 billion). Denmark is the 13th most competitive economy in the world, and 8th in Europe, according to the World Economic Forum in its Global Competitiveness Report 2014–2015. Denmark's currency, the krone (DKK), is pegged at approximately 7.46 kroner per euro through the ERM. It is an EU member state since January 1973 (Central Intelligence Agency, 2016), (Europa, 2016).

Energy Consumption of Country

Denmark consumed 166 TWh in 2013 which is lower than the previous 4 years. The energy consumption for each sector from 2009 to 2013 for Denmark is shown in Table 19. The transport sector is the bigger consumer and then the residential sector and the industrial sector.

Table 19 Energy Consumption by Sector – Denmark

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	27.7	28.68	28.67	27.43	26.65
Final consumption of transport	TWh	57.87	58.25	58.39	56.87	56.17
Final consumption of residential	TWh	52.39	58.08	52.1	51.63	51.31
Final consumption of agriculture	TWh	9.94	10.07	9.57	9.03	8.91
Final consumption of tertiary	TWh	23.22	24.75	22.66	23.04	22.96
Total final consumption	TWh	171.13	179.82	171.39	167.99	166

Source: (Odyssey, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Denmark's major industries are iron, steel, nonferrous metals, chemicals, food processing, machinery and transportation equipment, textiles and clothing, electronics, construction, furniture and other wood products, shipbuilding and refurbishment, windmills, pharmaceuticals and medical equipment.

Denmark is a leading producer of pork, and the largest exporter of pork products in the EU. Since 1945 Denmark has greatly expanded its industrial base so that by 2006 industry contributed about 25% of GDP. 70% of trade flows are inside the European Union. As of 2011, Denmark has the 10th highest export per capita in the world. Denmark's major industries include chemicals, food processing, shipbuilding, pharmaceuticals, and construction. The country's main exports are: industrial production/manufactured goods 73.3% (of which machinery and instruments were 21.4%, and fuels (oil, natural gas), chemicals, etc. 26%); agricultural products and others for consumption 18.7% (in 2009 meat and meat products were 5.5% of total export; fish and fish products 2.9%).

Energy Consumption of the Country's Industry

Table 20 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be observed, after the electricity, the more consumed fuels are gas and oil products. The less consumed energy in industry is the heat.

Table 20 Energy consumption of Industry by fuel/source – Denmark

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	1.09	1.22	1.34	1.01	1.08
Oil products consumption of industry	TWh	6.3	6.41	6.07	5.64	5.04
Gas consumption of industry	TWh	7.72	8.32	8.32	7.95	7.85
Heat consumption of industry	TWh	1.36	1.35	1.29	1.29	1.29
Renewable consumption of industry	TWh	2.78	2.77	2.93	2.94	2.98
Electricity consumption of industry	TWh	8.45	8.62	8.72	8.59	8.4
Final consumption of industry	TWh	27.7	28.68	28.67	27.43	26.65

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 21 shows the consumption of each industrial sector. As can be seen, the biggest consumer is the food and TOBACCO, followed by non-metallic minerals and machinery.

Table 21 Energy Consumption of Industry Sector in 2013 by industry – Denmark

	TWH	% of total industry
Industry (total)	26.024	100.00%
Iron & steel industry	0.511	1.96%
Chemical and Petrochemical industry	2.846	10.93%
Non-ferrous metal industry	0.000	0.00%
Non-metallic Minerals (Glass. pottery & building mat. Industry)	4.353	16.73%
Transport Equipment	0.393	1.51%
Machinery	3.215	12.35%
Mining and Quarrying	0.729	2.80%
Food and TOBACCO	7.266	27.92%
Paper. Pulp and Print	1.967	7.56%
Wood and Wood Products	1.031	3.96%
Construction	1.831	7.04%
Textile and Leather	0.289	1.11%
Non-specified (Industry)	1.594	6.13%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Estonia



Capital: Tallinn

Geographical size: 45 227 km²

Population: 1 315 819 (2014)

Population as % of EU population: 0.3 % (2014)

GDP: € 19.525 billion (2014)

Official EU language: Estonian

Currency: Euro

Industries: engineering, electronics, wood and wood products, textiles; information technology, telecommunications



Estonia, officially the Republic of Estonia, is in the Baltic region and in north Europe. It is in boarder with the Gulf of Finland on the north, the Baltic Sea on the west, Latvia on the south and Lake Peipus and Russia on the east.

Estonia's capital is Tallinn and the country's population in 2014 was 1,315,819 habitants, with GPD of € 19.525 billion. Estonia is an EU member since 1st of May 2004 and is member of the Schengen area.

The economy's most important sectors in 2014 were wholesale and retail trade, transport, accommodation and food services (22.5 %), industry (21.1 %) and public administration, defense, education, human health and social work activities (15.4 %). The country's top export destinations are Sweden, Finland and Latvia, while the import partners are Finland, Germany and Sweden.

Energy Consumption of Country

Estonia's energy consumption in 2013 was 32.7 TWh and is relative constant in the past 5 years. The energy consumption for each sector from 2009 to 2013 for Estonia is shown in Table 22. The highest energy consumption is noticed on the residential sector followed by the transport sector. The lowest consumption is observed in the agriculture sector with the tertiary second to last. The industry's energy consumption is observed to be relative low compared to the residential sector.

Table 22 Energy Consumption by Sector –Estonia.

	Unit	2009	2010	2011	2012	2013
<i>Final consumption of industry</i>	TWh	6.27	6.68	7.06	6.66	6.82
<i>Final consumption of transport</i>	TWh	8.65	9.13	9.07	9.2	8.86
<i>Final consumption of residential</i>	TWh	11.29	11.95	10.89	11.3	10.87
<i>Final consumption of agriculture</i>	TWh	1.08	1.1	1.26	1.28	1.27
<i>Final consumption of tertiary</i>	TWh	4.89	4.96	4.7	4.97	4.89
<i>Total final consumption</i>	TWh	32.15	33.8	32.97	33.39	32.7

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Estonia's industry concludes of oil shale mining, shipbuilding, phosphates, electric motors, excavators, cement, furniture, clothing, textiles, paper, shoes, and apparel. Estonia has been growing the industry's sector mostly on the electronics, cement, chemicals, and forest products and supplies electronic components to leading Scandinavian telecommunications companies and suppliers. The low taxes, low labor costs and trained workforce attracts foreign investors and is ideal for electronics manufacturing.

Energy Consumption of the Country's Industry

Further analysis on the industry's source/fuel is presented in Table 23 from 2009 to 2013. It can be observed that the industry's fuel/source is highly depended on electricity with the gas consumption following. The consumption from renewable energy has reduced in the last 2 years. The lowest consumption is observed from the heat and oil products.

Table 23 Energy consumption of Industry by fuel/source- Estonia.

	Unit	2009	2010	2011	2012	2013
<i>Coal consumption of industry</i>	TWh	1.05	0.83	1.29	0.98	0.84
<i>Oil products consumption of industry</i>	TWh	0.63	0.71	0.7	0.81	0.76
<i>Gas consumption of industry</i>	TWh	1.14	1.33	1.32	1.39	1.7
<i>Heat consumption of industry</i>	TWh	0.5	0.51	0.43	0.42	0.38
<i>Renewable consumption of industry</i>	TWh	1	1.21	1.27	0.89	0.98
<i>Electricity consumption of industry</i>	TWh	1.94	2.09	2.05	2.19	2.16
<i>Final consumption of industry</i>	TWh	6.27	6.68	7.06	6.66	6.82

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

The country's industry sectors are presented in Table 24. The highest consumption is observed in the Non-metallic Minerals (Glass, pottery & building mat. Industry) sector followed by the wood and wood products. The iron and steel industry is not consuming any form of energy since it does not play any role in the country's industry sector, and the Non-ferrous metal industry is consuming the least amount of energy.

Table 24 Energy Consumption of Industry Sector in 2013 by industry – Estonia.

	TWh	%
<i>Iron & steel industry</i>	0.00	0.00
<i>Chemical and Petrochemical industry</i>	0.87	11.57
<i>Non-ferrous metal industry</i>	0.03	0.38
<i>Non-metallic Minerals (Glass, pottery & building mat. Industry)</i>	1.98	26.40
<i>Transport Equipment</i>	0.14	1.86
<i>Machinery</i>	0.47	6.23
<i>Mining and Quarrying</i>	0.17	2.20
<i>Food and TOBACCO</i>	0.75	9.95
<i>Paper, Pulp and Print</i>	0.71	9.46
<i>Wood and Wood Products</i>	1.35	17.96
<i>Construction</i>	0.56	7.53
<i>Textile and Leather</i>	0.16	2.16
<i>Non-specified (Industry)</i>	0.32	4.25

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Finland



Capital: Helsinki

Geographical size: 338,435 km²

Population: 5,451,270 (2014)

Population as % of EU population: 1.1% (2014)

GDP: € 205.178 billion (2014)

EU language(s): Finnish, Swedish

Currency: Euro

Industries: metals and metal products, electronics, machinery and scientific instruments, shipbuilding, pulp and paper, foodstuffs, chemicals, textiles, clothing



Finland is one of the five Nordic countries and the northernmost country in the EU. Finland is bordered by Sweden to the west, Norway to the north and Russia to the east. Finland's population is about 5.5 million (1.1% of total EU population in 2014). In terms of area, it is the eighth largest country in Europe and the most sparsely populated country in the European Union with geographical size of 338,435 square kilometers. The country joined the European Union in 1995 and the Eurozone on 1 January 1999. The economy of Finland has a per capita output equal to that of other European economies such as France, Germany, Belgium, or the UK. The largest sector of the economy is services at 66%, followed by manufacturing and refining at 31%. Primary production is 2.9%. With respect to foreign trade, the key economic sector is manufacturing. The largest industries in 2007 were electronics (22%), machinery, vehicles, and other engineered metal products (21.1%), forest industry (13%) and chemicals (11%) (Central Intelligence Agency, 2016), (Europa, 2016).

Energy Consumption of Country

The table below shows the energy consumption of Finland by each sector (industry, transport, residential, agriculture and tertiary) for the period 2009 to 2013. The big sectors in 2013 considering the energy consumption of the country were the industry, the residential and the transport. Furthermore, agriculture consumes the least energy.

Table 25 Energy Consumption by Sector – Finland

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	132.17	149.45	147.46	141.91	145.21
Final consumption of transport	TWh	55.73	58.07	57.63	58.6	59.47
Final consumption of residential	TWh	62.5	67.98	59.7	65.3	61.64
Final consumption of agriculture	TWh	9.68	10.17	9.22	9.76	9.83
Final consumption of tertiary	TWh	32.93	35.02	32.32	34.18	33.56
Total final consumption	TWh	292.32	320.12	305.79	308.42	309.72

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

The most important sectors of Finland's economy in 2014 were public administration, defense, education, human health and social work activities (22.2%), industry (19.8%) and wholesale and retail trade, transport, accommodation and food services (16.5%).

Forests play a key role in the country's economy, making it one of the world's leading wood producers and providing raw materials at competitive prices for the crucial wood-processing industries. As in agriculture, the government has long played a leading role in forestry, regulating tree cutting, sponsoring technical improvements, and establishing long-term plans to ensure that the country's forests continue to supply the wood-processing industries.

Initially, most development was based on two broad groups of export-led industries, the "metal industry" and "forest industry". The "metal industry" includes shipbuilding, metalworking, the car industry, engineered products such as motors and electronics, and production of metals (steel, copper and chromium). The "forest industry" includes forestry, timber, pulp and paper, and is a logical development based on Finland's extensive forest resources (77% of the area is covered by forest, most of it in renewable use). However, the Finnish economy has diversified, with expansion into fields such as

electronics, metrology, transport fuels, chemicals, engineering consulting and information technology.

Energy Consumption of the Country's Industry

Table 26 presents the energy consumption of the industrial sector of Poland by fuel for the period 2009 until 2013. Renewable energy consumption is the biggest source in industry, followed by electricity and oil products consumption. The less consumed energy in industry is the heat.

Table 26 Energy consumption of Industry by fuel/source – Finland

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	13.66	16.55	16.89	15.26	14.4
Oil products consumption of industry	TWh	20.28	21.97	21.55	19.23	19.18
Gas consumption of industry	TWh	15.89	16.46	16.22	14.01	13.4
Heat consumption of industry	TWh	1.14	1.54	1.33	1.33	1.3
Renewable consumption of industry	TWh	43.91	51.48	51.13	52.77	57.11
Electricity consumption of industry	TWh	37.3	41.46	40.35	39.31	39.83
Final consumption of industry	TWh	132.17	149.45	147.46	141.91	145.21

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

As can be observed from Table 27, the largest industrial sector by energy consumption in Finland is the paper and printing with 54.55% of total consumption of industry. This results from the forest industry that mentioned before. The textile and leather industries and transport equipment consume the least energy considering all sectors.

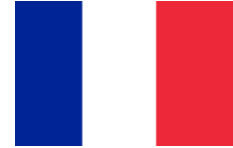
Table 27 Energy Consumption of Industry Sector in 2013 by industry – Finland

	TWH	% of total industry
Industry	125.489	100.00%
Iron & steel industry	13.064	10.41%
Chemical and Petrochemical industry	12.191	9.72%
Non-ferrous metal industry	3.475	2.77%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	3.100	2.47%
Transport Equipment	0.733	0.58%
Machinery	3.332	2.66%
Mining and Quarrying	1.841	1.47%
Food and TOBACCO	4.044	3.22%
Paper, Pulp and Print	68.455	54.55%
Wood and Wood Products	7.181	5.72%
Construction	4.628	3.69%
Textile and Leather	0.392	0.31%
Non-specified (Industry)	3.053	2.43%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

France



Capital City: Paris

Geographical Size: 632,833 km²

Population: 65,856,609 (2014 est.)

Population as % of EU population: 13 % (2014 est.)

GDP: €2.132 trillion.

Official Languages: French

Currency: € Euro

Industries: machinery, chemicals, automobiles, metallurgy, aircraft, electronics, textiles, food processing, tourism



France is located in Western Europe and is a member of the European Union, since 1st January 1958. It has joined the Eurozone, since 1st January 1999. France is the largest country of the Union and its borders are between the North Sea and the Mediterranean. The capital of France is Paris and the official language is French ("EUROPA - EU member countries," 2016).

The recorded population and GDP in 2014 were 65,856,609 and € 2.132 trillion, respectively, making the country one of the most important economies in the world. Its total area coverage is 632,833 km² and the 13.8 % of the French economy corresponds to the industrial sector, in 2014 ("EUROPA - EU member countries," 2016).

Energy Consumption of Country

France's total final energy consumption, in 2013, was 1780.98 TWh. Table 1 shows the final energy consumption by sector in France from 2009 up to 2013. As can be seen in the table, transport consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the table it can be concluded that the percentage share of the final energy consumption for each sector is 18.98 % for industry, 31.82% for transport, 27.77% for residential, 15.41% for tertiary and 3.08% for agriculture, in 2013.

Table 28 Energy Consumption by Sector – France.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	350.77	363.02	357.31	347.23	338.06
FINAL CONSUMPTION OF TRANSPORT	TWh	569.91	571.29	572.87	570.37	566.78
FINAL CONSUMPTION OF RESIDENTIAL	TWh	492.25	531.74	439.19	482.53	494.61
FINAL CONSUMPTION OF AGRICULTURE	TWh	51.79	51.78	52.58	52.17	54.88
FINAL CONSUMPTION OF TERTIARY	TWh	260.19	288.99	244.65	264.58	274.5
TOTAL FINAL CONSUMPTION	TWh	1761.3	1824.88	1709.59	1757.75	1780.98

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

France has a variety of industries each of them playing an important role to the economy of the country. The most important ones are machinery, chemicals, automobiles, metallurgy, aircraft, electronics, textiles, food processing and tourism ("CIA - The World Factbook," 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively ("SPF Economie," 2016).

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 29 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is electricity and the most consumed fuel is gas. The less consumed energy in industry is the energy from renewables. Although that shows upward trend from year to year, it is still the less consumed energy.

Table 29 Energy consumption of Industry by fuel/source- France.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	52.39	62.1	59.16	57.45	60.29
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	38.79	35.49	38.37	33.94	28.41
GAS CONSUMPTION OF INDUSTRY	TWh	123.67	126.5	123.77	119.19	110.37
HEAT CONSUMPTION OF INDUSTRY	TWh	n.a.	n.a.	n.a.	n.a.	n.a.
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	19.02	17.99	16.84	18.25	21.67
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	116.91	120.95	119.17	118.39	117.33
FINAL CONSUMPTION OF INDUSTRY	TWh	350.77	363.02	357.31	347.23	338.06

Source: (Odyssee, 2015), Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 30 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the iron and steel industry whereas on the other hand, mining and quarrying industry consumes the least energy. It can also be concluded that iron and steel, chemical and petrochemical and non-metallic minerals (glass, pottery & building mat.) industries are the most important industries in France.

Table 30 Energy Consumption of Industry Sector in 2013 by industry – France

	TWH	%
Industry	489.413	-
Iron & steel industry	90.301	18.45
Chemical and Petrochemical industry	84.407	17.25
Non-ferrous metal industry	18.570	3.79
Non-metallic Minerals (Glass, pottery & building mat. Industry)	67.941	13.88
Transport Equipment	18.124	3.70
Machinery	32.085	6.56
Mining and Quarrying	4.410	0.90
Food and TOBACCO	80.422	16.43
Paper, Pulp and Print	44.737	9.14
Wood and Wood Products	9.621	1.97
Construction	18.213	3.72
Textile and Leather	4.987	1.02
Non-specified (Industry)	15.596	3.19

Germany



Capital City: Berlin

Geographical Size: 357 340 km²

Population: 80,780,000 (2014 est.)

Population as % of EU population: 15.9 % (2014 est.)

GDP: € 2.904 trillion.

Official Languages: German

Currency: € Euro

Industries: iron, steel, coal, cement, chemicals, machinery, vehicles, machine tools, electronics, automobiles, food and beverages, shipbuilding, textiles



Germany is located in Western Europe and is a member of the European Union, since 1958. It has joined the Eurozone in 1st January 1999. It is one of the largest country of the Union and its borders are between the North Sea and the Baltic Sea. The capital of Germany is Berlin and the official language is German (“EUROPA - EU member countries,” 2016).

The recorded population and GDP in 2014 were 80,780,000 – largest in the Union – and € 2.904 trillion, respectively, making it the richest country in the Union and one of the richest in the world. Its total area coverage is 357 340 km² and the 25.9 % of the German economy corresponds to the industrial sector, in 2014, which is the most important sector of the country (“EUROPA - EU member countries,” 2016).

Energy Consumption of Country

German’s total final energy consumption, in 2013, was 2553.51TWh. The following table shows the final energy consumption of Germany by sector from 2009 up to 2014. Table 1 shows the final energy consumption by sector in Germany from 2009 up to 2013. As can be seen in the table, transport consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the table it can be concluded that the percentage share of the final energy consumption for each sector is 29.39 % for industry, 28.45% for transport, 27.11% for residential and 12.60% for tertiary, in 2013.

Table 31 Energy Consumption by Sector – France.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	654.72	735.84	746.82	734.26	750.48
FINAL CONSUMPTION OF TRANSPORT	TWh	704.84	710.79	713.16	714.1	726.51
FINAL CONSUMPTION OF RESIDENTIAL	TWh	687.56	743.11	648.06	675.27	692.37
FINAL CONSUMPTION OF AGRICULTURE	TWh	41.04	48.38	45.97	46.44	n.a.
FINAL CONSUMPTION OF TERTIARY	TWh	322	345.85	308.11	305.47	321.67
TOTAL FINAL CONSUMPTION	TWh	2413.93	2585.4	2466.68	2495.72	2553.51

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Germany has a variety of industries each of them playing an important role to the economy of the country. The most important ones are iron, steel, coal, cement, chemicals, machinery, vehicles, machine tools, electronics, automobiles, food and beverages, shipbuilding and textiles (“CIA - The World Factbook,” 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 32 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is electricity and the most consumed fuel is gas. The less consumed energy in industry is the energy from renewables and heat. Although that shows upward trend from year to year, it is still the less consumed energy.

It is also important to see the sectors of industry that the energy is consumed. Table 33 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the iron and steel industry whereas on the other hand, mining and quarrying industry consumes the least energy. It can also be concluded that iron and steel, chemical and petrochemical and non-ferrous metal industries are the most important industries in Germany.

Table 32 Energy consumption of Industry by fuel/source- Germany..

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	88.05	110.62	113.07	110.39	111.21
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	45.38	43.65	38.4	38.47	42.54
GAS CONSUMPTION OF INDUSTRY	TWh	227.49	255.63	256.04	250	259.09
HEAT CONSUMPTION OF INDUSTRY	TWh	42.16	40.51	47.12	58.94	59.26
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	48.55	60.22	61.64	46.59	46.79
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	203.08	225.21	230.55	229.88	231.59
FINAL CONSUMPTION OF INDUSTRY	TWh	654.72	735.84	746.82	734.26	750.48

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Table 33 Energy Consumption of Industry Sector in 2013 by industry – Germany

	TWH	%
Industry	990.023	-
Iron & steel industry	218.696	22.09
Chemical and Petrochemical industry	231.650	23.40
Non-ferrous metal industry	31.870	3.22
Non-metallic Minerals (Glass, pottery & building mat. Industry)	105.294	10.64
Transport Equipment	50.690	5.12
Machinery	95.811	9.68
Mining and Quarrying	6.112	0.62
Food and TOBACCO	80.536	8.13
Paper, Pulp and Print	94.923	9.59
Wood and Wood Products	24.017	2.43
Construction	-----	-----
Textile and Leather	8.050	0.81
Non-specified (Industry)	42.373	4.28

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Greece



Capital City: Athens

Geographical Size: 131,957 km²

Population: 10,992,589 (2014 est.)

Population as% of EU population: 2.2% (2014 est.)

GDP: €179.081 billion (2014 est.)

Official Languages: Greek

Currency: Euro €

Industries: tourism, food and tobacco processing, textiles, chemicals, metal products; mining, petroleum.



Greece is known since ancient times as Hellas. Greece is an EU member state since 1st January 1981 and member of the Eurozone since 1st January 2001 (europa.eu, 2015). It covers a total area of 131,957 km² and is located in southeastern Europe.

Greece is strategically located at the crossroads of Europe, Asia, and Africa. Situated on the southern tip of the Balkan peninsula, it shares land borders with Albania to the northwest, the Republic of Macedonia and Bulgaria to the north and Turkey to the northeast. Greece consists of nine geographic regions: Macedonia, Central Greece, the Peloponnese, Thessaly, Epirus, the Aegean Islands (including the Dodecanese and Cyclades), Thrace, Crete, and the Ionian Islands. The Aegean Sea lies to the east of the mainland, the Ionian Sea to the west, and the Mediterranean Sea to the south. Greece has the longest coastline on the Mediterranean Basin and the 11th longest coastline in the world in length, featuring a vast number of islands, of which 227 are inhabited (CIA, 2015).

Greece is a developed country with high standards of living and high Human Development Index. Its economy mainly comprises the service sector, industry, and agriculture. Important Greek industries include tourism (7th most visited country in the European Union and 16th in the world) and merchant shipping, while the country is also a considerable agricultural producer (including fisheries) within the union.

Energy Consumption of Country

Greece consumed 176.87 TWh of primary energy in 2013 which is lower than the previous 4 years. Table 34 shows the energy consumption of Greece by sector from 2009 to 2013. As can be observed, the transport sector is the biggest consumer of energy, the second bigger is the residential sector and third the industry. As can be observed, there is a decrease in the total final consumption the last 5 years.

Table 34 Energy Consumption by Sector –Greece.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	40.24	40.37	38.63	34.68	31.47
FINAL CONSUMPTION OF TRANSPORT	TWh	107.05	94.86	86.58	74.35	73.71
FINAL CONSUMPTION OF RESIDENTIAL	TWh	56.23	53.66	63.6	58.75	43.77
FINAL CONSUMPTION OF AGRICULTURE	TWh	10.17	9.3	7.78	3.68	3.77
FINAL CONSUMPTION OF TERTIARY	TWh	24.92	22.63	22.86	27.48	24.08
TOTAL FINAL CONSUMPTION	TWh	238.72	220.97	219.45	199.08	176.87

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

The main industrial sectors of Greece are tourism, food and tobacco processing, textiles, chemicals, metal products; mining and petroleum. Manufacturing, which now ranks ahead of agriculture as an income earner, has increased rapidly owing to a vigorous policy of industrialization. However, Greek industry must rely on imports for its raw materials, machinery, parts, and fuel. Greece has only a rudimentary iron and steel industry and does not manufacture basic transport equipment, such as cars and trucks. Industry is concentrated in the Athens area.

Chief industries in 1995 accounted for the following proportions of manufacturing's share of the GDP: food, beverages and tobacco, 25%; metals and metals manufactures, machinery and electrical goods, 17%; chemicals, 13%; textiles, 18%; nonmetallic minerals, 6%; and transport equipment, 4.3%. Although the government controls certain basic industries, such as electric power and petroleum refining, most industry is privately owned.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 35 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the most consumed source is the electricity and then the renewables. The consumption of gas is zero for the last years and consumption of heat is zero in 2013 although it was higher the previous years.

Table 35 Energy consumption of Industry by fuel/source- Greece.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	1.95	3.47	2.45	2.64	2.45
TOTAL PRIMARY CONSUMPTION	TWh	16.66	15.56	12.04	12.33	11.42
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	4.74	4.35	6.45	5.91	6.24
GAS CONSUMPTION OF INDUSTRY	TWh	0	0	0	0	0
HEAT CONSUMPTION OF INDUSTRY	TWh	2.82	2.85	3.05	2.23	0
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	14.06	14.14	14.64	11.57	11.36
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	40.24	40.37	38.63	34.68	31.47
FINAL CONSUMPTION OF INDUSTRY	TWh	1.95	3.47	2.45	2.64	2.45

It is also important to see the sectors of industry that the energy is consumed. Table 36 shows the consumption of industrial sector by each industry. As can be observed, the biggest consumer is the non-ferrous metal industry and the second bigger consumer is the non-metallic minerals (glass, pottery and building materials).

Table 36 Energy Consumption of Industry Sector in 2013 by industry – Greece.

	TWH	%
Industry	32.9736	-
Iron & steel industry	1.6372	4.97%
Chemical and Petrochemical industry	1.2944	3.93%
Non-ferrous metal industry	10.2608	31.12%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	8.4556	25.64%
Transport Equipment	0.1406	0.43%
Machinery	0.3083	0.94%
Mining and Quarrying	0.8633	2.62%
Food and TOBACCO	5.4711	16.59%
Paper, Pulp and Print	1.1386	3.45%
Wood and Wood Products	0.3381	1.03%
Construction	1.0017	3.04%
Textile and Leather	0.5058	1.53%
Non-specified (Industry)	1.5581	4.73%

Hungary



Capital: Budapest

Geographical size: 93,024 km²

Population: 9,879,000 (2014)

Population as % of EU population: 1.9 % (2014)

GDP: € 103.217 billion (2014)

Official EU language(s): Hungarian

Currency: Hungarian Forint HUF



Industries: mining, metallurgy, construction materials, processed foods, textiles, chemicals (especially pharmaceuticals), motor vehicles.

Hungary is a landlocked country in Central Europe. It is bordered by Slovakia to the north, Romania to the east, Serbia to the south, Croatia to the southwest, Slovenia to the west, Austria to the northwest, and Ukraine to the northeast. Hungary has an area of 93,024 square kilometres and a population of 9,879,000 in 2014 (1.9% of total EU population). The country's capital and largest city is Budapest. Hungary is a member of the European Union since May 2004. The currency of Hungary is called the "forint" (sign: Ft; code: HUF) which was introduced in 1946. The private sector accounts for more than 80% of the Hungarian gross domestic product (GDP: €103.217 billion in 2014). Hungary has made the transition from a centrally planned to a market economy, with a per capita income nearly two-thirds that of the EU-28 average. The most important sectors of Hungary's economy in 2014 were industry (26.4%), wholesale and retail trade, transport, accommodation and food services (18.5%) and public administration, defense, education, human health and social work activities (17.5%) (Central Intelligence Agency, 2016), (Europa, 2016).

Energy Consumption of Country

The following table shows the energy consumption of Hungary for each sector (industry, transport, residential, agriculture, and tertiary) for the period 2009 – 2013. The big sectors in 2013 considering

the energy consumption of the country were the residential, the industry and the transport. Moreover, the industry is the only sector that presents an increasing consumption the latest years.

Table 37 Energy Consumption by Sector –Hungary.

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	30.72	33.25	32.72	29.47	41.11
Final consumption of transport	TWh	53.07	48.44	47.11	44.23	41.12
Final consumption of residential	TWh	64.2	66.75	63.81	59.73	56.26
Final consumption of agriculture	TWh	5.13	5.67	5.61	4.63	5.91
Final consumption of tertiary	TWh	34.75	36.47	36.56	32.17	28.58
Total final consumption	TWh	187.87	190.57	185.81	170.15	172.93

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Hungary's main industries are mining, metallurgy, construction materials, processed foods, textiles, chemicals (especially pharmaceuticals), and motor vehicles. In foreign investments, Hungary has seen a shift from lower-value textile and food industry to investment in luxury vehicle production, renewable energy systems, high-end tourism, and information technology.

The automotive sector is one of Hungary's core industries and generates almost 21% of total exports. The electronics industry accounts 22% of total Hungarian manufacturing production. Also, the country is the largest electronics producer in the CEE region, providing 26% of total regional production. Finally, the food industry generates 6% of the country's exports.

Energy Consumption of the Country's Industry

The industrial sector plays a significant role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 38 shows the energy consumption of the industrial sector of Hungary by fuel from 2009 to 2013. Gas is the leading fuel of the industrial consumption, followed by the electricity source. The less consumed energy in industry is the energy from renewables.

Table 38 Energy consumption of Industry by fuel/source – Hungary

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	3.65	3.82	4.28	4.07	2.27
Oil products consumption of industry	TWh	1.79	1.64	0.98	1.03	3.23
Gas consumption of industry	TWh	11.83	13.51	13.37	11.13	15.84
Heat consumption of industry	TWh	3.83	3.49	3.24	3.58	4.3
Renewable consumption of industry	TWh	1.05	1.01	0.98	0.75	0.65
Electricity consumption of industry	TWh	8.56	9.78	9.88	8.91	14.82
Final consumption of industry	TWh	30.72	33.25	32.72	29.47	41.11

As we can see from Table 39, the leading industry in 2013 was chemical industry (plastic production, pharmaceuticals), followed by food industry, while mining, metallurgy and textile industry seemed to be losing importance in the past two decades. In spite of the significant drop in the last decade, food industry is still giving up to 14.5% of total industrial production and amounts to 7-8% of the country's exports. Nearly 50% of energy consumption is dependent on imported energy sources. Gas and oil are transported through pipelines from Russia forming 72% of the energy structure, while nuclear power produced by the nuclear power station of Paks accounts for 12%.

Table 39 Energy Consumption of Industry Sector in 2013 by industry – Hungary

	TWH	%
Iron & steel industry	4.536	11.08%
Chemical and Petrochemical industry	8.728	21.33%
Non-ferrous metal industry	1.753	4.28%
Non-metallic Minerals (Glass. pottery & building mat. Industry)	4.406	10.76%
Transport Equipment	2.375	5.80%
Machinery	4.413	10.78%
Mining and Quarrying	0.309	0.75%
Food and TOBACCO	5.938	14.51%
Paper. Pulp and Print	2.118	5.17%
Wood and Wood Products	0.728	1.78%
Construction	2.325	5.68%
Textile and Leather	0.411	1.00%
Non-specified (Industry)	2.887	7.05%

Ireland



Capital City: Dublin

Geographical size: 69,797 km²

Population: 4,604,029 (2014 est.)

Population as % of EU population: 0.9%

GDP: €185.412 billion (2014 est.)

Official Languages: English

Recognized regional languages: Irish 38.7%

Currency: Euro €

Industries: pharmaceuticals, chemicals, computer hardware and software, food products, beverages and brewing; medical devices



Ireland is an EU member country since 1st of January 1973 and member of the Eurozone since 1st of January 1999. Ireland is located in the Western Europe and covers a total area of 69,797 km². Ireland and Great Britain together with many nearby smaller islands known collectively as the British Isles, has a total area of 84.421 km² (europa.eu, 2015).

Ireland is an island in the North Atlantic. It is separated from Great Britain to its east by the North Channel, the Irish Sea, and St George's Channel. Ireland is the second-largest island of the British Isles, the third-largest in Europe, and the twentieth-largest on Earth (CIA, 2015).

Politically, Ireland is divided between the Republic of Ireland, which covers five-sixths of the island, and Northern Ireland, which is part of the United Kingdom, and located in the northeast of the island. In 2011 the population of Ireland was about 6.4 million, ranking it the second-most populous island in Europe after Great Britain. Just under 4.6 million live in the Republic of Ireland and just over 1.8 million live in Northern Ireland (CIA, 2015).

Energy Consumption of Country

Ireland consumed 124.65 TWh of primary energy in 2013 which is almost same with 2012 but lower than the previous years. The energy consumption for each sector from 2009 to 2013 for Italy is shown in Table 40. As can be observed, the transport sector is the bigger consumer every year, and the second bigger consumer is the residential and third the industry.

Table 40 Energy Consumption by Sector –Ireland.

	UNIT	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	25.6	26.29	25.82	25.3	25.85
FINAL CONSUMPTION OF TRANSPORT	TWh	56.55	53.46	51.42	48.52	48.71
FINAL CONSUMPTION OF RESIDENTIAL	TWh	35.88	38.02	33.03	31.7	32.12
FINAL CONSUMPTION OF AGRICULTURE	TWh	3.65	3.42	3.27	3.18	2.89
FINAL CONSUMPTION OF TERTIARY	TWh	17.79	17.11	15.57	15.49	15.08
TOTAL FINAL CONSUMPTION	TWh	139.47	138.3	129.11	124.17	124.65

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

The major industries in Ireland are: the drinks industry, the aircraft leasing industry, the engineering industry, the IT industry and the biopharmaceuticals industry.

The drinks industry employs approximately 92,000 people and contributes 2 billion euro annually to the Irish economy making it one of the biggest sectors. It supports jobs in agriculture, distilling and brewing. It is subdivided into 5 areas; beer, cider, spirits, whiskey and wine. The Aircraft leasing industry employs 1,200 people, with Irish lessors managing more than €100 billion in assets. This means that Ireland manages nearly 22% of the fleet of aircraft worldwide and a 40% share of Global fleet of leased aircraft. Ireland has 14 of the top 15 lessors by fleet size. The Engineering sector employs over 18,500 people and contributes approximately 4.2 billion euro annually. This includes approximately 180 companies in areas such of industrial products and services, aerospace, automotive and clean tech. The Information and communications technology (ICT) sector employs over 37,000 people and generates 35 billion annually. The top ten ICT companies are located in Ireland, with over 200 companies in total. A number of these ICT companies are based at the Silicon Docks in Dublin. Google, Facebook, Twitter, LinkedIn, Amazon, eBay, PayPal and Microsoft many of which have their EMEA / Europe & Middle East headquarters in Ireland. The biopharmaceutical sector employs approximately 50,000 people and is responsible for 55 billion euro of exports.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector is the third major energy consumer in Ireland. Table 41 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is the electricity and the most consumed fuel is gas.

Table 41 Energy consumption of Industry by fuel/source- Ireland.

	UNIT	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	1.32	1.32	1.15	1.01	0.96
Total primary consumption	TWh	169.16	168.97	157.83	153.98	152.33
Oil products consumption of industry	TWh	8.89	8.81	6.7	5.98	6.34
Gas consumption of industry	TWh	5	5.19	6.67	7.28	7.22
Heat consumption of industry	TWh	0	0	0	0	0
Renewable consumption of industry	TWh	1.78	1.87	1.82	1.87	2.04
Electricity consumption of industry	TWh	8.6	9.11	9.49	9.16	9.29
Final consumption of industry	TWh	25.6	26.29	25.82	25.3	25.85

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

The energy consumption by the industrial sector is the third bigger after the transport and residential. However, to analyze more the energy consumption of the industry every year, Table 42 shows the energy consumption of the various industrial sectors. As shown, the biggest consumer is the non-ferrous metal industry and then the food industry. The less consumer is the chemical industry.

Table 42 Energy Consumption of Industry Sector in 2013 by industry – Ireland.

	tWh	%
Industry	25.394	-
Iron & steel industry	0.013	0.05%
Chemical and Petrochemical industry	2.667	10.50%
Non-ferrous metal industry	5.640	22.21%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	3.515	13.84%
Transport Equipment	0.251	0.99%
Machinery	2.818	11.10%
Mining and Quarrying	1.255	4.94%
Food and TOBACCO	5.048	19.88%
Paper, Pulp and Print	0.275	1.08%
Wood and Wood Products	1.620	6.38%
Construction	0.073	0.29%
Textile and Leather	0.217	0.86%
Non-specified (Industry)	2.003	7.89%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Italy



Capital City: Rome

Geographical Size: 302,073 km²

Population: 60,782,668 (2014 est.)

Population as% of EU population: 12% (2014 est.)

GDP: €1.616 trillion The GDP value of Italy represents 3.45% of the world economy (2014 est.)

Official Languages: Italian

Currency: Euro €

Industries: tourism, machinery, iron and steel, chemicals, food processing, textiles, motor vehicles, clothing, footwear, ceramics.



Italy is an EU member state since 1st January 1958 and member of the Eurozone since 1st of January 1999. Italy covers an area of 302,073 km² and has a largely Mediterranean and temperate climate; due to its shape, it is often referred to in Italy as *lo Stivale* (the Boot).

With 61 million inhabitants, it is the 4th most populous EU member state. Located in the heart of the Mediterranean Sea, Italy shares open land borders with France, Switzerland, Austria, Slovenia, San Marino and Vatican City (europa.eu, 2015).

Italy has the third largest economy in the Eurozone and the eighth largest economy in the world. It has a very high level of human development and enjoys the highest life expectancy in the EU. Italy plays a prominent role in regional and global military, cultural and diplomatic affairs. The Italian economy is driven in large part by the manufacture of high-quality consumer goods produced by small and medium-sized enterprises, many of them family-owned. Italy also has a sizable underground economy, which by some estimates accounts for as much as 17% of GDP. These activities are most common within the agriculture, construction, and service sectors. Italy is the third-largest economy in the euro-zone, but its exceptionally high public debt and structural impediments to growth have rendered it vulnerable to scrutiny by financial markets (CIA, 2015).

Energy Consumption of Country

Italy consumed 1382.52 TWh of primary energy in 2013 which is lower than the previous 4 years. The energy consumption for each sector from 2009 to 2013 for Italy is shown in Table 43. As can be observed, the transport sector is the bigger consumer and then the residential sector and the industrial sector except from 2011 and 2012 where the second bigger consumer was the industry and third the residential.

Table 43 Energy Consumption by Sector –Italy.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	349.69	368.04	360.78	352.28	323.75
FINAL CONSUMPTION OF TRANSPORT	TWh	485.3	480.63	481.71	454.33	444.07
FINAL CONSUMPTION OF RESIDENTIAL	TWh	371.13	375.7	328.72	351.22	349.45
FINAL CONSUMPTION OF AGRICULTURE	TWh	36.3	34.19	34	32.83	32.38
FINAL CONSUMPTION OF TERTIARY	TWh	221.36	233.2	230.65	233.3	232.69
TOTAL FINAL CONSUMPTION	TWh	1463.89	1491.86	1436.17	1424.11	1382.52

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Italy's major industries are tourism, machinery, iron and steel, chemicals, food processing, textiles, motor vehicles, clothing, footwear and ceramics. Production is primarily situated in the northern part of the country and is dominated by private enterprises. Two major industrial cities in the north are Turin, the country's manufacturing capital, and Milan, the business and fashion capital. The Italy's top five industries are, the automotive industry, food Industry, aerospace industry, textile and leather industry and the metalworking industry.

The Italy's top export industries are, the mechanical machinery and equipment, the transport equipment, the chemical products and the electrical equipment. Italy's engineering sector, covering mechanical machinery and equipment, is now the second largest in the EU and fast catching up with leading manufacturer Germany. It produced 18.7% of machinery in the EU in 2008 and also made significant gains in Russia, Africa and South America. Italy's automobile industry is the country's largest employer with an estimated (2004) 196,000 employees. The automobile sector is dominated by Fiat which ranks number ten in the world's top motor vehicle manufacturing companies, although as a country Italy ranks only 17th in terms of motor vehicle producing countries. Chemical products and synthetic fibres is a crucial sector for Italy With a turnover of €57 billion it is the fourth largest chemical producer in the EU. There are three thousand companies in the sector employing around 126,000 people. The electrical equipment sector has suffered from the global economic crisis, but analyst firm Gartner reported in October 2009 that the industry is showing signs of recovery, although this will not stabilize until 2010, with mobile phones expected to lead the recovery (CIA, 2015).

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 44 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is the electricity and the most consumed fuel is gas. The less consumed energy in industry is the energy from renewables. Although that shows upward trend from year to year, it is still the less consumed energy.

Table 44 Energy consumption of Industry by fuel/source- Italy.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	21.57	34.23	40.17	39.89	27.77
TOTAL PRIMARY CONSUMPTION	TWh	2006.11	2053.97	1988.34	1910.18	1838.4
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	50.3	40.47	40.35	38	31.79
GAS CONSUMPTION OF INDUSTRY	TWh	117.38	123.55	117.56	117.22	112.57
HEAT CONSUMPTION OF INDUSTRY	TWh	34.16	36.39	28.43	30.03	29.77
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	5.3	5.12	5.83	6.42	6.46
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	120.99	128.29	128.44	120.71	115.38
FINAL CONSUMPTION OF INDUSTRY	TWh	349.69	368.04	360.78	352.28	323.75

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 45 shows the consumption of industrial sector by each industry. As can be observed, the biggest consumer is the iron and steel industry and then the non-metallic minerals (glass, pottery and building materials).

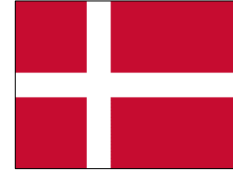
Table 45 Energy Consumption of Industry Sector in 2013 by industry – Italy.

	TWH	%
Industry	313.950	-
Iron & steel industry	60.555	19.29%
Chemical and Petrochemical industry	47.931	15.27%
Non-ferrous metal industry	7.432	2.37%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	58.084	18.50%
Transport Equipment	4.243	1.35%
Machinery	39.032	12.43%
Mining and Quarrying	1.344	0.43%
Food and TOBACCO	30.903	9.84%
Paper, Pulp and Print	23.494	7.48%
Wood and Wood Products	4.695	1.50%
Construction	4.202	1.34%
Textile and Leather	13.568	4.32%
Non-specified (Industry)	18.469	5.88%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Latvia



Capital: Riga

Geographical size: 64 573 km²

Population: 2 001 468 (2014)

Population as % of EU population: 0.4 % (2014)

GDP: € 24.060 billion (2014)

Official EU language(s): Latvian

Currency: Euro

Industries: processed foods, processed wood products, textiles, processed metals, pharmaceuticals, railroad cars, synthetic fibers, electronics



Latvia, officially the Republic of Latvia, is a country in the Baltic region in the north east Europe. It is in border with Lithuania and Belarus in the south, Russia on the east, Estonia on the north and the Baltic Sea in the west. Latvia's capital is Riga, has a population of 2,001,468 habitants in 2014 (0.4% of total EU population) and covers an area of 6,573 km². Latvia is an EU member since 1st of May 2004, member of the Eurozone in 1st of January 2014 and is a member of the Schengen area.

Latvia's most important economy sectors in 2014 were wholesale and retail trade, transport, accommodation and food services (25.3 %), industry (16.4 %) and public administration, defense, education, human health and social work activities (15.1 %) (Europa, 2016).

Latvia's exports contribute nearly a third of the country's GDP and although the economy experienced GDP growth of more than 10% per year during 2006-07 when the country entered the recession in 2008 and due to collapse of the second largest bank, GDP plunged 18% in 2009 (Central Intelligence Agency, 2016).

Energy Consumption of Country

Latvia's total energy consumption by 2013 was 44.84 TWh which was reduced from the previous 4 years. Table 46 presents the energy consumption of the country's different sectors from 2009

to 2013. The highest consumption is observed in the residential sector followed by the transport sector. The least consumption is observed in the agriculture sector.

Table 46 Energy Consumption by Sector – Latvia

	Unit	2009	2010	2011	2012	2013
<i>Final consumption of industry</i>	TWh	7.59	9.01	8.7	9.65	8.93
<i>Final consumption of transport</i>	TWh	13.27	13.96	12.56	12.17	12.35
<i>Final consumption of residential</i>	TWh	17.84	16.15	15.43	16	14.74
<i>Final consumption of agriculture</i>	TWh	1.61	1.82	1.8	1.74	1.8
<i>Final consumption of tertiary</i>	TWh	6.67	6.96	6.5	7.23	7
<i>Total final consumption</i>	TWh	46.99	47.93	44.99	46.82	44.84

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Latvia's major industries consist of processed foods, processed wood products, textiles, processed metals, pharmaceuticals, railroad cars, synthetic fibers, electronics. Latvia's main export partners are Lithuania, Russia and Estonia and the import partners are Lithuania, Germany and Poland.

The country's most economically strong industries are agriculture, chemicals, logistics and woodworking. Good temperature and soil has raised the Agriculture sector where grain is taking a third of the industry (Latvia, 2015). The Chemical industry relies on the highly educated low cost labor. Due to the country's geographical location transit services are highly-developed (Central Intelligence Agency, 2016).

Energy Consumption of the Country's Industry

Table 47 shows the energy consumption of the country's industrial sector by fuel from 2009 to 2013. Renewable energy is the highest consumed source in the industry sector followed by electricity. It has to be noted that the renewable energy source takes approximately half of the total final consumption of the industry sector. Heat as a source for energy consumption in the industry sector is the least consumed.

Table 47 Energy consumption of Industry by fuel/source – Latvia

	Unit	2009	2010	2011	2012	2013
<i>Coal consumption of industry</i>	TWh	0.42	0.54	0.64	0.64	0.41
<i>Oil products consumption of industry</i>	TWh	0.83	0.99	0.66	0.75	0.72
<i>Gas consumption of industry</i>	TWh	2.47	2.82	2.02	2.12	1.66
<i>Heat consumption of industry</i>	TWh	0.08	0.11	0.07	0.07	0.13
<i>Renewable consumption of industry</i>	TWh	2.29	2.96	3.63	4.08	4.2
<i>Electricity consumption of industry</i>	TWh	1.51	1.59	1.67	1.99	1.81
<i>Final consumption of industry</i>	TWh	7.59	9.01	8.7	9.65	8.93

Source: (Odyssee, 2015), Conversion base: 1toe=11630kWh

Another important aspect to examine is the different sectors within the industry sectors. Table 48 presents the consumption of each individual industrial sub sectors. The highest industry's energy consumption by difference is the Wood and Wood Products followed by Non-metallic Minerals (Glass, pottery & building mat. Industry) and Food and TOBACCO. The minimum energy consumption is observed in the Non-ferrous metal industry and the Paper, Pulp and Print industry.

Table 48 Energy Consumption of Industry Sector in 2013 by industry – Latvia

	TWh	%
<i>Iron & steel industry</i>	0.32	3.56
<i>Chemical and Petrochemical industry</i>	0.29	3.28
<i>Non-ferrous metal industry</i>	0.04	0.44
<i>Non-metallic Minerals (Glass, pottery & building mat. Industry)</i>	1.69	18.89
<i>Transport Equipment</i>	0.11	1.18
<i>Machinery</i>	0.22	2.48
<i>Mining and Quarrying</i>	0.15	1.64
<i>Food and TOBACCO</i>	1.08	12.15
<i>Paper, Pulp and Print</i>	0.09	0.97
<i>Wood and Wood Products</i>	4.17	46.74
<i>Construction</i>	0.50	5.56
<i>Textile and Leather</i>	0.13	1.45
<i>Non-specified (Industry)</i>	0.15	1.66

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Lithuania



Capital: Vilnius

Geographical size: 65 300 km²

Population: 2 943 472 (2014)

Population as % of EU population: 0.6 % (2014)

GDP: € 36.309 billion (2014)

Official EU language(s): Lithuanian

Currency: Euro

Industries: metal-cutting machine tools, electric motors, television sets, refrigerators and freezers, petroleum refining, shipbuilding (small ships), furniture, textiles, food processing, fertilizers, agricultural machinery, optical equipment, lasers, electronic components, computers, amber jewelry, information technology, video game development, biotechnology



Lithuania, officially the Republic of Lithuania, is the largest and most populous country in the Baltic region in the north east Europe. It is in border with Latvia on the north, Poland on the south, Russia on the west and Baltic Sea in the east. Lithuania's capital is Vilnius, it has a population of 2,943,472 habitants in 2014 (0.6% of total EU population) and covers an area of 65,300 km². Lithuania is an EU member 1st of May 2004, member of the Eurozone since 1st of January 2015 and member of the Schengen area.

Lithuania's economy in 2014 was based on the following sectors, wholesale and retail trade, transport, accommodation and food services (32.7 %), industry (23.6 %) and public administration, defense, education, human health and social work activities (13.9 %).

Energy Consumption of Country

Lithuania had a total energy consumption of 53.89 TWh in 2013. Table 49 presents the energy consumption of the country's different sectors from 2009 to 2013. It can be observed that the transport sector has the highest energy consumption followed by the residential sector. The least consumption is observed in the agriculture sector. The country's total energy consumption in

2012 is observed to be the highest and in addition a rising total energy consumption within the range presented in the table below.

Table 49 Energy Consumption by Sector – Lithuania

	Unit	2009	2010	2011	2012	2013
<i>Final consumption of industry</i>	TWh	9	9.83	10.31	11	10.75
<i>Final consumption of transport</i>	TWh	17.35	17.92	17.85	18.21	18.28
<i>Final consumption of residential</i>	TWh	18.09	18.37	17.65	17.64	16.86
<i>Final consumption of agriculture</i>	TWh	1.21	1.29	1.29	1.28	1.22
<i>Final consumption of tertiary</i>	TWh	6.87	6.98	6.78	7.11	6.91
<i>Total final consumption</i>	TWh	52.46	54.31	53.78	55.12	53.89

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Lithuania's main export partners are Russia, Latvia and Poland while its main import partners are Russia, Germany and Poland (Europa, 2016).

Lithuanian's most profitable industry sector is the chemical industry. The main elements of the chemical sector include nitrogen and phosphate fertilizers. Other segments of the industry are pharmaceuticals, cosmetics and soap, and glues, oils and resinoids (truelithuania, 2015). The clothing industry which used to be strong in the Lithuania's economy has been hit by outsourcing to Asia whereas the textile industry remains strong. The electronics industry sector has declined through the years with main electronic products of televisions, electronic measurement equipment, semiconductors, and other computer equipment.

Energy Consumption of the Country's Industry

An analysis of the energy consumption of the country's industrial sector by fuel from 2009 to 2013 is presented in Table 2. Electricity energy is the highest consumed source in the industry sector followed by Gas in 2013. Oil products as a source for energy consumption in the industry sector is the least consumed.

Table 50 Energy consumption of Industry by fuel/source – Lithuania

	Unit	2009	2010	2011	2012	2013
<i>Coal consumption of industry</i>	TWh	0.64	0.85	1.07	1.22	1.42
<i>Oil products consumption of industry</i>	TWh	0.45	0.31	0.27	0.32	0.3
<i>Gas consumption of industry</i>	TWh	2.93	3.19	3.07	3.24	2.79
<i>Heat consumption of industry</i>	TWh	1.92	2.08	2.38	2.45	2.38
<i>Renewable consumption of industry</i>	TWh	0.74	0.84	0.85	0.96	0.97
<i>Electricity consumption of industry</i>	TWh	2.33	2.55	2.67	2.81	2.88
<i>Final consumption of industry</i>	TWh	9	9.83	10.31	11	10.75

Source: (Odyssee, 2015), Conversion base: 1toe=11630kWh

Furthermore, breakdown of the different sectors within the industry sector is presented in Table 51 with the consumption of each individual industrial sub sectors in 2013. The highest industry's energy consumption by difference is the Chemical and Petrochemical followed Food and TOBACCO. The Non-ferrous metal industry has the minimum energy consumption followed by Iron & steel industry.

Table 51 Energy Consumption of Industry Sector in 2013 by industry – Lithuania

	TWh	%
Industry	11.39	-
Iron & steel industry	0.03	0.26
Chemical and Petrochemical industry	3.54	31.10
Non-ferrous metal industry	0.01	0.08
Non-metallic Minerals (Glass, pottery & building mat. Industry)	2.23	19.60
Transport Equipment	0.04	0.35
Machinery	0.26	2.25
Mining and Quarrying	0.06	0.50
Food and TOBACCO	2.21	19.38
Paper, Pulp and Print	0.43	3.76
Wood and Wood Products	1.07	9.42
Construction	0.48	4.17
Textile and Leather	0.36	3.16

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Luxembourg

Capital City: City of Luxembourg

Geographical Size: 2,586 km²

Population: 549,684 (2014 est.)

Population as % of EU population: 0.11 % (2014 est.)

GDP: € 49,428 billion.

Official Languages: German and French

Currency: € Euro

Industries: banking and financial services, construction, real estate services, iron, metals, and steel, information technology, telecommunications, cargo transportation and logistics, chemicals, engineering, tires, glass, aluminum, tourism, biotechnology



Luxembourg (officially Grand Duchy of Luxembourg), is located in Northern Europe and is a member of the European Union, since 1958. It is one of the smallest countries, but the richest one in the EU per capita. The capital of Luxembourg is the city of Luxembourg and the official language is German and French (“EUROPA - EU member countries,” 2016).

The recorded population and GDP in 2014 were 549,684 and € 49,428 billion, respectively. Its total area coverage is 2,586 km² and the 15.8 % of the Luxembourg economy corresponds to the industrial sector, in 2014, (“EUROPA - EU member countries,” 2016)

Energy Consumption of Country

Luxembourg’s total final energy consumption, in 2014, was 46.52 TWh (“Eurostat - Final energy consumption by sector,” 2016). Table 152 shows the final energy consumption by sector in Germany from 2009 up to 2013. As can be seen in the table, transport consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the table it can be concluded that the percentage share of the final energy consumption for each sector is 13.17 % for industry, 61.89% for transport, 10.97% for residential, 0.17% for agriculture and 13.30% for tertiary, in 2013. Even Luxembourg is one of the smallest country in the Union, the highest amount of final energy is consumed in transport.

Table 52 Energy Consumption by Sector – Luxembourg.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	7.6	8.6	7.67	6.73	6.33
FINAL CONSUMPTION OF TRANSPORT	TWh	29.1	30.56	31.71	30.19	29.74
FINAL CONSUMPTION OF RESIDENTIAL	TWh	6.01	5.94	5.56	5.41	5.27
FINAL CONSUMPTION OF AGRICULTURE	TWh	0.11	0.1	0.1	0.09	0.08
FINAL CONSUMPTION OF TERTIARY	TWh	4.76	5.28	5.05	6.11	6.39
TOTAL FINAL CONSUMPTION	TWh	47.49	50.38	49.99	48.59	48.05

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Luxembourg has a variety of industries each of them playing an important role to the economy of the country. The most important ones are banking and financial services, construction, real estate services, iron, metals, and steel, information technology, telecommunications, cargo transportation and logistics, chemicals, engineering, tires, glass, aluminium, tourism, biotechnology ("CIA - The World Factbook," 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 53 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is electricity and the most consumed fuel is gas. The less consumed energy in industry is heat.

Table 53 Energy consumption of Industry by fuel/source- Luxembourg.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	0.77	0.77	0.67	0.62	0.55
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	0.09	0.16	0.09	0.11	0.08
GAS CONSUMPTION OF INDUSTRY	TWh	3.14	3.39	3.13	2.95	2.67
HEAT CONSUMPTION OF INDUSTRY	TWh	0.12	0.15	0.12	0.05	0.06
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	0.39	0.49	0.46	0.45	0.47
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	3.1	3.63	3.2	2.56	2.5
FINAL CONSUMPTION OF INDUSTRY	TWh	7.6	8.6	7.67	6.73	6.33

Source: (Odyssee, 2015), Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 54 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the iron and steel industry whereas on the other hand, transport equipment consumes the least energy. It can also be concluded that iron and steel, chemical and petrochemical and non-metallic minerals (glass, pottery & building mat.) industries are the most important industries in Luxembourg.

Table 54 Energy Consumption of Industry Sector in 2013 by industry – Luxembourg

	TWH	%
Industry	6.313	-
Iron & steel industry	2.751	0.51
Chemical and Petrochemical industry	0.600	0.11
Non-ferrous metal industry	0.000	0.00
Non-metallic Minerals (Glass, pottery & building mat. Industry)	1.244	0.23
Transport Equipment	0.064	0.01
Machinery	0.263	0.05
Mining and Quarrying	0.011	0.00
Food and TOBACCO	0.329	0.06
Paper, Pulp and Print	0.139	0.03
Wood and Wood Products	0.218	0.04
Construction	0.282	0.05
Textile and Leather	0.217	0.04
Non-specified (Industry)	0.196	0.04

Malta



Capital City: Valetta

Geographical size: 316 km²

Population: 425,384 (2014 est.)

Population as % of EU population: 0.1%

GDP: €7.912 billion (2014 est.)

Official Languages: English

Recognized regional languages: Maltese

Currency: Euro €

Industries: tourism, electronics, ship building and repair, construction, food and beverages, pharmaceuticals, footwear, clothing, tobacco, aviation services, financial services, information technology services.



Malta is an island in the southern Europe, in the Mediterranean Sea at the south of Sicily (Italy), with area of 316 km². Malta became an EU member in May 2004 and began using the euro as currency in 2008. A popular tourist destination, Malta has some of the oldest free-standing structures in the world. In 2014, the estimated population was 425,384 which ranks 171st in the world (Eurostat, 2015).

Malta has the smallest economy in the euro zone - produces only about 20% of its food needs, has limited fresh water supplies, and has few domestic energy sources. Malta's geographic position between Europe and North Africa makes it a target for irregular migration, which has strained Malta's political and economic resources. Malta's fertility rate is below the EU average, and population growth in recent years has largely been from immigration, putting increasing pressure on the pension system. Malta's economy is dependent on foreign trade, manufacturing, and tourism. Malta has weathered the Eurozone crisis better than most EU member states due to a low debt-to-GDP ratio and financially sound banking sector (CIA, 2015).

Energy Consumption of Country

Malta consumed 505 TWh of primary energy in 2012, similar to the consumption of the previous years. As shown in Table 55, the largest amount of this energy is consumed by the transport sector. The second biggest consumer is the industrial sector.

Table 55 Energy Consumption by Sector – Malta.

	UNIT	2009	2010	2011	2012	2013
Final consumption of industry	TWh	0.73	0.85	0.93	0.95	n.a.
Final consumption of transport	TWh	3.06	3.12	3.17	3.08	n.a.
Final consumption of residential	TWh	0.87	0.93	0.79	0.78	n.a.
Final consumption of agriculture	TWh	0.04	0.04	0.04	0.05	n.a.
Final consumption of tertiary	TWh	0.57	0.57	0.64	0.64	n.a.
Total final consumption	TWh	5.27	5.51	5.58	5.5	n.a.

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

In Malta, the industry sector is not vast and not many heavy industrial firms operate from Malta. The most active industry in Malta is the manufacturing industry followed by that in the machinery and fabricated metal products, construction and the chemical industry (CIA, 2015) .

Energy Consumption of the Country's Industry

Regarding the major energy consumer Table 56 shows the energy consumption of the industrial sector by fuel from 2009 to 2012. As can be seen, after the total primary consumption, the most consumed source is the electricity. There is no consumption of coal and there is no use of renewable energy technologies or heat recovery systems.

Table 56 Energy consumption of Industry by fuel/source – Malta.

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	0	0	0	0	n.a.
Total primary consumption	TWh	10.9	10.92	10.84	11.28	n.a.
Oil products consumption of industry	TWh	0.09	0.21	0.21	0.22	n.a.
Gas consumption of industry	TWh	0.04	0.04	0.04	0.05	n.a.
Heat consumption of industry	TWh	0	0	0	0	n.a.
Renewable consumption of industry	TWh	0	0	0	0	n.a.
Electricity consumption of industry	TWh	0.6	0.6	0.68	0.67	n.a.
Final consumption of industry	TWh	0.73	0.85	0.93	0.95	n.a.

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Table 57 shows the breakdown of the consumption in the industrial sector. As can be observed, the most active industry in Malta is the machinery (25%) and then the food industry (12%).

Table 57 Energy Consumption of Industry Sector in 2013 by industry – Malta.

	TWh	%
Industry	0.443	-
Iron & steel industry	-	0%
Chemical and Petrochemical industry	0.038	9%
Non-ferrous metal industry	-	0%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	0.006	1%
Transport Equipment	0.016	4%
Machinery	0.109	25%
Mining and Quarrying	0	0%
Food and TOBACCO	0.054	12%
Paper, Pulp and Print	0.024	5%
Wood and Wood Products	0	0%
Construction	0.015	3%
Textile and Leather	0.037	8%
Non-specified (Industry)	0.142	32%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Netherlands

Capital City: Amsterdam

Geographical Size: 41,450 km²

Population: 16,829,289 (2014 est.)

Population as % of EU population: 3.3 % (2014 est.)

GDP: € 662,770 billion (2014 est.)

Official Languages: Dutch

Currency: € Euro

Industries: agroindustries, metal and engineering products, electrical machinery and equipment, chemicals, petroleum, construction, microelectronics, fishing



Netherlands is a seaside country located in the Western Europe and is a member of the European Union, since 1958. The capital of the Netherlands is Amsterdam and the official language is Dutch ("EUROPA - EU member countries," 2016).

The recorded population and GDP in 2014 were 16,829,289 and € 662,770 billion, respectively. Its total area coverage is 41,540 km² and the 16.9 % of the economy of Netherlands corresponds to the industrial sector, in 2014, ("EUROPA - EU member countries," 2016)

Energy Consumption of Country

Netherlands's total final energy consumption, in 2013, was 607.84 TWh ("Eurostat - Final energy consumption by sector," 2016). Table 1 shows the final energy consumption by sector in Netherlands from 2009 up to 2013. As can be seen in the table, transport consumes most of the final energy whereas on the other hand agriculture consumes the least energy. Moreover, from the table it can be concluded that the percentage share of the final energy consumption for each sector is 21.92 % for industry, 28.04% for transport, 20.49% for residential and 10.75% for agriculture in 2013.

Table 58 Energy Consumption by Sector – Netherlands.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	129.83	140.31	138.72	135.71	133.22
FINAL CONSUMPTION OF TRANSPORT	TWh	175.82	175.57	179.2	172.83	170.77
FINAL CONSUMPTION OF RESIDENTIAL	TWh	117.71	132.75	112.15	118.96	124.54
FINAL CONSUMPTION OF AGRICULTURE	TWh	54.98	58.67	56.3	62.43	65.37
FINAL CONSUMPTION OF TERTIARY	TWh	87.29	94.02	85.79	93.22	n.a.
TOTAL FINAL CONSUMPTION	TWh	588.99	626.08	588.23	600.35	607.84

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Netherlands has a variety of industries each of them playing an important role to the economy of the country. The most important ones are agroindustries, metal and engineering products, electrical machinery and equipment, chemicals, petroleum, construction, microelectronics and fishing (“CIA - The World Factbook,” 2016).

Various types of fuels as well as RES are used in the industry for either production lines or energy consumption or both. The following tables show the energy consumption by type of industry and the total energy consumption of industry by fuel, respectively.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 59 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is electricity and the most consumed fuel is gas. The less consumed energy in industry is the energy coming from renewables.

Table 59 Energy consumption of Industry by fuel/source- Netherlands.

	Unit	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	5.06	5.24	6.55	7.62	6.18
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	6.08	5.37	5.07	5.52	5.03
GAS CONSUMPTION OF INDUSTRY	TWh	61.24	67.8	65.34	66.6	66.06
HEAT CONSUMPTION OF INDUSTRY	TWh	19.21	21.11	21.33	19.62	19.96
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	2.03	1.73	1.58	1.38	1.52
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	36.21	39.06	38.86	34.97	34.47
FINAL CONSUMPTION OF INDUSTRY	TWh	129.83	140.31	138.72	135.71	133.22

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 60 shows the consumption of industrial sector by each industry. It can be observed that most of the energy is consumed in the chemical & petrochemical industry whereas on the other hand, wood & wood products consumes the least energy. It can also be concluded that iron and steel, chemical and petrochemical and food & TOBACCO industries are the most important industries in the Netherlands.

Table 60 Energy Consumption of Industry Sector in 2013 by industry – Netherlands

	TWH	%
Industry	221.315	-
Iron & steel industry	38.141	17.23
Chemical and Petrochemical industry	98.123	44.34
Non-ferrous metal industry	5.039	2.28
Non-metallic Minerals (Glass, pottery & building mat. Industry)	8.929	4.03
Transport Equipment	1.526	0.69
Machinery	8.385	3.79
Mining and Quarrying	1.790	0.81
Food and TOBACCO	31.029	14.02
Paper, Pulp and Print	11.194	5.06
Wood and Wood Products	0.909	0.41
Construction	7.801	3.52
Textile and Leather	1.701	0.77
Non-specified (Industry)	221.315	17.23

Poland



Capital: Warsaw

Geographical size: 312,679 km²

Population: 38,495,659 (2014)

Population as % of EU population: 7.6 % (2014)

GDP: € 413.134 billion (2014)

Official EU language(s): Polish

Currency: Polish Złoty PLN

Industries: mining, metallurgy, construction materials, processed foods, textiles, chemicals (especially pharmaceuticals), motor vehicles.



Poland, officially the Republic of Poland, is a country in Central Europe bordered by Germany to the west, the Czech Republic and Slovakia to the south, Ukraine and Belarus to the east and Lithuania to the north. The total area of Poland is 312,679 square kilometres, making it the 9th largest in Europe. With a population of about 38.5 million people, Poland is the 8th most populous country in Europe and the 6th most populous member of the European Union (7.6% of total EU population). Poland is a member of the European Union since May 2004. According to Eurostat data, Polish PPS GDP per capita stood at 67% of the EU average in 2012 (GDP: € 413.134 billion in 2014). The currency of Poland is the Polish Złoty (PLN). Poland is a democratic country with an advanced high-income economy, a high quality of life and a very high standard of living. Moreover, the country is visited by nearly 16 million tourists every year (2013), which makes it one of the most visited countries in the world. Poland is the sixth largest economy in the European Union and among the fastest rising economic states in the world. The most important sectors of Poland's economy in 2014 were wholesale and retail trade, transport, accommodation and food services (27.1%), industry (25.1%) and public administration, defense, education, human health and social work activities (14.3%) (Central Intelligence Agency, 2016), (Europa, 2016).

Energy Consumption of Country

The table below shows the energy consumption of Poland for each sector (industry, transport, residential, agriculture, and tertiary) for the period 2009 – 2013. The big sectors in 2013 considering the energy consumption of the country were the residential, the transport and the industry. Additionally, agriculture consumes the least energy.

Table 61 Energy Consumption by Sector – Poland

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	164.88	158.55	165.56	162.37	169.29
Final consumption of transport	TWh	187.96	200.05	201.84	194.21	181.72
Final consumption of residential	TWh	219.79	253.9	233.66	241.03	237.22
Final consumption of agriculture	TWh	40.94	44.01	42.36	42.25	41.36
Final consumption of tertiary	TWh	88.75	98.66	93.96	96.45	93.17
Total final consumption	TWh	702.13	758.99	740.85	735.88	722.78

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Poland's high-income economy is considered to be one of the healthiest of the post-Communist countries and is one of the fastest growing within the EU. Having a strong domestic market, low private debt, flexible currency, and not being dependent on a single export sector, Poland is the only European economy to have avoided the late-2000s recession. The country's most successful exports include machinery, furniture, foods and meats, motor boats, light planes, hardwood products, casual clothing, shoes and cosmetics.

Poland has a large number of private farms in its agricultural sector, with the potential to become a leading producer of food in the European Union. The biggest money-makers abroad include smoked and fresh fish, fine chocolate, and dairy products, meats and specialty breads, with the exchange rate conducive to export growth. Food exports amounted to 62 billion zloty in 2011, increasing by 17% from 2010. Structural reforms in health care, education, the pension system, and state administration have resulted in larger-than-expected fiscal pressures.

Energy Consumption of the Country's Industry

Table 62 shows the energy consumption of the industrial sector of Poland by fuel from 2009 to 2013. After electricity consumption, which is the biggest source, the gas and coal consumption are also important fuels in industry. The less consumed energy in industry is the heat.

Table 62 Energy consumption of Industry by fuel/source – Poland

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	37.83	37.22	40.77	38.53	37.19
Oil products consumption of industry	TWh	16.1	13.99	13.24	11.42	12.65
Gas consumption of industry	TWh	38.88	42.55	43.4	43	43.88
Heat consumption of industry	TWh	16.5	7.87	7.03	7.39	7.28
Renewable consumption of industry	TWh	15.78	15.1	16.52	16.82	20.47
Electricity consumption of industry	TWh	39.79	41.82	44.61	45.21	47.82
Final consumption of industry	TWh	164.88	158.55	165.56	162.37	169.29

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

The largest industry by energy consumption in Poland is the chemical sector and then the non-metallic materials and iron and steel industry (Table 63). The textile and leather industries consume the least energy considering all sectors.

Table 63 Energy Consumption of Industry Sector in 2013 by industry – Poland.

	TWH	% of total industry
Industry	175.575	100.00%
Iron & steel industry	28.081	15.99%
Chemical and Petrochemical industry	34.638	19.73%
Non-ferrous metal industry	4.724	2.69%
Non-metallic Minerals (Glass. pottery & building mat. Industry)	29.644	16.88%
Transport Equipment	4.733	2.70%
Machinery	8.485	4.83%
Mining and Quarrying	4.427	2.52%
Food and TOBACCO	21.394	12.19%
Paper. Pulp and Print	18.268	10.40%
Wood and Wood Products	9.963	5.67%
Construction	2.132	1.21%
Textile and Leather	1.347	0.77%
Non-specified (Industry)	7.739	4.41%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Portugal



Capital City: Lisbon

Geographic Size: 92,225 km²

Population: 10,427,301 (2014 est.)

Population as% of EU population: 2.1% (2014 est.)

GDP: €173.044 billion (2014 est.)

Official Languages: Portuguese

Recognized regional languages: Mirandese

Currency: Euro €

Industries: textiles, clothing, footwear, wood and cork, paper and pulp, chemicals, lubricants, automobiles and auto parts, base metals, minerals, porcelain and ceramics, glassware, technology, telecommunications; dairy products, wine, other foodstuffs; ship construction and refurbishment; tourism, plastics, financial services, optics.



Portugal is an EU member country since 1st of January 1986 and member of the Eurozone since 1st of January 1999. Portugal is a country on the Iberian Peninsula in southwestern Europe. It is the westernmost country of mainland Europe, being bordered by the Atlantic Ocean to the west and south and by Spain to the north and east. The Portugal-Spain border is 1,214 km long and considered the longest uninterrupted border within the European Union. Portugal has a total area of 92,225 km². Portugal was one of the original member states of the Eurozone (Eurostat, 2015).

Energy Consumption of the Country

In 2001, the Portuguese government launched a new energy policy instrument – the E4 Program (Energy Efficiency and Endogenous Energies), consisting of a set of multiple, diversified measures aimed at promoting a consistent, integrated approach to energy supply and demand. By promoting energy efficiency and the use of renewable energy (endogenous) sources, the program sought to upgrade the competitiveness of the Portuguese economy and to modernize the

country's social fabric, while preserving the environment by reducing gas emissions, especially the carbon dioxide responsible for climate change.

Portugal consumed 173.43 TWh of primary energy in 2013, which is less than the previous years from 2009. Table 64 shows the energy consumption by sector from 2009 to 2013. As can be observed, the major consumer is the transport sector and the second the industrial sector. The transport sector accounts for 36.27% of the total consumption and the industrial sector the 30%.

Table 64 Energy Consumption by Sector – Portugal.

	UNIT	2009	2010	2011	2012	2013
Final consumption of industry	TWh	58.68	63.3	55.67	55.61	52.99
Final consumption of transport	TWh	84.78	85.17	84.17	78.05	62.91
Final consumption of residential	TWh	37.22	32.81	32.39	30.9	30.46
Final consumption of agriculture	TWh	4.92	5.38	5.16	5.07	5.21
Final consumption of tertiary	TWh	24.88	23.13	23.07	22.03	21.86
Total final consumption	TWh	210.48	211.4	200.72	191.67	173.43

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Major traditional manufactures include processed food, textiles, metals, machinery and ship repair, chemicals, wood (particularly cork), glass and pottery items, refined petroleum, and building materials.

Industry is diversified, ranging from automotive (Volkswagen Autoeuropa and Peugeot Citroen), aerospace (Embraer and OGMA), electronics and textiles, to food, chemicals, cement and wood pulp. Modern non-traditional technology-based industries, such as aerospace, biotechnology and information technology, have been developed in several locations across the country. Following the turn of the 21st century, many major biotechnology and information technology industries have been founded, and are concentrated in the metropolitan areas of Lisbon, Porto, Braga, Coimbra and Aveiro.

Energy Consumption of the Country's Industry

Consuming the 30% of the total energy consumption of the country, industry is a very important sector in terms of energy needs. Table 65 shows the energy consumption of fuels/sources for the industrial sector. As can be observed, the major source of consumption is heat and the electricity. The less consumed fuel is coal and the energy from renewables accounts only for the 5.13% of the final consumption of industry in 2013.

Table 65 Energy consumption of Industry by fuel/source – Portugal.

	UNIT	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	0.26	0.58	0.23	0.22	0.22
Total primary consumption	TWh	264.88	248.55	239.18	229.97	233.11
Oil products consumption of industry	TWh	12.09	12.41	10.07	8.1	7.67
Gas consumption of industry	TWh	10.43	11.08	12.25	12.09	12.11
Heat consumption of industry	TWh	12.87	15.01	15.67	15.05	15.56
Renewable consumption of industry	TWh	7.65	7.56	1.2	4.81	2.27
Electricity consumption of industry	TWh	15.37	16.66	16.24	15.33	15.17
Final consumption of industry	TWh	58.68	63.3	55.67	55.61	52.99

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the energy consumption of the industrial sector for each industry individually. Table 66 shows the energy consumption of the industrial sector by type of industry. It can be observed that the paper industry consumes the biggest amount of energy by 30.63% and then the non-metallic minerals industry with 23.65%.

Table 66 Energy Consumption of Industry Sector in 2013 by industry – Portugal.

	TWH	%
Industry	53.362	-
Iron & steel industry	2.050	3.84%
Chemical and Petrochemical industry	5.752	10.78%
Non-ferrous metal industry	0.269	0.50%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	12.619	23.65%
Transport Equipment	0.581	1.09%
Machinery	1.865	3.49%
Mining and Quarrying	1.334	2.50%
Food and TOBACCO	4.888	9.16%
Paper, Pulp and Print	16.344	30.63%
Wood and Wood Products	1.157	2.17%
Construction	1.642	3.08%
Textile and Leather	3.368	6.31%
Non-specified (Industry)	1.494	2.80%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Romania



Capital: Bucharest

Geographical size: 238 391 km²

Population: 19 942 642 (2014)

Population as % of EU population: 3.9 % (2014)

GDP: € 150.019 billion (2014)

Official EU language(s): Romanian

Currency: Romanian Leu RON

Industries: electric machinery and equipment, textiles and footwear, light machinery, auto assembly, mining, timber, construction materials, metallurgy, chemicals, food processing, petroleum refining



Romania, officially the Republic of Romania, located in the eastern Europe and in border with the Black Sea and Moldova on the west, Ukraine in the north, Hungary and Serbia in the east, and Bulgaria in the south. Romania's capital is Bucharest and the country's population in 014 was 19,942,642habitats. The country's GPD was €150.019 billion in 2014, it has been an EU member since 1st of January 2007 and is not a member of the Schengen area.

Romania's sectors with the highest impact factor on economy in 2014 were industry (27.3 %), wholesale and retail trade, transport, accommodation and food services (17.9 %) and public administration, defense, education, human health and social work activities (10.3 %).

Energy Consumption of Country

Croatia's total energy consumption in 2011 was reported at 280.61 TWh and is presented in Table 67 with the energy consumption of the country's different sectors from 2009 to 2013. The source (national statistics) does not report the years 2012 and 2013 and this is due to the lack of information provided by the country's energy department. Nevertheless, the highest reported energy consuming sector in 2011 was the industry sector followed by the residential sector. The least consuming energy sector is the agriculture with a big difference from the second to last, tertiary sector.

Table 67 Energy Consumption by Sector –Romania.

	Unit	2009	2010	2011	2012	2013
<i>Final consumption of industry</i>	TWh	76.61	86.19	98.1	n.a.	n.a.
<i>Final consumption of transport</i>	TWh	62.8	59.24	56.55	n.a.	n.a.
<i>Final consumption of residential</i>	TWh	93.18	94.29	96.02	n.a.	n.a.
<i>Final consumption of agriculture</i>	TWh	4.26	4.4	4.64	n.a.	n.a.
<i>Final consumption of tertiary</i>	TWh	21.56	23.82	25.6	n.a.	n.a.
<i>Total final consumption</i>	TWh	259.43	268.24	280.61	n.a.	n.a.

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Romania's leading industrial branches consist of electric machinery and equipment, textiles and footwear, light machinery, auto assembly, mining, timber, construction materials, metallurgy, chemicals, food processing, petroleum refining.

Romania's export partners consist of Germany, Italy and France where the country's export activities are related to machinery and equipment, metals and metal products, textiles and footwear, chemicals, agricultural products, minerals and fuels (Central Intelligence Agency, 2016). The main import partners consist of Germany, Italy and Hungary and the commodities consist of machinery and equipment, chemicals, fuels and minerals, metals, textile and products, agricultural products.

Energy Consumption of the Country's Industry

Romania's industry consumption by source/fuel is presented in Table 68 from 2009 to 2013. The gas as fuel has the highest consumption and coal consumption as fuel follows in 2011. The least consumption by fuel is reported to be the heat source and the renewable sources. An increase in the total energy consumption is observed in all the fuel/sources.

Table 68 Energy consumption of Industry by fuel/source- Romania.

	Unit	2009	2010	2011	2012	2013
<i>Coal consumption of industry</i>	TWh	8.95	14.99	25.08	n.a.	n.a.
<i>Oil products consumption of industry</i>	TWh	11.41	10.48	9.63	n.a.	n.a.
<i>Gas consumption of industry</i>	TWh	32.83	34.13	35.49	n.a.	n.a.
<i>Heat consumption of industry</i>	TWh	2.76	3.29	3.4	n.a.	n.a.
<i>Renewable consumption of industry</i>	TWh	2.47	2.91	3.43	n.a.	n.a.
<i>Electricity consumption of industry</i>	TWh	18.2	20.4	21.08	n.a.	n.a.
<i>Final consumption of industry</i>	TWh	76.61	86.19	98.1	n.a.	n.a.

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

The country's industry sectors are presented in Table 69. The highest consumption is observed in the Iron & steel industry sector and the Chemical and Petrochemical industry. The Non-ferrous metal industry does not consume any source of energy since it is not used and the Mining and Quarrying also produce the minimum amount of energy.

Table 69 Energy Consumption of Industry Sector in 2013 by industry – Romania.

	TWh	%
Industry	73.38	-
<i>Iron & steel industry</i>	19.45	26.50
<i>Chemical and Petrochemical industry</i>	19.14	26.08
<i>Non-ferrous metal industry</i>	0.00	0.00
<i>Non-metallic Minerals (Glass, pottery & building mat. Industry)</i>	9.18	12.51
<i>Transport Equipment</i>	2.39	3.25
<i>Machinery</i>	4.19	5.71
<i>Mining and Quarrying</i>	0.50	0.69
<i>Food and TOBACCO</i>	6.15	8.38
<i>Paper, Pulp and Print</i>	0.93	1.27
<i>Wood and Wood Products</i>	3.02	4.11
<i>Construction</i>	4.57	6.23

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Slovakia



Capital: Bratislava

Geographical size: 49,035 km²

Population: 5,415,949 (2014)

Population as % of EU population: 1.1 % (2014)

GDP: € 75.215 billion (2014)

Official EU language(s): Slovak

Currency: Euro

Industries: automobiles, metal and metal products, electricity, gas, coke, oil, nuclear fuel, chemicals, synthetic fibers, wood and paper products, machinery, earthenware and ceramics, textiles, electrical and optical apparatus, rubber products, food and beverages, pharmaceutical.



Slovakia is a country in Central Europe. It is bordered by the Czech Republic and Austria to the west, Poland to the north, Ukraine to the east and Hungary to the south. Slovakia's territory spans 49,035 square kilometres and it is mostly mountainous. The population is over 5 million and comprises mostly ethnic Slovaks. The capital and largest city is Bratislava. The country joined the European Union in 2004 and the Eurozone on 1 January 2009. The Slovak economy is a developed, high-income economy, with the GDP per capita equaling to 76% of the average of the European Union in 2014 (GDP: € 75.215 billion in 2014). The ratio of government debt to GDP in Slovakia reached 58% by the end of 2013. Slovakia is an attractive country for foreign investors mainly because of its low wages, low tax rates and well educated labour force. In recent years, Slovakia has been pursuing a policy of encouraging foreign investment. Slovakia's main export partners are Germany, the Czech Republic and Poland while its main import partners are Germany, the Czech Republic and Austria (Central Intelligence Agency, 2016), (Europa, 2016).

Energy Consumption of Country

The energy consumption for each sector from 2009 to 2013 for Slovakia is shown in Table 70. As can be observed for the last five years, the industrial sector is the bigger consumer and then the transport and the residential sector. Agriculture is the least consumer, having a large difference compared to the other sectors.

Table 70 Energy Consumption by Sector – Slovakia

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	41.86	50.58	49.27	50.27	49.63
Final consumption of transport	TWh	27.41	30.62	30.66	27.18	27.33
Final consumption of residential	TWh	24.95	26.87	24.67	24.02	24.97
Final consumption of agriculture	TWh	1.5	1.55	1.83	1.66	1.53
Final consumption of tertiary	TWh	22.51	24.35	18.57	16.78	22.87
Total final consumption	TWh	118.23	133.97	125	119.91	126.33

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Although Slovakia's GDP comes mainly from the tertiary (services) sector, the industrial sector also plays an important role within its economy. The main industry sectors are car manufacturing and electrical engineering. Since 2007, Slovakia has been the world's largest producer of cars per capita, with a total of 571,071 cars manufactured in the country in 2007 alone. The most important sectors of Slovakia's economy in 2014 were industry (24.7%), wholesale and retail trade, transport, accommodation and food services (22.4%) and public administration, defense, education, human health and social work activities (14.5%).

Energy Consumption of the Country's Industry

The industrial sector plays an important role on the country's energy consumption. The energy consumption of the industrial sector by fuel from 2009 to 2013 is shown in Table 71. It can be observed that the most consumed fuel in 2013 was the gas followed by coal and electricity. The oil products and heat consumption are the least consumed sources in industry.

Table 71 Energy consumption of Industry by fuel/source – Slovakia

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	11.09	15.16	13.55	14.67	14.65
Oil products consumption of industry	TWh	1.53	1.26	1.23	1.93	0.77
Gas consumption of industry	TWh	12.92	17.62	17.75	16.79	16.59
Heat consumption of industry	TWh	0.95	1.24	1.22	1.82	1.7
Renewable consumption of industry	TWh	4.58	4.37	4.28	3.15	4.14
Electricity consumption of industry	TWh	10.78	10.93	11.24	11.91	11.78
Final consumption of industry	TWh	41.86	50.58	49.27	50.27	49.63

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 72 shows the energy consumption of each industrial sector. The biggest consumer is the iron and steel industry with 51.66% of total industrial consumption.

Table 72 Energy Consumption of Industry Sector in 2013 by industry – Slovakia

	TWH	% of total industry
Industry	49.641	100.00%
Iron & steel industry	25.643	51.66%
Chemical and Petrochemical industry	3.433	6.92%
Non-ferrous metal industry	2.844	5.73%
Non-metallic Minerals (Glass. pottery & building mat. Industry)	4.536	9.14%
Transport Equipment	1.856	3.74%
Machinery	2.173	4.38%
Mining and Quarrying	0.076	0.15%
Food and TOBACCO	1.588	3.20%
Paper. Pulp and Print	5.014	10.10%
Wood and Wood Products	0.470	0.95%
Construction	0.342	0.69%
Textile and Leather	0.330	0.66%
Non-specified (Industry)	1.337	2.69%

Source: (Eurostat, 2015), Conversion base: 1toe=11630kWh

Slovenia



Capital: Ljubljana

Geographical size: 20 273 km²

Population: 2 061 085 (2014)

Population as % of EU population: 0.4 % (2014)

GDP: € 37.246 billion (2014)

Official EU language(s): Slovenian

Currency: Euro

Industries: ferrous metallurgy and aluminum products, lead and zinc smelting; electronics (including military electronics), trucks, automobiles, electric power equipment, wood products, textiles, chemicals, machine tools



Slovenia, officially the Republic of Slovenia, is a country in the southern central Europe and is in border with Croatia in the south, Hungary in the east, Austria in the north and Italy and Adriatic Sea in the west. Slovenia's capital is Ljubljana, has a population of 2,061,085 habitants in 2014 with 0.4% of EU population and covers an area of 20,273 km². The country's GDP rate at 2014 was €37.246 billion, Slovenia is an EU member since 1st of May 2004, member of the Eurozone since 1st of January 2007 and is a member of the Schengen area (Europa, 2016).

Slovenia's most important economy sectors in 2014 were industry (27.1 %), wholesale and retail trade, transport, accommodation and food services (20.4 %) and public administration, defence, education, human health and social work activities (17.0 %) (Europa, 2016).

Energy Consumption of Country

Slovenia's total energy consumption was 56.49 TWh in 2013 and the energy consumption for each sector from 2009 to 2013 is presented in Table 73. The highest consumption in 2013 is observed to be the transport sector followed by the industry sector, and the agriculture sector is consuming the least amount of energy.

Table 73 Energy Consumption by Sector – Slovenia

	Unit	2009	2010	2011	2012	2013
<i>Final consumption of industry</i>	TWh	14.19	14.8	14.37	14.03	13.92
<i>Final consumption of transport</i>	TWh	20.42	21.6	22.61	23.06	22.42
<i>Final consumption of residential</i>	TWh	14.04	14.53	14.04	13.71	13.44
<i>Final consumption of agriculture</i>	TWh	0.77	0.87	0.84	0.88	0.87
<i>Final consumption of tertiary</i>	TWh	5.96	6.45	6.39	5.62	5.85
<i>Total final consumption</i>	TWh	55.37	58.24	58.26	57.3	56.49

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Slovenia's major industries are ferrous metallurgy and aluminum products, lead and zinc smelting; electronics (including military electronics), trucks, automobiles, electric power equipment, wood products, textiles, chemicals, machine tools.

Slovenia's export partners consist of Germany, Italy and Austria and the commodities exported are manufactured goods, machinery and transport equipment, chemicals, food. The import partners in 2014 are Germany 16.2%, Italy 14.4%, Austria 10.3%, South Korea 4.6%, China 4.4%, Croatia 4.3%, Hungary 4.1% and the commodities imported are machinery and transport equipment, manufactured goods, chemicals, fuels and lubricants, food (Central Intelligence Agency, 2016).

Energy Consumption of the Country's Industry

Table 74 presents the energy consumption of the industry's sector by source/fuel from 2009 to 2013. It can be observed that the leading source used in the electricity followed by the Gas fuel. Energy consumption from the Heat source is the least consumed with the renewable energy sources.

Table 74 Energy consumption of Industry by fuel/source – Slovenia

	Unit	2009	2010	2011	2012	2013
<i>Coal consumption of industry</i>	TWh	0.63	0.55	0.62	0.59	0.55
<i>Oil products consumption of industry</i>	TWh	1.78	1.47	1.33	1.23	1.35
<i>Gas consumption of industry</i>	TWh	5.22	5.62	4.95	4.84	4.58
<i>Heat consumption of industry</i>	TWh	0.66	0.62	0.68	0.64	0.6
<i>Renewable consumption of industry</i>	TWh	0.93	1.05	0.94	0.82	0.95
<i>Electricity consumption of industry</i>	TWh	4.97	5.49	5.86	5.92	5.88
<i>Final consumption of industry</i>	TWh	14.19	14.8	14.37	14.03	13.92

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

The energy consumed by the industry's sub sectors are presented in Table 75 for the year 2013. The Non-metallic Minerals (Glass, pottery & building mat. Industry) sub industry sector has the highest energy consumption followed by the Paper, Pulp and Print industry sector. In addition, it

can be observed that the Iron & steel industry, the Chemical and Petrochemical industry and the Non-ferrous metal industry are consuming the approximately the same amount of energy. The sub industry with the minimum amount of energy consumed is the Mining and Quarrying industry with the Construction industry and the Textile and Leather following with the same amount of energy.

Table 75 Energy Consumption of Industry Sector in 2013 by industry – Slovenia

	TWh	%
Industry	13.91	-
Iron & steel industry	1.72	12.33
Chemical and Petrochemical industry	1.74	12.50
Non-ferrous metal industry	1.75	12.56
Non-metallic Minerals (Glass, pottery & building mat. Industry)	2.08	14.96
Transport Equipment	0.37	2.65
Machinery	1.55	11.13
Mining and Quarrying	0.18	1.32
Food and TOBACCO	0.73	5.23
Paper, Pulp and Print	1.92	13.76
Wood and Wood Products	0.45	3.23
Construction	0.31	2.19
Textile and Leather	0.31	2.25
Non-specified (Industry)	0.82	5.89

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Spain



Capital City: Madrid

Geographic Size: 505,970 km²

Population: 46,507,760 (2014 est.)

Population as% of EU population: 9.2% (2014 est.)

GDP: €1.058 trillion (2014 est.)

Official Languages: Spanish (74%)

Recognized regional languages: Catalan 17%, Galician 7%, and Basque 2%

Currency: Euro €

Industries: textiles and apparel (including footwear), food and beverages, metals and metal manufactures, chemicals, shipbuilding, automobiles, machine tools, tourism, clay and refractory products, footwear, pharmaceuticals, medical equipment.



Spain is an EU member country since 1st of January 1986 and a member of the Eurozone since 1st of January 1999. Spain covers an area of 505,970 km² from which 498,980 km² land and 6,990 km² water. Spain is the world's fifty-second largest country and Europe's fourth largest country. It is some 47,000 km² smaller than France and 81,000 km² larger than the US state of California. Mount Teide (Tenerife) is the highest mountain peak in Spain and is the third largest volcano in the world from its base (europa.eu, 2015).

Spain is located in Southwestern Europe, bordering the Mediterranean Sea, North Atlantic Ocean, Bay of Biscay, and Pyrenees Mountains; southwest of France. Due to the strategic location along approaches to Strait of Gibraltar; Spain controls a number of territories in northern Morocco including the enclaves of Ceuta and Melilla, and the islands of Penon de Velez de la Gomera, Penon de Alhucemas, and Islas Chafarinas.

Spain's capitalist mixed economy is the 16th largest worldwide and the 5th largest in the European Union, as well as the Eurozone's 4th largest. After experiencing a prolonged recession in the wake of the global financial crisis that began in 2008, in 2014 Spain marked the first full year of positive economic growth in seven years, largely due to increased private consumption. At the onset of

the global financial crisis Spain's GDP contracted by 3.7% in 2009, ending a 16-year growth trend, and continued contracting through most of 2013. Spain is a middle power and a developed country with the world's fourteenth largest economy by nominal GDP and sixteenth largest by purchasing power parity (CIA, 2015).

Energy Consumption of Country

Spain is one of the world's leading countries in the development and production of renewable energy. Renewable energies sources (RES) consumption reached 15.9% for final energy consumption in Spain in 2014. The final objective for 2020 is 20%. In 2010 Spain became the solar power world leader when it overtook the United States with a massive power station plant called La Florida, near Alvarado, Badajoz. Spain is also Europe's main producer of wind energy. In 2010 its wind turbines generated 42,976 GWh, which accounted for 16.4% of all electrical energy produced in Spain. On 9 November 2010, wind energy reached an instantaneous historic peak covering 53% of mainland electricity demand and generating an amount of energy that is equivalent to that of 14 nuclear reactors. Other renewable energies used in Spain are hydroelectric, biomass and marine. Non-renewable energy sources used in Spain are nuclear (8 operative reactors), gas, coal, and oil. Fossil fuels together generated 58% of Spain's electricity in 2009, just below the OECD mean of 61%. Nuclear power generated another 19%, and wind and hydro about 12% each (CIA, 2015).

Spain consumed 939.37 TWh of primary energy in 2013. In 2014, total consumption per capita was 2.4 toe (21% lower than the EU average) and electricity consumption per capita was 5,000 kWh (8.5% below the EU average). The energy consumption for each sector from 2009 to 2013 for Italy is shown in Table 76. As can be observed, the transport sector is the bigger consumer and then the industrial and residential sectors.

Table 76 Energy Consumption by Sector –Spain.

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	246.25	250.33	247.55	240.73	241.28
FINAL CONSUMPTION OF TRANSPORT	TWh	438.58	430.52	417.31	386.37	370.1
FINAL CONSUMPTION OF RESIDENTIAL	TWh	183.73	195.02	179.73	178.37	172.19
FINAL CONSUMPTION OF AGRICULTURE	TWh	27.4	25.97	27.85	31.47	32.4
FINAL CONSUMPTION OF TERTIARY	TWh	109.4	113.96	118.68	116.78	111.21
TOTAL FINAL CONSUMPTION	TWh	1018.14	1034.97	1005.23	964.68	939.37

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Spain's most important industries include tourism, chemicals and petro-chemicals, heavy industry and food and beverages. Spain is also Europe's fourth large manufacturing country after Germany, France and Italy.

The automotive industry is one of the largest employers in the country. By 2009 it employed 9% of the total workforce and contributed to 3.3% of the Spanish GDP. In 2008 the contribution of

the automobile industry rose up to 18% of the country's total exports, becoming the 2nd most exported industry. In 2014 Spain produced over 2.4 million cars which made it the 9th largest automobile producer country in the world and the 2nd largest car manufacturer in Europe after Germany.

Energy Consumption of the Country's Industry

As shown earlier, industrial sector plays an important role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 77 shows the energy consumption of the industrial sector by fuel from 2009 to 2013. As can be seen, after the total primary consumption, the more consumed source is the electricity and the most consumed fuel is gas. The less consumed energy in industry is the energy from heat which is zero.

Table 77 Energy consumption of Industry by fuel/source- Spain.

	UNIT	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	10.39	12.97	15.78	11.61	15.54
TOTAL PRIMARY CONSUMPTION	TWh	1497.55	1490.25	1475.86	1455.25	1377.87
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	55.03	57.18	50.66	40.54	31.16
GAS CONSUMPTION OF INDUSTRY	TWh	90.01	93.37	93.06	101.35	107.72
HEAT CONSUMPTION OF INDUSTRY	TWh	0	0	0	0	0
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	14.02	13.32	14.6	14.76	16.88
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	76.8	73.49	73.45	72.47	69.98
FINAL CONSUMPTION OF INDUSTRY	TWh	246.25	250.33	247.55	240.73	241.28

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

It is also important to see the sectors of industry that the energy is consumed. Table 78 shows the consumption of industrial sector by each industry. As can be observed, the biggest consumer is the chemical and petrochemical industry and then the non-metallic minerals (glass, pottery and building materials).

Table 78 Energy Consumption of Industry Sector in 2013 by industry – Spain.

	TWH	%
Industry	243.945	-
Iron & steel industry	37.236	15.26%
Chemical and Petrochemical industry	46.673	19.13%
Non-ferrous metal industry	12.759	5.23%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	39.338	16.13%
Transport Equipment	4.465	1.83%
Machinery	10.041	4.12%
Mining and Quarrying	4.896	2.01%
Food and TOBACCO	25.259	10.35%
Paper, Pulp and Print	23.864	9.78%
Wood and Wood Products	5.896	2.42%
Construction	14.559	5.97%
Textile and Leather	4.018	1.65%
Non-specified (Industry)	14.942	6.13%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Sweden



Capital: Stockholm

Geographical size: 438,574 km²

Population: 9,644,864 (2014)

Population as % of EU population: 1.9 % (2014)

GDP: € 430.258 billion (2014)

Official EU language(s): Swedish

Currency: Swedish krona SEK

Industries: iron and steel, precision equipment (bearings, radio and telephone parts, armaments), wood pulp and paper products, processed foods, motor vehicles



Sweden is a Scandinavian country in Northern Europe. It borders Norway to the west and Finland to the east, and is connected to Denmark in the southwest by a bridge-tunnel. At 438,574 square kilometres, Sweden is the third-largest country in the European Union by surface area, with a total population of over 9.6 million (2014). Sweden consequently has a low population density, with the highest concentration in the southern half of the country. The capital city is Stockholm, which is also the most populous city in the country. Approximately 85% of the population lives in urban areas. Southern Sweden is predominantly agricultural, while the north is heavily forested. Sweden provides universal health care and tertiary education for its citizens. It has the world's eighth-highest per capita income and ranks highly in numerous metrics of national performance, including quality of life, health, education, protection of civil liberties, economic competitiveness, equality, prosperity and human development. The most important sectors of Sweden's economy in 2014 were public administration, defense, education, human health and social work activities (24.5%), industry (19.7%) and wholesale and retail trade, transport, accommodation and food services (17.4%). Sweden's main export partners are Norway, Germany and the UK, while its main import partners are Germany, Norway and the Netherlands. Sweden's engineering sector

accounts for 50% of output and exports, while telecommunications, the automotive industry and the pharmaceutical industries are also of great importance. Sweden is the ninth-largest arms exporter in the world. Agriculture accounts for 2% of GDP and employment. The country ranks among the highest for telephone and Internet access penetration. Finally, Sweden has been a member of the European Union since 1 January 1995, but declined Eurozone membership following a referendum (Central Intelligence Agency, 2016), (Europa, 2016).

Energy Consumption of Country

Table 79 shows the energy consumption of Hungary for each sector (industry, transport, residential, agriculture, and tertiary) for the period 2009 – 2013. The big sectors in 2013 considering the energy consumption of the country were the industry, the transport and the residential sector. In addition, agriculture is the least consumer of all remaining sectors.

Table 79 Energy Consumption by Sector – Sweden

	Unit	2009	2010	2011	2012	2013
Final consumption of industry	TWh	137.21	151.74	148.19	143.6	142.14
Final consumption of transport	TWh	97.05	98.94	98.25	94.42	93.9
Final consumption of residential	TWh	86.18	92.31	84.52	86.25	86.23
Final consumption of agriculture	TWh	10.28	10.78	10.99	9.64	10.04
Final consumption of tertiary	TWh	45.47	48.58	44.84	45.61	45.89
Total final consumption	TWh	376.39	402.34	387.16	383.86	378.19

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

Sweden is a highly industrialized country. Sweden's main industries are iron and steel, precision equipment (bearings, radio and telephone parts, armaments), wood pulp and paper products, processed foods and motor vehicles. The Swedish sawmill industry is still the largest in Europe and accounts for about 10% of the world's exports. In the pulp and paper industries, Sweden was the third largest exporter in the world in the early 90s. The Swedish forestry is the main supplier to the forest industry.

Over the course of the 20th century, Swedish industry has evolved from traditional sectors with lower added value, such as wood and iron ore processing, to modern industries with a higher degree of skill and technology input, such as automobiles and precision and specialized engineering. The change of priorities became even more evident in the 1990s, with the emergence of new research-intensive industries, such as information technology and pharmaceuticals, which replaced the more traditional engineering industries as the driving force of growth and business activity. During this transition, some sectors, like textiles and iron,

contracted considerably while others, such as shipbuilding, have all but disappeared, but Swedish restructuring has been smooth in terms of economic and social stability. By 2000, major industries included information technology (telephone, radio, and computer equipment), communications, pharmaceuticals, precision equipment (bearings and armaments), high-quality steel, automobiles, electrical motors and other electrical equipment, printed and published goods (including software and popular music), home and office furnishings, and processed foods.

Energy Consumption of the Country's Industry

The industrial sector plays a significant role on the country's energy consumption. However, it is also important to identify the consumption of fuel/sources for the industrial sector. Table 80 shows the energy consumption of the industrial sector of Sweden by fuel/source from 2009 to 2013. Renewable energy is the leading source of the industrial consumption, followed by the electricity source. The less consumed energy in industry is the heat.

Table 80 Energy consumption of Industry by fuel/source – Sweden

	Unit	2009	2010	2011	2012	2013
Coal consumption of industry	TWh	9.76	14.96	14.08	15.69	17.42
Oil products consumption of industry	TWh	14.7	15.14	13.49	11.44	9.8
Gas consumption of industry	TWh	6.38	6.27	5.95	6.24	5.67
Heat consumption of industry	TWh	4.45	7.34	6.87	4.17	4.08
Renewable consumption of industry	TWh	52.75	55.46	54.84	54.65	55.26
Electricity consumption of industry	TWh	49.18	52.56	52.98	51.41	49.9
Final consumption of industry	TWh	137.21	151.74	148.19	143.6	142.14

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

As we can see from Table 81, the leading industry in 2013 was wood pulp and paper products, followed by iron and steel industry. The textile and leather industries consume the least energy considering all sectors.

Table 81 Energy Consumption of Industry Sector in 2013 by industry – Sweden

	TWh	% of total industry
Industry	133.219	100.00%
Iron & steel industry	18.348	13.77%
Chemical and Petrochemical industry	6.477	4.86%
Non-ferrous metal industry	3.827	2.87%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	3.719	2.79%
Transport Equipment	2.346	1.76%
Machinery	4.001	3.00%
Mining and Quarrying	5.196	3.90%
Food and TOBACCO	4.376	3.28%
Paper, Pulp and Print	68.016	51.06%
Wood and Wood Products	6.298	4.73%
Construction	1.125	0.84%
Textile and Leather	0.228	0.17%
Non-specified (Industry)	9.263	6.95%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

United Kingdom



Capital City: London

Geographical size: 248,528 km²

Population: 64,308,261 (2015 est.)

Population as % of EU population: 12.7%

GDP: €2.223 trillion (2014 est.)

Official Languages: English

Recognized regional languages: Scottish, Irish

Currency: Pound Sterling £

Industries: machine tools, electric power equipment, automation equipment, railroad equipment, shipbuilding, aircraft, motor vehicles and parts, electronics and communications equipment, metals, chemicals, coal, petroleum, paper and paper products, food processing, textiles, clothing, other consumer goods.



United Kingdom is an EU member country since 1st of January 1973. United Kingdom is a sovereign state in Europe. UK has a total area of 248,528 km². Lying off the north-western coast of the European mainland, it includes the island of Great Britain—a term also applied loosely to refer to the whole country—the north-eastern part of the island of Ireland and many smaller islands (Eurostat, 2015).

The United Kingdom is a developed country and has the world's fifth-largest economy by nominal GDP and tenth-largest economy by purchasing power parity. The UK, a leading trading power and financial center, is the third largest economy in Europe after Germany and France. Agriculture is intensive, highly mechanized, and efficient by European standards, producing about 60% of food needs with less than 2% of the labor force. The UK has large coal, natural gas, and oil resources, but its oil and natural gas reserves are declining and the UK has been a net importer of energy since 2005. Services, particularly banking, insurance, and business services, are key drivers of British GDP growth. Manufacturing, meanwhile, has declined in importance but still accounts for about 10% of economic output (CIA, 2015). The United Kingdom (UK) is the sixth largest economy in the world, as well as the largest producer of oil and the second-largest producer of natural gas in the European Union (EU) (CIA, 2015).

Energy Consumption of the Country

United Kingdom consumed 939.37 TWh of primary energy in 2013 and this is the lowest consumption for the previous 4 years. As shown in Table 82 for the country's energy consumption by sector, the biggest energy consumer is the transport sector and the second bigger is the industrial sector

Table 82 Energy Consumption by Sector – United Kingdom

	Unit	2009	2010	2011	2012	2013
FINAL CONSUMPTION OF INDUSTRY	TWh	246.25	250.33	247.55	240.73	241.28
FINAL CONSUMPTION OF TRANSPORT	TWh	438.58	430.52	417.31	386.37	370.1
FINAL CONSUMPTION OF RESIDENTIAL	TWh	183.73	195.02	179.73	178.37	172.19
FINAL CONSUMPTION OF AGRICULTURE	TWh	27.4	25.97	27.85	31.47	32.4
FINAL CONSUMPTION OF TERTIARY	TWh	109.4	113.96	118.68	116.78	111.21
TOTAL FINAL CONSUMPTION	TWh	1018.14	1034.97	1005.23	964.68	939.37

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

Description of the Industrial Sector of the Country

The United Kingdom, where the industrial revolution began in the late 18th century, has a long history of manufacturing, which contributed to Britain's early economic growth. During the second half of the 20th century, there was a steady decline in the importance of manufacturing and the economy of the United Kingdom shifted toward services, although manufacturing remained important for overseas trade and accounted for 83% of exports in 2003. In June 2010, manufacturing in the United Kingdom accounted for 8.2% of the workforce and 12% of the country's national output. The East Midlands and West Midlands (at 12.6 and 11.8% respectively) were the regions with the highest proportion of employees in manufacturing (CIA, 2015).

Other important sectors of the manufacturing industry include food, drink, tobacco, paper, printing, publishing and textiles. The UK is also home to three of the world's biggest brewing companies: Diageo, SABMiller and Scottish and Newcastle, other major manufacturing companies such as Unilever, Cadbury, Tate & Lyle, British American Tobacco, Imperial Tobacco, EMAP, HarperCollins, Reed Elsevier being amongst the largest present.

The British aerospace industry is the second- or third-largest national aerospace industry depending on the method of measurement. The pharmaceutical industry plays an important role in the economy and the UK has the third-highest share of global pharmaceutical R&D. The automotive industry is also a major employer and exporter.

Energy Consumption of the Country's Industry

Regarding the industrial sector and the energy consumption by this sector, the most consumed source is the electricity and the gas. Table 83 shows the energy consumption of industry by fuel/source from 2009 to 2013.

Table 83 Energy consumption of Industry by fuel/source – United Kingdom.

	UNIT	2009	2010	2011	2012	2013
COAL CONSUMPTION OF INDUSTRY	TWh	18.28	20.62	18.29	18.69	22.61
TOTAL PRIMARY CONSUMPTION	TWh	2279.67	2345.56	2191.34	2242.44	2230.17
OIL PRODUCTS CONSUMPTION OF INDUSTRY	TWh	56.45	60.16	49.34	51.19	47.43
GAS CONSUMPTION OF INDUSTRY	TWh	82.12	89.02	85.05	82.36	83.69
HEAT CONSUMPTION OF INDUSTRY	TWh	8.87	9.56	8.95	8.9	10.71
RENEWABLE CONSUMPTION OF INDUSTRY	TWh	4.12	4.46	5.01	4.57	5.69
ELECTRICITY CONSUMPTION OF INDUSTRY	TWh	99.72	104.5	102.34	98.16	97.65
FINAL CONSUMPTION OF INDUSTRY	TWh	269.55	288.33	268.98	263.86	267.77

Source: (Odyssee, 2015)

Conversion base: 1toe=11630kWh

As shown in Table 84, from the industrial sector, most energy goes to the iron and steel industry and then to the chemical and petrochemical industry. According to the table, the mining and quarrying industry accounts only 0.05% of the total energy consumption of the industrial sector.

Table 84 Energy Consumption of Industry Sector in 2013 by industry – United Kingdom.

	TWH	%
Industry	299.006	-
Iron & steel industry	45.044	15.06%
Chemical and Petrochemical industry	37.813	12.65%
Non-ferrous metal industry	6.323	2.11%
Non-metallic Minerals (Glass, pottery & building mat. Industry)	30.460	10.19%
Transport Equipment	11.344	3.79%
Machinery	20.854	6.97%
Mining and Quarrying	0.150	0.05%
Food and TOBACCO	31.142	10.42%
Paper, Pulp and Print	18.955	6.34%
Wood and Wood Products	0	0%
Construction	7.172	2.40%
Textile and Leather	8.432	2.82%
Non-specified (Industry)	81.317	27.20%

Source: (Eurostat, 2015)

Conversion base: 1toe=11630kWh

Part II:

Major industrial sectors in EU-28: waste heat streams and respective temperature levels

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1 Iron and Steel Production

1.1 Description of the industry

During the Industrial revolution, the iron and steel along with the coal and cotton were the primary materials used. Since the eighteenth century the industry has developed and has advanced in increasing the output. A sudden increase of Crude steel production since 2000 and the main reason for the worldwide increase is that China tripled its steel production in 2006 (Stahl, 2008). By analyzing the location of integrated steelworks in the EU-27 it can be observed that steelworks are focused in Central Europe and that most of the EU member countries have an integrated steelwork.

1.2 Processes used involving heat

There are four methods worldwide used for the steelmaking process: the blast furnace/basic oxygen furnace route, the direct melting of scrap (electric arc furnace), the smelting reduction and the direct reduction. In this section only the processes that implicate waste heat in the process are outlined. The following figure presents the four methods and the processes involved.

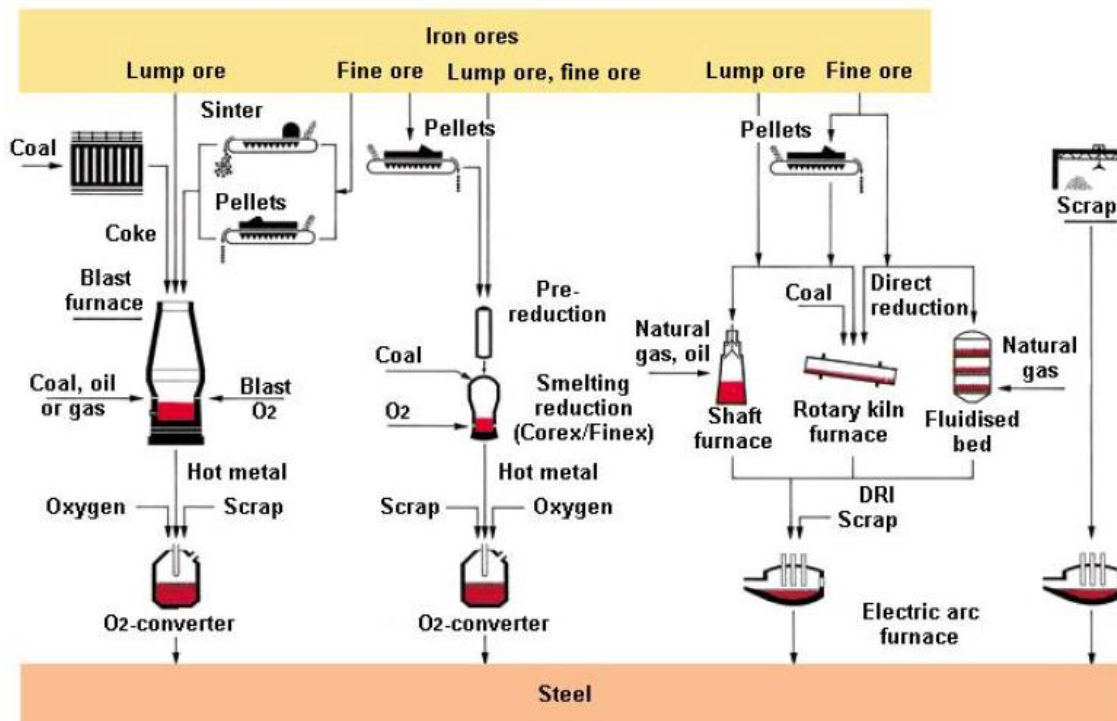


Figure 1 Crude steel production methods (Degner, 2008)

European steel production in 2006 was based on the blast furnace/basic oxygen route (59.8%) and the Electric Arc Furnace (EAF) route (40.2%) where the world output of Direct Reduce Iron (DRI) was only represented by Germany and Sweden with 1.5% and Direct Reduction (DR) with 6.8% (Hille, 1997) (Commission, 2001).

1.2.1 Techniques to improve heat recovery

Heat recovery can improve energy efficiency in the steel manufacturing process and some options include:

- the recovery of waste heat by heat exchangers or the district heating network,
- Installation of steam boilers in large reheating furnaces,
- Preheating of the combustion air in furnaces and other boiler systems to save fuel,
- Recover heat from products e.g. sinter,
- Where steel needs to be cooled, the use of heat pumps and solar panels,
- Use of flue-gas boilers in furnaces with high temperatures,

The oxygen evaporation and compressor cooling to exchange energy across heat exchangers.

In integrated steelworks, there is a need for steam for heating and specific purposes. Steam is processed in the blast furnace operations, the coking plant (steam turbine for gas exhausting), and for vacuum treatment in the steel plant. Most of the steam should be produced by heat recovery where applicable. The demand for steam determines the amount of waste heat recovered. Additionally, heat recovery from the EAF steelmaking plants can be applied similar to the cooling systems.

1.2.2 Sinter plants

Sinter process has a charge that consists of a mixture of fine ores, additives and recycled iron-bearing materials, to which coke breeze is added to enable the ignition of the total charge. Down draft sintering on continuous travelling grates is only used in Europe.

- Sinter strand operation

The temperatures from the Sinter strand operation and in the zone of incineration (sintering zone) reaches 1300-1480 °C. There are different layers in the sinter strand operation with different temperatures. Such zones are the drying zone (100-200 °C), the evaporation zone (200-900 °C), the calcination and reduction zone (900-1000 °C), incineration or sintering zone (1100-1400 °C), the oxidation zone (1200-1400 °C) and the cooling zone (50-1200 °C).

- Sinter cooling and seduction operation

In the hot sinter cooling screening and cooling process the waste gas can reach temperatures up to 300 °C and can be used in a waste heat boiler by recirculating the hot gases for preheating

combustion air in the sinter grate ignition hoods, and by preheating the sinter raw mix or for the sinter process.

Potential heat recovery from the Sinter plants can be found in two forms, the heat from the main exhaust gas from the sintering machines and the heat from the cooling air from the sinter cooler. Concerning the heat recovered from the sinter bed cooling air there is more than one way for the heat to be recovered. The following methods are considered:

- Steam generation in a waste heat boiler for use in the iron and steel works
- Hot water generation for district heating
- Preheating combustion air in the ignition hood of the sinter plant
- Preheating the sinter raw mix
- Use of the sinter cooler gases in a waste gas recirculation system.

It cannot be processed to recover heat from the exhaust gas with the aid of a heat exchanger, due to condensations and corrosion issues but with the use of Partial waste gas recirculation where the heat is redirected back to the sinter bed.

1.2.3 Palletization plants

Palletization is the process small crystallized balls of iron ore are produced termed pellets. The process consists of 4 different stages, the grinding and drying or dewatering, the wetting and mixing, the balling and induration and lastly the screening and handling. Same as the Sintering process, the palletization process are complementary process routes for preparation of iron oxide raw materials. There are six in total Palletization plants in Europe, where only one in the Netherlands is integrated steelworks and the rest are standalone in Sweden. The total production of these plants in 2007 was 27 million tons/year whereas the consumption of the EU-25 in 2007 was 43 million tons.

- Induration process

The process that waste heat can be recovered is in the induration process (thermal treatment), which consist of drying and, heating and cooling where is then separated into two different systems, the “straight grate” and the “grate kiln”. In the “straight grate” system the green balls are heated to a temperature of 1300-1350 °C during oxidation and sintering to obtain pellets of a high strength, which is achieved with a row of burners on each side of the travelling grate. Concerning the “grate kiln” system, it is similar to the “straight grate” system where there is a travelling grate but consist only of a single burner with temperature approximately 1250 °C.

To take advantage of the waste heat in the induration strand the palletization plant is designed to redirect the heat (temperature approximately 250 °C) from the primary cooling section to the secondary combustion air in the firing zone, and the heat from the firing zone section to be redirected to the drying section (600 – 800 °C) of the induration strand. Additionally, waste heat from the secondary cooling section is to be used in the drying zone. By using waste heat from the cooling section, considerably less firing is needed in the drying chamber.

In the case study of the Dutch palletization strand, the hot air recirculation duct, accounts for an energy recovery of approximately 4% of the gross energy consumption.

1.2.4 Coke Oven plants

Coal pyrolysis means the heating of coal in an oxygen-free atmosphere to produce coke (solid), gases and liquids. Coal pyrolysis at high temperature is called carbonization. In this process, the temperature of the flue-gases from under firing is normally 1150 – 1350 °C indirectly heating the coal up to 1000 – 1100 °C for 14 – 28 hours.

The coke-making process is subdivided into five stages, the coal handling and preparation, the battery operation (coal charging, heating/firing, coking, coke pushing, coke quenching), the coke handling (discharge, storage, conveyance) and preparation, the coke oven gas treatment with recovery and treatment of by-products in the case of a conventional coking plant, and lastly the heat recovery of the cooking and treatment of the flue gas in the case of a heat recovery coking plant.

The tar and gases released from the coking process are combusted within the oven and the sole flue in the heat recovery coking process. 'Jewell- Thompson oven' is the foundation of the heat recovery plant where several ovens are assembled to form one battery.

The heat recovery coke oven plant requires a different design than the convectional plants and requires a large area to be occupied by the ovens. Additionally, it is only applicable to a new plant and it does not seem economically profitable to be embedded at existing operational steelworks.

On the other hand, the heat recovery technique can benefit from lower labor requirements and the use of lower quality coals (lower cost), including weak-coking coals and swelling coals for producing coke equivalent in quality to that produced in a conventional plant.

1.2.5 Blast furnaces

The production of hot metal relies on the blast furnace process where it is considered the most imported process. Blast furnace is a closed loop system into which iron-bearing materials (iron

ore lump, sinter and/or pellets), additives (slag formers such as limestone) and reducing agents (i.e. coke) are continuously fed from the top of the furnace shaft through a charging system that prevents escape of blast furnace gas (BF gas).

- Hot stoves

To improve energy efficiency at the hot stoves, heat recovery can be applied to preheat the fuel or combustion air in conjunction with insulation of the cold blast line and waste gas flue. Sensible heat from the flue-gas can be used to preheat the fuel media. To be economically feasible, it is recommended for the system to take benefit from the heat recovery to have a waste gas temperature from the stoves above 250 °C. It is also possible to retrieve heat from the sinter cooler if the distance between the two processes is practical.

1.2.6 Basic oxygen steelmaking and casting

The Basic Oxygen Furnace (BOF) and the EAF are currently the only processes in the EU to produce steel where the BOF accounts for the two thirds of the production. The objective of the process is to burn (i.e. oxidise) the undesirable impurities contained in the hot metal feedstock. The main elements thus converted into oxides are carbon, silicon, manganese and phosphorus (Eurofer, 2007). Sulphur content is mainly reduced during pretreatment of the hot metal.

Waste heated gas produced during the oxygen blowing with temperature of approximately 1200°C leaves the BOF and enters the primary ventilation. BOF waste heated gas can be fully or partially combusted with the allowance of the ambient air into the primary ventilation system, where the heat and the gas flow increases resulting in higher steam generation in the boiler. In both existing and new steelmaking plans, waste heat recovery can be applied depending on the energy management.

2 Large Combustion Plants

2.1 Description of the industry

Combustion can be defined as the rapid chemical combination of oxygen with the combustible elements of a fuel. Electric and thermal power generation are using all available energy sources in Europe. The type of fuel that each country is using is recorded in the country's profile in this document and is highly depended upon the national availability of the energy resources.

Combustion plants can be large utility plants or industrial combustion plants providing electricity, steam, or heat to industrial production processes. Large combustion plants for electricity demand are classified as base-load, middle-load and peak-load plants. The loading of the plants and the duration is depended upon the usage e.g. Emergency plant or back-up plant.

The energy sources are the fossil fuels (hard coal, lignite, petroleum products, natural gas, derived gases, biomass and peat and other fuels), the nuclear energy (which is the second biggest source of electrical power generation, and renewable energies. The following figure presents the operations of a generalized combustion plant in a flow diagram.

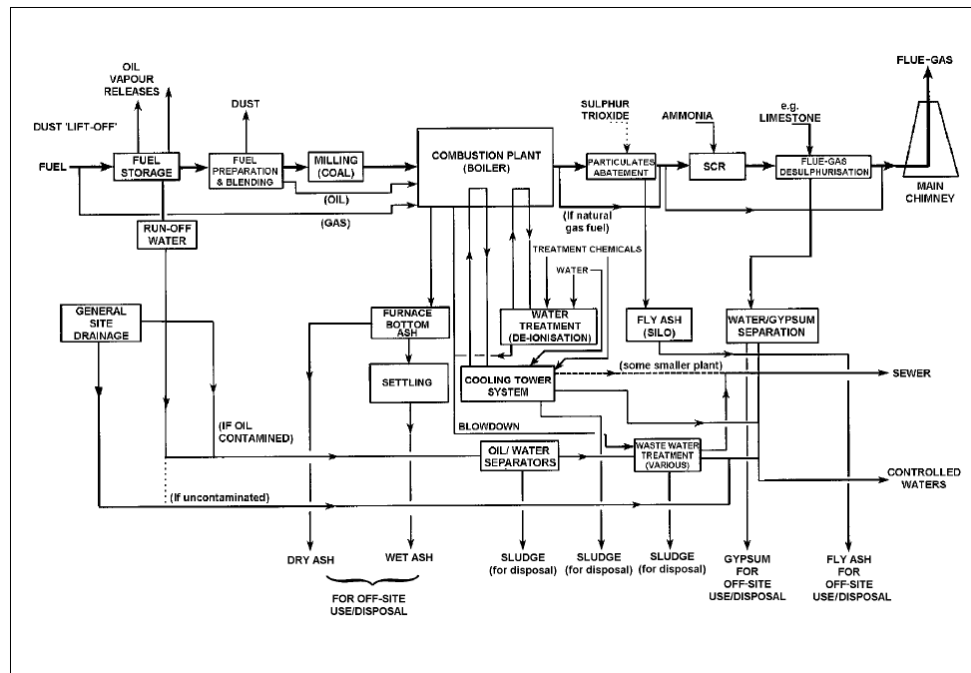


Figure 2 Generalized flow diagram of a combustion plant and its associated operations (HMIP, 1995)

2.2 Processes used involving heat

- Combustion process

Large Combustion plants include several processes for general fuel heat conversion, included are pulverised solid fuel firing, fluidised bed combustion furnace, grate firing, oil and gas firing and gasification/liquefaction.

- Gasification/Liquifaction process

Gasification in large power plants requires high pressure and temperature where in the small units often used in biomass operate at atmospheric pressure. The waste heat from the gasification can be recovered using steam generation to improve the efficiency of the system. The approximate operating temperature are 430 – 630 °C.

- Steam process

Steam process is used in most power plants where the use of the fuel energy generates steam at a high pressure and temperature, both necessary for high efficiency. In order to produce the required steam, a boiler requires a source of heat. Fossil fuels are burned in a furnace or combustion chamber of the boiler at a temperature of approximately 540-570 °C, where steam generators might also use thermal energy in the form of waste heat from another process. The steam process plants can be divided into the vacuum condensing power plants and the co-generation/combined heat and power plants.

- Co-generation/combined heat and power

Co-generation is the simultaneous generation of heat in the form of steam and power. There are two available methods in the combined heat power process to recover heat. The first method is the backpressure, where extraction of the higher pressure steam from the low pressure steam turbine is occurred and the waste heat available is supplied to a district heating system. In the condensation method, the steam from the low pressure steam generator is extracted at less than atmospheric pressure. The temperature that the back pressure system recovers heat at approximately 100°C.

- Combined cycle plants

The combine cycle plants are using both gas turbine engines and steam turbines. The waste heat from the gas turbine with temperature of approximately 500-700 °C, is redirected to the steam turbine to take advantage of that heat. Combined cycle principles may also be applicable to combustion engines. Combined cycle is also used in the co-generation or CHP with additional back pressure heat recovery of condensation energy.

- Fuel energy source Combustion plants

There are several fuels categorizing the different combustion plants. The fuel that heat recovery from waste gas can occur is at the combustion using coal and lignite, and using gaseous fuels. Depending on the energy source (fuel) the plants have different structure but follow the same principles and take advantage of the waste gas at the same processes.

3 Large Volume Inorganic Chemicals- Ammonia, Acids and Fertilizers

3.1 Description of the industry

Fertilizers are the product of ammonia, nitric acid, sulfuric acid and phosphoric acid, where the fertilizer industry is concerned by three plant nutrients, nitrogen, phosphorus and potassium in plant available forms. Around 97 % of nitrogen fertilizers are derived from ammonia and 70 % of phosphate fertilizers are derived from phosphoric acid. The following figure demonstrates an overview of the boundaries and links between the large volume inorganic chemicals – ammonia, acids and fertilizer industries.

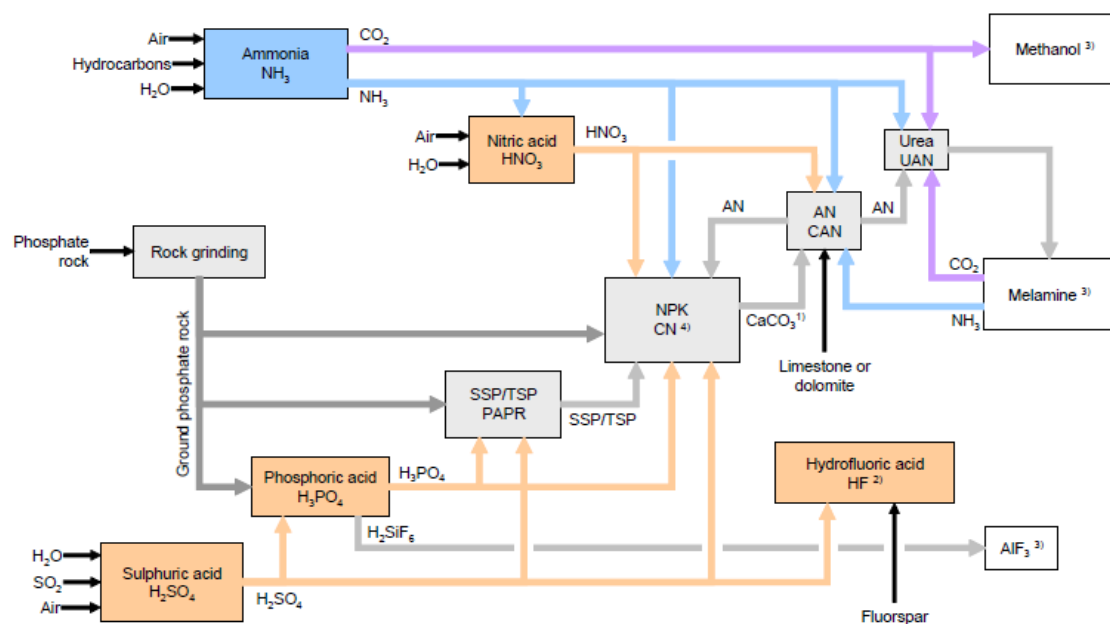


Figure 3 Overview of boundaries and links between the LVIC-AAF industries (Austrian UBA, 2002) 1) only with NPK production using the nitro phosphate route 2) not typically produced on fertilizer sites 3) not described in this document 4) CN is $\text{Ca}(\text{NO}_3)_2$, and is alternatively produced by neutralization of HNO_3 with lime

3.2 Processes used involving heat

- Ammonia - Conventional steam reforming

The sub-processes involved in the steam reforming are the desulphurization, the primary and secondary reforming, the shift conversion, the CO_2 removal, the methanation, the compression and finally the NH_3 synthesis.

Efficiency improvement of the plant can be achieved by using the waste heated exhaust gases as preheated combustion air to the reformer. The refrigeration compressor and the compressor

responsible for pressurizing process air are using the same method. A noted advantage of these methods applied is that the machines can be driven directly by steam turbines using mainly waste heat.

- Desulphurization process

This process is used to remove the sulfur dioxide (SO₂) from exhaust flue gases. It requires the feed gas to be preheated to a temperature between 350-400°C.

- Primary and Secondary reforming

Followed on the gas from the previous process (desulphuriser), gas enters the primary reformer and heated at a temperature of 400-600 °C. Heat is achieved with natural gas or other gaseous fuel where only half of the heat from the reforming reaction is utilized, and the other half remains in flue-gas where it is utilized in the convection section to preheat several other processes.

In the secondary reforming, nitrogen is added, which is required for the synthesis. In this process, air is compressed and heated at a temperature of 500-600°C with the reaction proceeded adiabatically, resulting in a gas outlet temperature of approximately 1000 °C. A heat stream boiler is responsible for collecting the waste heat to cool the gas back to 330-380°C.

- Ammonia partial oxidation

Through the process of Partial oxidation, gasification of heavy feedstock is achieved, such as residual oils and coal. Partial oxidation has several two processes of the air separation unit and the auxiliary boiler, where the air separation unit has sub processes which include gasification, soot removal/recovery, Sulphur removal/recovery, shift conversion, CO₂ removal, Liquid N₂ wash, compression and NH₃ synthesis.

- Gasification of heavy hydrocarbons and coal

After gasifying the heavy hydrocarbons, the gas containing soot is cooled down by entering a waste heat boiler where heat is extracted.

In the coal gasification there are two types used, the “entrained flow gasification” and the “moving bed gasification”. Recycled gas from the waste heat boiler is supplied to the raw gas, therefore a lower gasification temperature is required where the raw gas contains higher amount of impurities such as tars, phenols and some higher hydrocarbons.

- Sulphur removal

The raw gas contains sulfur originated from the feedstock where is this process of removal the raw gas is cooled down using waste heat recovery boiler.

- Sulphuric Acid - Sulphur combustion SO₂ production process

The combustion temperature is between 900-1500 °C and is using either one or two stage units where it consists of the combustion chamber followed by the waste heat boiler.

- Sulphuric Acid - Regeneration of spent acids SO₂ production process

Spent acids are the product from the processes where oleum or H₂SO₄ are used as catalyst or where H₂SO₄ is used to clean, dry, or eliminate water. By heating the spent sulphuric acid, reductive decomposition is achieved at temperature between 400-1000 °C and the decomposed result is SO₂. The exhaust gases are treated by thermal oxidation at temperatures of 1100-1300°C. The combustion gases contain 2-15% SO₂ and waste heat is recovered as steam in a waste heat boiler.

- Sulphuric Acid - Spent acid from TiO₂ production and roasting of metal sulphates

Spent acid from TiO₂ production is reconcentrated by applying vacuum and heating, using the heat from the subsequent H₂SO₄ plant. Decomposed ferrous sulphate is achieved in a furnace at temperature of 850 °C or more. The exhaust heated gas contains SO₂ and is cooled in a waste heat boiler down to 350-400°C where it is later processed to the gas cleaning system.

4 Large Volume Inorganic Chemicals - Solids and Others industry

4.1 Description of the industry

The chemical industry in the EU is mostly using liquid sources of energy as feedstock, where fuel and power sources are the gaseous sources of energy and electricity.

The key Large Volume Inorganic Chemicals – Solids production processes are the Soda ash with refined sodium bicarbonate, Titanium dioxide, Carbon black, Synthetic amorphous silica, Inorganic detergent, and food and feed phosphates. The different production processes for each element have different procedures. The following figure presents an overview infrastructure of the Large Volume Inorganic Chemicals – Solids and others (LVIC-S), with the sub-units.

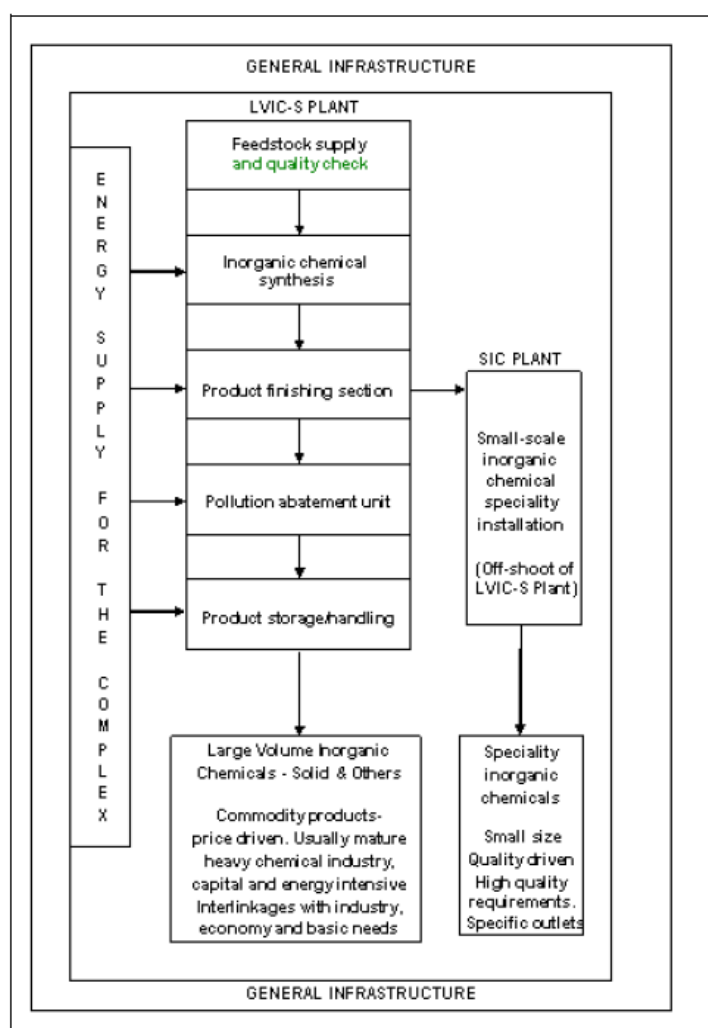


Figure 4 Inorganic chemical complex with a boundary between LVIC-S and SIC plants (CEFIC, 2002)

As presented in the above figure, the LVIC-S has several sub units included are the energy supply unit (produces steam and/or electrical energy, energy may partially be recovered from the synthesis step as heat), supply and preparation of raw materials (feedstock) unit, synthesis

process, the purification process of the crude product (filtering, washing and drying the crude product), the packing, storage and loading process and the waste stream management.

In the chemical industry, due to the complexity of the chemical plants, there are no universal applied processes and each case is sensitive to the local conditions for the selection processes and techniques.

4.2 Processes used involving heat

- Sulphur burning process

The temperature required for the Sulphur to melt or liquefied is approximately 145 °C and it is burned to produce Sulphur dioxide (SO₂) stream in air. The waste heat gas and the surplus heat can be recovered to produce steam, where the gas is cooled down and scrubbed to remove the Sulphur trioxide. A flow diagram of the Sulphur burning process is presented in the below figure.

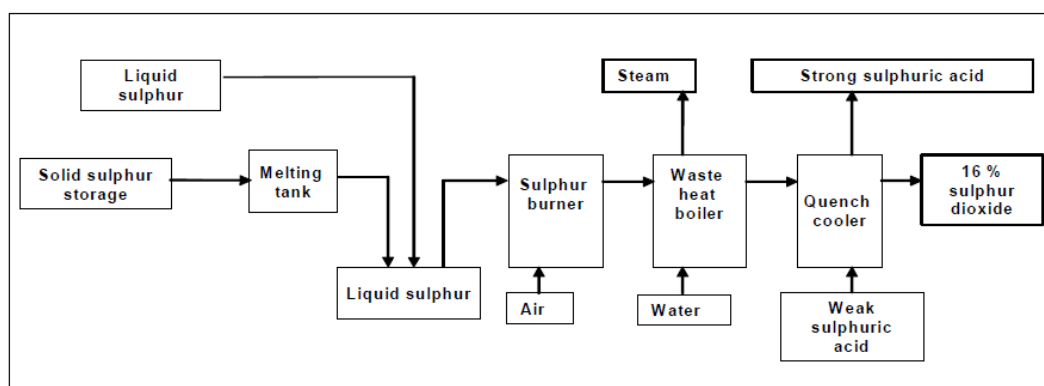


Figure 5 Flow diagram for Sulphur burning to produce Sulphur dioxide (Entec, 2004)

- Tank furnace process

The alternating use of regenerators can recover heat by preheating the combustion air, as presented in the following figure. The process starts where the hot flue gas flows out of the regenerator via a brick layer, where the regenerator is heated, and it allows after some time to be filled with cold air, where the air is heated by the hot bricks. Regular changes of the regenerators are occurring and the process has a continuous operation flow. The emissions from this process are NO_x: 0.64 g /Nm₃, Dust: <20 m g/Nm₃ and CO: 36.0 mg/Nm₃.

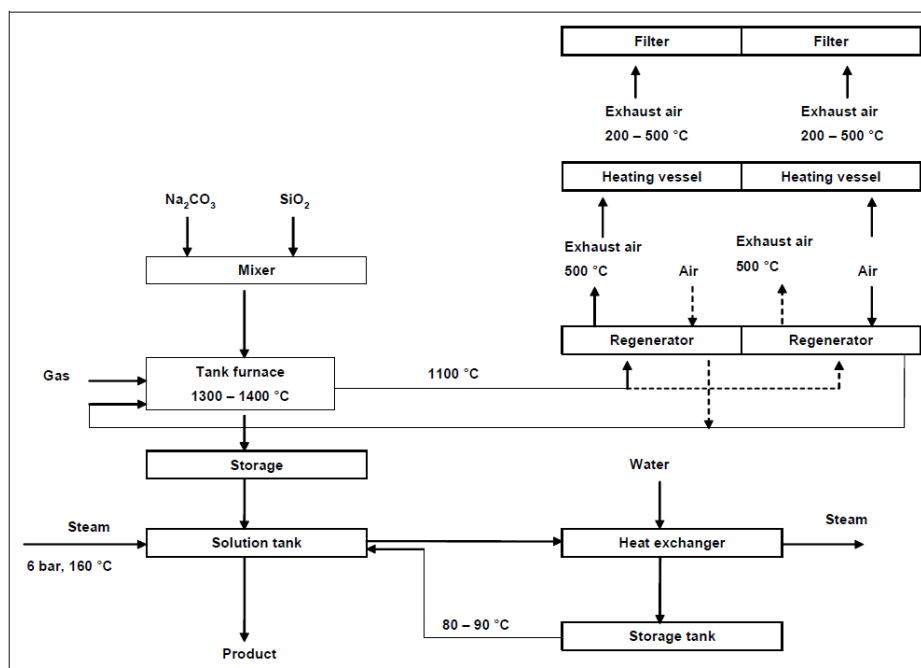


Figure 6 Heat recovery by regenerators (UBA, 2001)

- Sodium silicate plant (revolving hearth furnace) process

A revolving hearth furnace to recover heat in a sodium silicate plant is presented in the following figure.

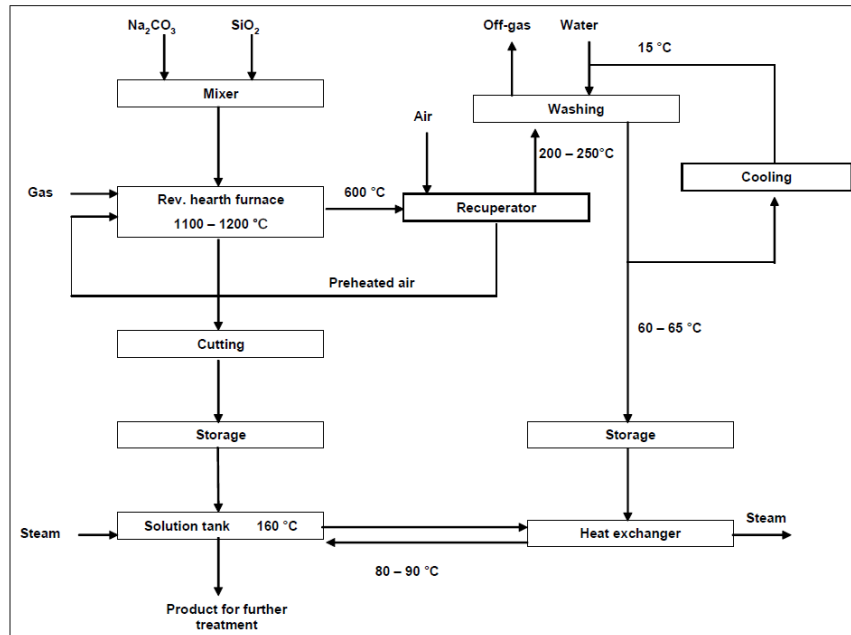


Figure 7 The principle of heat recovery in a sodium plant (revolving hearth furnace) (UBA, 2001)

There are two methods to be taken into consideration in order to increase efficiency and where heat recovery can be achieved. The first method is the Counter –stream principle, where the waste heated gas is exchanging heat with the incoming feedstock as far as possible. In order to achieve this the mixture of sand and soda have to be led counter currently to the

outflowing exhaust air. The revolving hearth furnace has an operating temperature of more than 1100 °C while the exhaust air has a temperature of approximately 600°C. The second method is the recuperator for preheating the air, where the exhaust heated air is exchanging heat with the incoming air to the combustion process. The exhaust air is reducing its temperature from 600°C to 200-250°C and the inflowing air is increasing its temperature to 350-400°C.

5 Food, Drink and Milk Industry

5.1 Description of the industry

The Food, Drink and Milk (FDM) industry produces not only finished products but in addition, products that are designated for further processing. Production of most FDM products exceeds consumption in EU. In the EU-15 in the year 2000, the statistics show that there are over 2600 companies which most of them have more than 20 employees.

The diversity of the FDM industry differs from the other industries in terms of the size and nature of the companies; wide range of selection of raw materials, numerous combinations of the products and processes, specialist products (e.g. traditional) and the production of homogenized global products. The FDM industry also depends on the localization and the local economy, as well as the social and environmental conditions, and varying national legislation.

5.2 Processes used involving heat

- Seed oil extraction process

Crude vegetable oil production from oilseeds is subdivided into two processes. The first process involves the cleaning and preparation where the second process includes the extraction of the oil from the pressed cake or flake beans with hexane. The mixture of the hexane and oil is also referred to as miscella, and is further processed in a distillation process to recover the hexane from the vegetable oil. Steam is used along the process where hexane in the cake is recovered by a stripping process. The hexane/steam vapors are used in the miscella distillation process for solvent and heat recovery. The final stage is for the meal to be dried and cooled before being stored.

- De-colorization

De-colorization occurs for color improvement, purity, ageing, microbiological stability and shelf-life of certain food products. When the product is heated to meet the optimum conditions, the waste heat can be recovered by normal heat recovery systems.

- Oilseed - Solid output process

Vegetable oil, protein rich meal, lecithin and acid oil are the products that yield from the oilseed process and vegetable oil refining. During the oilseed processing, solid output of raw material is generated where the major part is of vegetable origin. During the further treatment to extract the residual oil, it is sent for heat recovery.

- Frying (Recirculate and burn exhaust gases)

High frying temperature is approximately at 180-200°C where the exhaust air is extracted, vented and recirculated to the burner in order to recover heat. The frying heat recovery procedure is presented in the following figure.

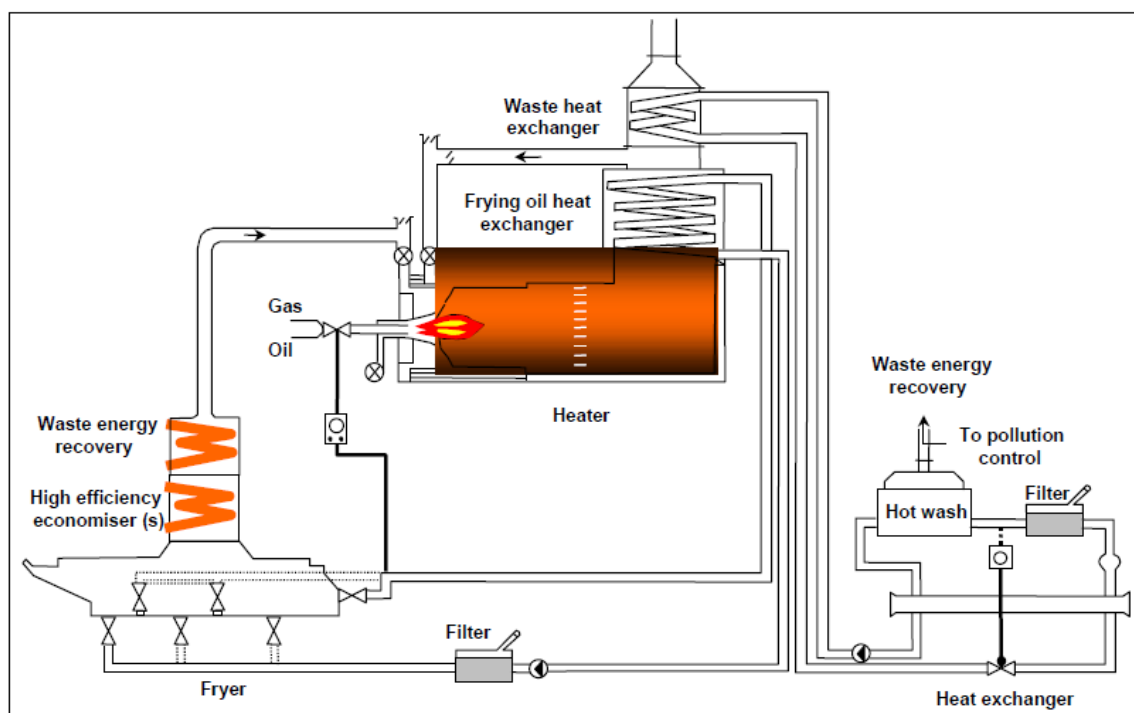


Figure 8 Heat and oil recovery: heat-exchangers mounted in the fryer exhaust hood

- Heat recovery from cooling systems

Additional to the FDM industry, heat recovery from the cooling system and compressor can be recovered with the aid of heat exchangers and hot water storage tanks. An approximate temperature of 50-60°C can be achieved depending on the cooling equipment. It is reported that recovered heat can be used for heating tap water or ventilation air, thawing deep frozen goods, or preheating the cleaning liquids or the product.

- Utility processes

When an in-house CHP is used, the exhaust gases from the waste heat recovery, such as a steam boiler, are used for drying purposes. The heat recovery from the CHP process is further discussed and clarified in the Large Combustion Plants section of this document.

- Solubilisation/alkalizing process

Solubilisation is the neutralization of cocoa nibs or cocoa liquor with an alkaline solution, resulting in a darker color and a milder taste. The temperature for the desired solubility is between 45-130°C and water vapor and undesirable volatile components are released to the air, where a heat exchanger or a waste heat boiler system can be applied to recover heat.

6 Manufacture of Glass

6.1 Description of industry

Glass industry refers to the industries that manufacture products such as container glass, flat glass, continuous filament glass fibre, domestic glass, special glass (no water glass), mineral wool with two divisions (glass wool and stone wool), high temperature insulation wools excluding polycrystalline wool and frits.

Both the techniques used and the products, manufactured in the glass industry, vary in the European Union. The range of the products vary from complex lead crystal goblets – made by hand – to the mass production of float glass used in the construction and automotive industries. Additionally, the range of the techniques used in the glass industry also vary from the small electrically heated ovens (high temperature insulation wools) to the cross-fired regenerative ovens kilns (flat glass). A typical production of a large production in the glass industry could reach the 1000 tonnes/day where a small production could be up to 20 tonnes/day.

6.2 Processes used involving heat

The main processes and techniques used in the glass industry, associated with heat and their respective heat streams, are summarised below.

- Heating

Fossil fuels are mainly used for providing the heat required by the melting process. The required temperature's range is between 1300 °C and 1550 °C. During this process, the heat is mainly transferred with the aid of the radiative transmission through the flames heating the kiln at a temperature of 1650 °C.

- Primary melting

A slow process due to the low thermal conductivity of the raw materials. The decarbonisation of the materials occurs at 500 °C approx. and the melting begins between 750 °C and 1200 °C. Maximum temperatures encountered in the kilns are 1600 °C for container glass, 1620 °C for flat glass, 1650 °C for special glass and continuous filament glass fibre and 1400 °C for glass wool.

For the above processes either natural gas or fuel-oil are commonly used in the glass industry. The use of the natural gas is increasing; however, compared to fuel-oil types natural gas has higher amounts of NO_x emissions.

7 Manufacture of Organic Fine Chemicals

7.1 Description of industry

Chemical industry is another significant sector for the European economy as the total exports are over € 519 000 million among which a trade surplus of € 65 000 million. Holding the third place in the top industries of EU, 4.7 million people are currently employed in the chemical industry among which 1.7 million are directly employed and the rest directly supporting the industry.

As Organic Fine Chemicals (OFC) is one of the key sectors in the chemical industry, it is important to identify the key environmental issues associated with it. Such environmental issues are the emissions of volatile organic compounds, the waste waters with potential for high loads of non-degradable organic compounds, the relatively large quantities of spent solvents and the non-recyclable waste in high ratio. Thus, the use of different management techniques regarding the recovery of different waste gases and heat is very important. Figure 1 shows the general management system of the waste streams in a typical OFC industry.

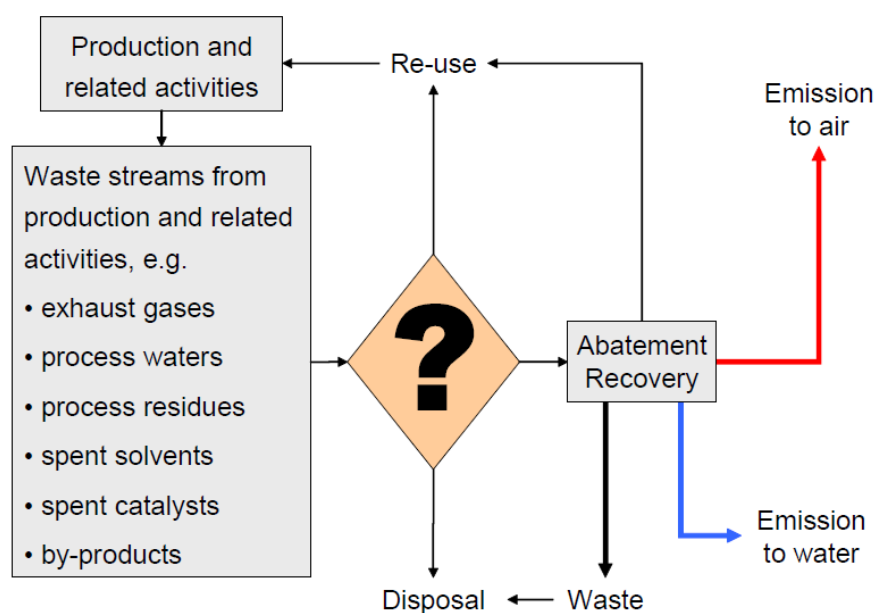


Figure 2: Management of Waste Streams (European Commission, 2006)

7.2 Processes used involving heat

- Distillation

Distillation is a process used to cleanse volatile components from less volatile components. During the process the material fed to the distillation unit, the column or the vapour line are heated up. A heat exchanger is also used to reduce the vapours. The environmental effects of such a process are as follows.

- energy efficiency (efficient design, insulation, heating, cooling)

- emissions to air from the condenser vent in case of atmospheric distillations
- waste streams (which can be re-used or recovered, or disposed of)
- wastes from cleaning

- Halogenation

Halogenation is very important and in chemistry. Figure 2 shows the typical sequential steps followed during halogenation to distillable products. Figure 3 shows a typical sequence of operations for the halogenation precipitation of the product.

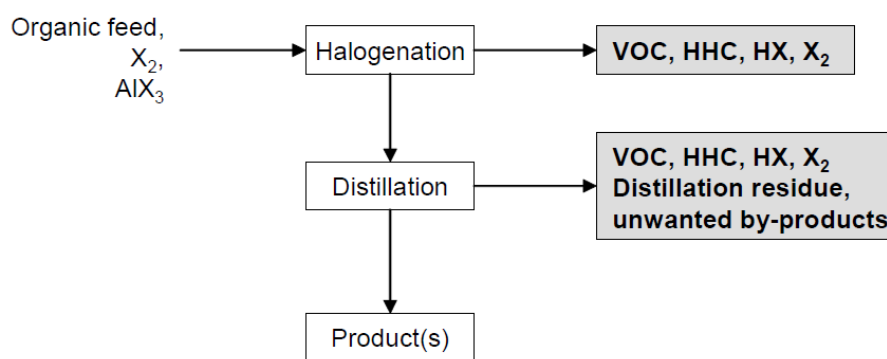


Figure 10: Typical sequence of operations for the halogenation to distillable products. Possible input materials (on the left) and the associated waste streams (grey background) (European Commission, 2006)

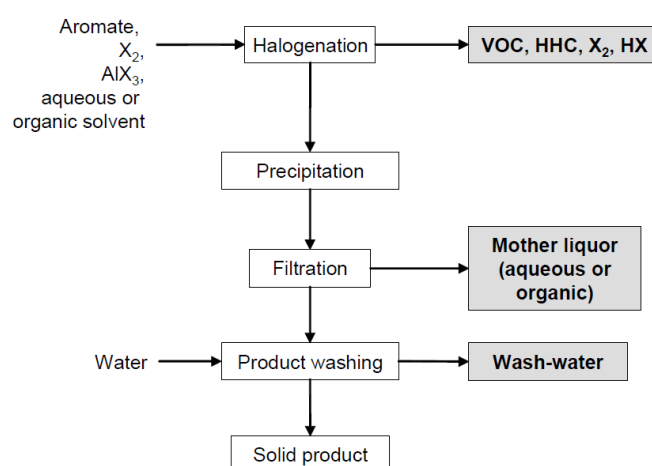


Figure11: Typical sequence of operations for halogenation with precipitation of the products. Possible input materials (on the left) and the associated waste streams (grey background) (European Commission, 2006)

Most side chain chlorinations are processed continuously or discontinuously in bubble column reactors of enamel or glass. The reactor is initially fed with the initial material, then heated to at least 80 °C and chlorine is added up to the point where the satisfactory degree of chlorination is reached. Finally, the reaction ends when N₂ is added.

- Nitration

Nitration process is the permanent addition of one or more nitro groups into an aromatic system by electrophilic replacement of a hydrogen atom. The reaction takes place in cast iron, stainless steel or enamel-lined mild steel reactors. Temperatures ranges during this process are between 25 and 100 °C. The substrate is dissolved in the sulphuric acid phase and as a result, the addition of the mixed acid takes place. While the reaction is complete, the lot is immersed in water so a two phase mixture of diluted acid and an organic product phase are given.

- Catalytic reduction with hydrogen

Most aromatic nitro compounds are hydrogenated in the liquid phase. In this case, the pressure and temperature may vary independently. Nevertheless, the temperature is limited by the hydrogenation reaction of the aromatic ring. The hydrogenation of the aromatic ring occurs at temperatures higher than 170 – 200 °C. The reduction is carried out at 100 – 170 °C.

7.3 Data available for waste heat recovery

An example of two waste heat boilers installed in a factory share an exhaust gas recuperator for energy supply to the plant. The smaller boiler (boiler 1) is used in summer when the demand for steam is low and the larger boiler (boiler 2) is used in winter when the steam demand is higher. Boiler 1 and boiler 2 are capable for producing steam of 80 tonnes/hour and 160 tonnes/hour, respectively. The cold water enters the recuperator, which cools the exhaust gas from 130 °C to about 45 °C and thus the water is heated to 60 °C. An amount of 3.8 MW waste heat approx. is recovered. The typical schematic of the process is shown in Figure 4.

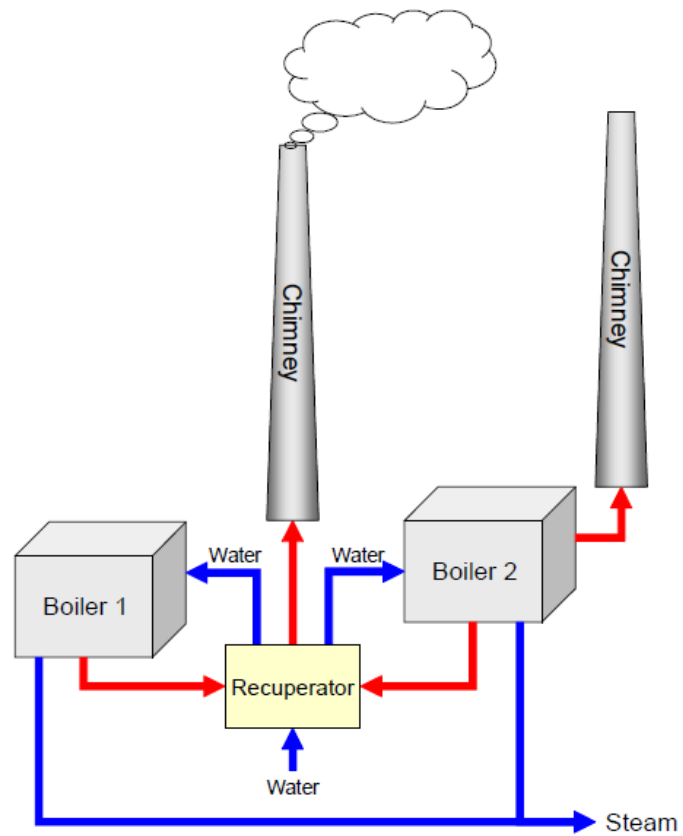


Figure12: Example of an energy supply setup with two boilers (European Commission, 2006)

8 Manufacture of Non-Ferrous Metals

8.1 Description of industry

Non-ferrous metal industry is another important industry, especially in the economic sector of the EU, since metals are found everywhere. For instance, copper and aluminium alloys are the main materials used for the generation and distribution of electricity, for the manufacture of electronic circuits and for the construction of buildings. The estimated production of such metals is 18 – 20 million tonnes, with sales of up to 45 billion and with more than 200,000 people being employed in the EU.

Various types of metals are produced in the non-ferrous metals industries. There is no company able to produce every type of metal; however, there are some companies able to produce some of them. The types of metals produced in the EU are as follows.

- Copper and its alloys
- Aluminum
- Lead and Tin
- Zinc and Cadmium
- Precious Metals (e.g. gold and silver)
- Ferro-Alloys
- Nickel and Cobalt
- Carbon and Graphite

8.2 Processes used involving heat

Non-ferrous metal industries are associated with processes requiring an extensive amount of heat. However, each process is a metal-specific process meaning that the steps followed or even the process itself varies for the production of a non-ferrous metal. Therefore, heat stream ranges are quite different from product to product and depend on the furnace used (rotary kilns, fluidised bed reactors etc.). Nevertheless, some general processes followed are summarised below.

- Thawing

Thawing is a process carried out for heating the frozen raw material to a desired level so the material can be further processed and handled. As an example, thawing is carried out when raw materials (minerals, concentrates or solid fossil fuels – e.g. coal) are transferred from a train or ship in winter. Steam jets are used so the ice can melt and the material can be unloaded.

- Drying

During the drying process, rotary, steam coil and other indirect dryers are used, to produce a raw material suitable for the main production process. Heat is directly supplied through burners or steam jets. Alternatively, heat can also be indirectly supplied to the dryers with the

aid of steam or hot air in heat exchanger coils. Furthermore, heat from pyrometallurgical processes (e.g. anode furnaces) and flammable exhaust gases such as CO may also be used for drying the raw material. In this process, rotary kilns and fluidised bed dryers are also used. Potential SO₂ emissions may be present in this process.

- Sintering and calcination

The increment in size of the raw material or the chemical composition occurs in this process. This allows the material to be further processed. In sintering, the ore is bonded when it is heated up to a level, the gangue minerals begin to melt and individual particles are bonded in a matrix of molten slag. The sintering and roasting of sulphide ores are usually processed at high temperatures and the gases produced are rich in sulphur dioxide. The oxidation of sulphur supplies enough heat for the process.

- Fuming

Fuming are the processes used for fuming volatile metals. Such metals include lead or zinc from a substrate. High temperatures along with a carbon source are used in these processes in order to produce an inert slag. As a result, metals are able to be recovered in the form of oxide which allows them to be further processed. In such processes, Waelz kilns, Herreshoff and slag-fuming furnaces are used.

- De-coating and de-oiling

De-coating and de-oiling operations are usually executed on secondary raw materials. This results to the reduction of the organic content of the feed to some main processes. Washing and pyrolysis processes are used. The oil and some coatings is removed in a furnace such as a swarf dryer. Usually, a rotary furnace is used to volatilise oil and water. This operation is achieved at low temperatures. Direct and indirect heating of the material is also used. The organic products produced in the furnace are demolished with the aid of an afterburner heated at high temperatures (more than 850 °C) and the filtration of the gases usually takes place in a fabric filter.

- Incineration and pyrolysis

Photographic film, sweepings, catalysts and other materials are treated during incineration and pyrolysis. This allows the concentration of some precious metal contents or the recovery of nickel. The two processes are also used for the pre-treatment of catalysts and the removal of the organic content before any further treatment. Low temperatures occur during these two processes as it is necessary to avoid the carryover of metals. An afterburner and a fabric filters are used for the treatment of the gases produced in the incinerator.

The above processes are associated with the pre-treatment and the preparation of the raw materials before their transfer to the plant, since such processes are usually standard for any type of a non-ferrous metal.

In general, Pyrometallurgy and Hydrometallurgy are the main processes used in the production of non-ferrous metals and they are associated with high amount of heat (roasting, melting and smelting). However, these processes may combine several steps in the production of each metal and thus no further explanation will be given. Nevertheless, an example regarding the pyrometallurgical process during the production of Zinc and Cadmium is given below.

- Roasting of zinc and cadmium

Zinc sulphide (sphalerite) concentrates are fed in closed fluidised bed roasters to produce zinc oxide and sulphur dioxide. Roasting air or oxygen-enriched air is blown into the roasting bed. As the roasting of sulphidic material is an exothermic process, no extra fuel is required. Some of the excess heat is absorbed in cooling coils and in the form of evaporator heating surfaces connected to the forced circulation system of the waste heat boiler (see Figure 13). The roasting process is maintained at temperatures between 900 °C and 1000 °C with the aid of cooling elements integrated in the fluid bed.

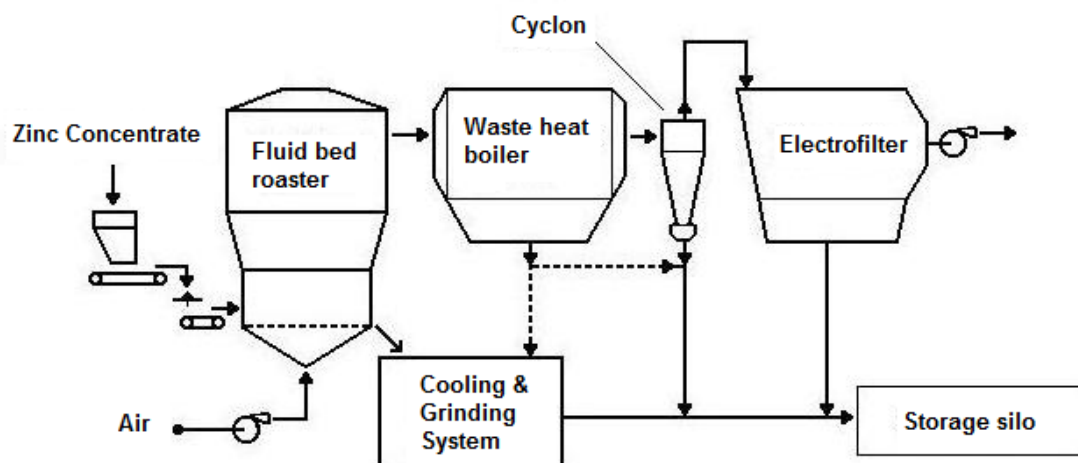


Figure13: Roasting gas-cleaning stage 1: dry gas-cleaning (cyclone optional) (Joint Research Centre, 2014)

8.3 Data available for waste heat recovery

Hot gases are produced during the smelting or roasting processes of sulphide ores. These gases are usually transferred through steam-raising boilers and the steam generated may be used to generate electricity and/or for heating. For instance, a copper smelter generates the 25% of the electrical energy required (10 MW) by the steam generated through the waste heat boiler of a flash furnace. The steam is also used in the concentrate dryer and any residual heat wasted is used for preheating the combustion air.

Using the hot gases from the melting phases to preheat the furnace is an obvious technique of heat recovery. For example, the main fuel used in almost all of the cathode/copper scrap melting shaft furnaces is natural gas. Such design gives a thermal efficiency (fuel utilisation) between 58 – 60 %, depending on the furnace design. The typical fuel consumption is 330

kWh/tonne approximately. A heat exchanger, transfer fan and ductwork are used as it is necessary to diversify the stack gases coming from the furnace. The approximate heat recovered in this case is between 4 and 6 % of the furnace fuel consumption.

Table 2 shows some more examples of heat recovery technologies used in semi-closed furnaces, during the production of non-ferrous metals.

Table 85: Examples of heat recovery from semi-closed furnaces (Joint Research Centre, 2014)

Technology	Waste heat medium	Heat recovered as	Temperature range of waste heat (°C)	Yield (%)	m EUR/MWh
	Waste gas/cooling water/hot oil	Hot water	50 – 200	75 – 95	0.4 – 2
Heat pump	Water/exhaust air	Hot water (temp. 50 – 90 °C)	25 – 60	COP: 3 – 5	30 – 50
Shell boiler water-based	Waste Gas	Saturated steam 6 – 15 bar; Temp 160 – 200 °C	200 – 600	30 – 65	25 – 50
Water tube boiler, water-based	Waste gas	Superheated steam 8 – 60 bar; Temp. 280 – 480 °C	400 – 1000	30 – 75	40 – 150
Boiler ORC/turbine	Waste gas	Electricity	150 – 500	10 – 15	70 -120
Water boiler/turbine	Waste gas	Electricity	500 – 1000	20 – 35	300 – 400
Thermoelectric panel		Electricity	Heat radiation 400 – 1500	5 – 10	

9 Production of Cement, Lime and Magnesium Oxide

9.1 Description of industry

9.1.1 Cement Industry

Cement industry has widely grown since 1950 both in EU and worldwide, due to the rapid increase of the construction industry, in which cement is the main ingredient. As known, cement is the main material of concrete. Concrete is made by mixing cement with sand, aggregates and water and then hardens due to the formation of calcium silicate hydrates. In total there are 268 installations manufacturing cement in the EU with a total production of 267 Mt recorded in 2006. A typical process flow diagram from a cement plant is shown in Figure 14.

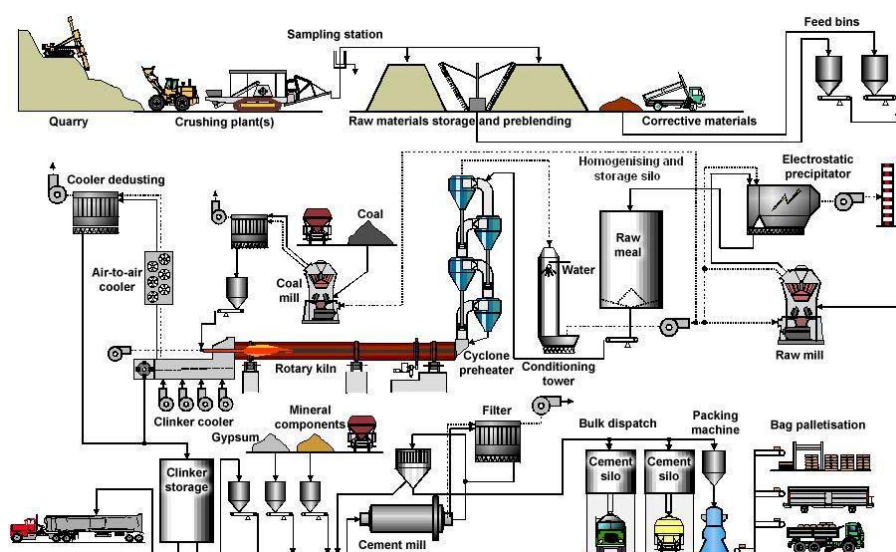


Figure14: General overview of a cement manufacturing process (Frauke, Kourti, Scalet, Roudier, & Sancho, 2013)

9.1.2 Lime Industry

Lime is used in the construction – particularly quicklime (CaO) and hydrated lime (Ca(OH)_2), since 1000 BC in the Near East. In the market, lime is widely used as it can be found in the steel industry for steel refining, in the construction industry as a binder and for water treating. Moreover, lime is also used in the following sectors.

- Gas – e.g. neutralisation of pollutants (e.g. sulphur, chlorine)
- Waste – e.g. treatment of medical and hazardous waste
- Contaminated lands – e.g. adjustment of pH and immobilisation of sulphates, phosphates and heavy metals
- Agriculture – e.g. soil pH adjustment
- Chemical and paper industry – e.g. leather tanning

- Pharmaceutical, personal care and food – e.g. used in the manufacture of calcium phosphate, a toothpaste additive

Figure 15 shows the lime manufacturing process and the cornerstones for lime production, respectively.

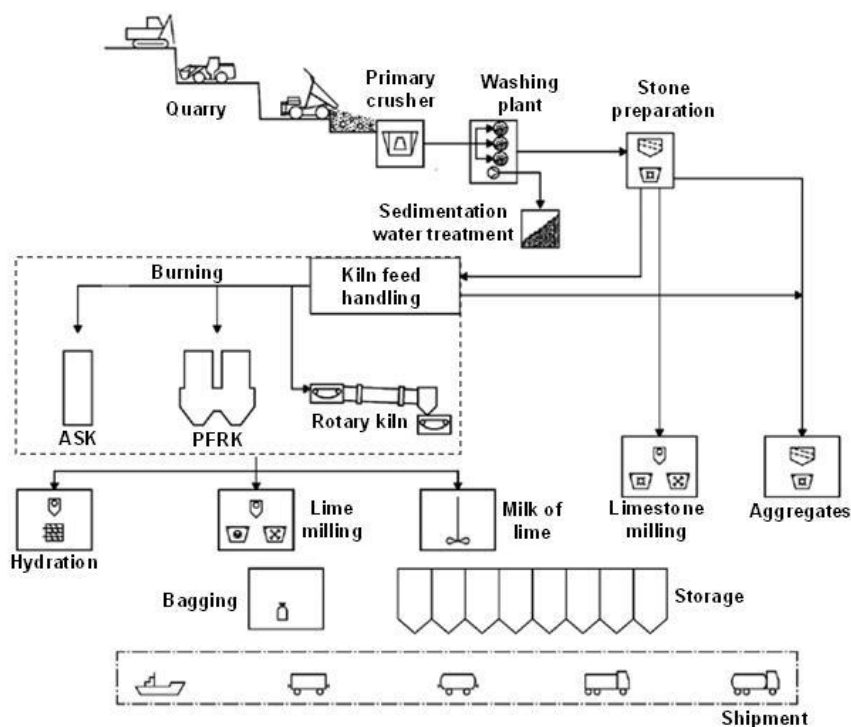


Figure15: Overview of the lime manufacturing process (Frauke et al., 2013)

9.1.3 Magnesium Oxide Industry

The most important substance in industry is the Magnesium oxide. It can mainly be found in industries such as steel, refractory, food and animal food. Magnesium oxide is mainly made of magnesium carbonate and brucite, which are taken from seawater and brines. The world's production of magnesite was more than 12 Mt, in 2003, among which the 18% approximately was mainly manufactured in Europe. The process used for producing different types of magnesia is shown in Figure 16.

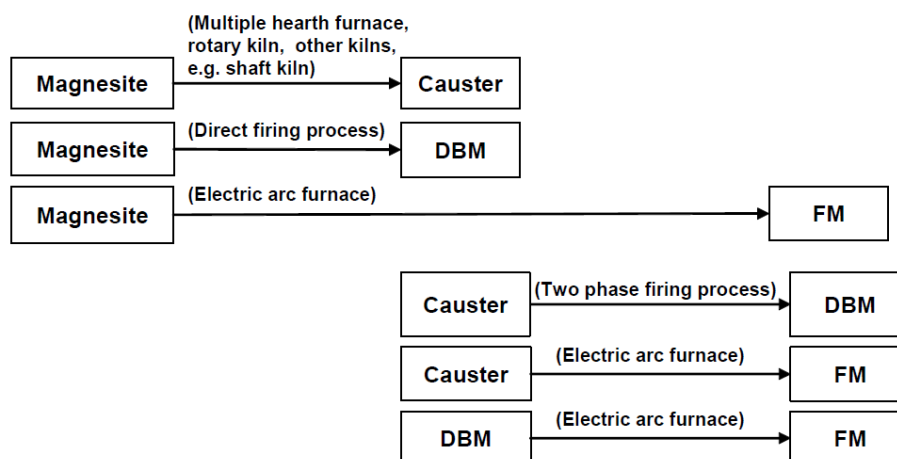


Figure16: Process scheme of natural pathway for magnesia production
(Frauke, Kourti, Scalet, Roudier, & Sancho, 2013)

9.2 Processes used involving heat

9.2.1 Cement Industry

- Clinker burning

During this process, the raw material is dried, preheated, calcined and sintered in the rotary kiln. This process is necessary for producing cement clinker. Air is used to cool down the clinker which is then stored. High temperature ranges are necessary during this process in order to transform the mixture of raw materials into cement clinker. Such temperatures vary between 1400 and 1500 °C, but held constant inside the kiln (sintering zone) with the flames burning at around 2000 °C. Moreover, it is necessary to use oxidising for firing the clinker and as a result, additional air is needed. For the manufacture of white cement, the temperatures inside the sintering zone can reach 1600 °C, based on the synthesis of the mixture of raw materials and the synthesis required of the final product. The temperature of flames, in this case, overreach 2000 °C, due to the absence of fusing elements of raw materials.

- Kiln firing

A burner, at the beginning of the chain, burns the main fuel and provides flames at 2000 °C approx. The adjustment control of the flames is necessary to keep the temperature within specified limits for optimizing the ongoing process.

9.2.2 Lime Industry

- Calcination of limestone – chemical reaction

Lime is the result of burning calcium and/or magnesium carbonates. Temperatures of such process vary between 900 – 1200°C. Nevertheless, temperatures may reach 1800°C for achieving sintering. The process is highly dependent on flames temperatures of minimum 800°C. This is necessary for ensuring decarbonisation and a good residence time. In other

words, guaranteeing that the temperature of lime/limestone remains constant at 1000–1200°C for long periods. This enables the control of the lime/limestone reactivity.

- Calcining of limestone in the kiln

The supply of limestone to the kiln is divided into three heat transfer zones as follows.

- Preheating zone: Gases, surplus air and CO₂ from calcinations heat the limestone up to 800 °C.
- Burning zone or calcining zone: Warm air from the cooling zone is for burning the fuel. In addition, 'combustion' air is added to the fuel. During this step the temperature becomes higher than 900°C. The outer layer of limestone begins to decompose at temperature ranges between 800 to 900 °C. At higher temperatures (i.e. >900°C) the layer below the surface of pebbles starts decomposing, too. At 900°C, the pebbles should transfer to the next phase (or zone). Sometimes the pebbles may be found as residual limestone resulting to their trapping inside. In that case, sintering process is applied in order to allow the transfer of the pebbles to the next heat transfer zone.
- Cooling zone: Quicklime leaving the calcining zone at 900°C is cooled by air directly. The air used in this zone is a portion or even the combustion air as a whole, which is preheated. When the temperature reaches 100°C or below lime leaves the cooling zone.

9.2.3 Magnesium Oxide Industry

- Production process overview of magnesia from magnesite

Multiple Health Furnace (MHF), shaft kilns or rotary sintering kilns heat the treated and prepared raw material (natural stone) to produce magnesia. This process is endothermic and high temperatures are required. Moreover, high amount of energy is concentrated through this process. Specifically, the input energy required is $nH = + 113 \text{ kJ/mol MgO}$. The process takes place at temperature ranges of 550 – 800 °C. At this point, magnesite is de-acidified and carbon dioxide is released. The output product of this process is the caustic calcined magnesia (CCM). Afterwards, flames in temperature ranges of 1600 and 2200°C heat the CCM in either one or two phases in order to form sintered or dead burned magnesia.

➤ *Firing processes*

- Direct firing process (single phase firing)

Analysis, separation and storage in quality classes are performed in the first process. Charging cycles are made by mixing different quality classes of the raw materials. Afterwards, the mixture is heated with flames inside a shaft or rotary sintering kiln at 1450 and 2200 °C. The raw sinter magnesia is further processed and treated.

- Preparation of the raw sinter

The raw sinter magnesia is separated using either a permanent magnet or an electromagnetic separator. When the magnesia is cooled down to 900 °C magnesia ferrite (MgFe_2O_4) is formed, which is used as a magnetising carrier.

- Two phase firing process

Deacidification of raw magnesite is carried out in a kiln with temperatures up to 1000 °C. Grinding of CCM may then take place, which is important for achieving Sintered/Dead Burned Magnesia (DBM) of high densities. The grinded material is burned in either a rotary or a shaft kiln to DBM once it is formed into briquettes.

9.3 Data available for waste heat recovery

9.3.1 Cogeneration of electric power via the conventional steam cycle process–Slite cement plant in Sweden

Recoverable heat is transferred to an existing electricity plant next to the cement plant. The electricity plant operator uses a steam turbine to generate electricity from the recovered heat. A heat recovery boiler produces the steam in two steps. The first step is carried out at the clinker cooler and the second step carried out at the bottom duct of the kiln. A simplified diagram of the above process is shown in Figure 9.

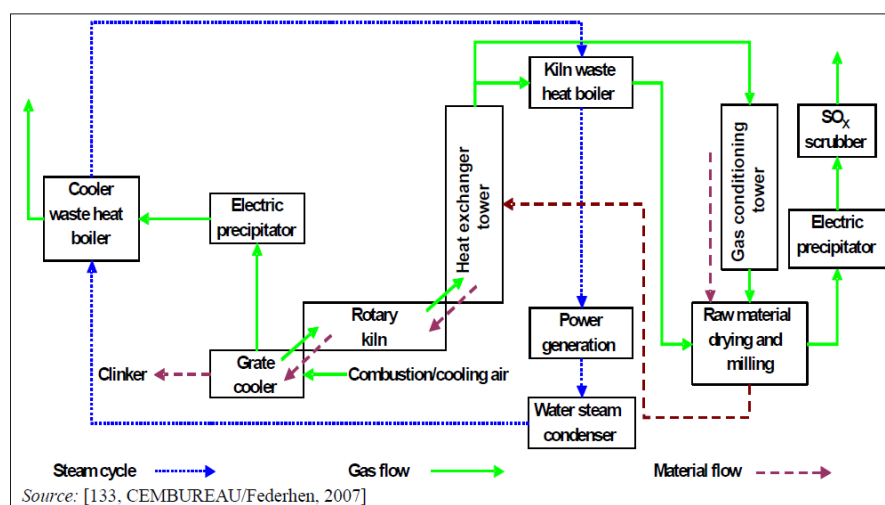


Figure17: Flow diagram of a two-step water-based heat recovery system for power cogeneration at the Slite cement plant in Sweden

The plant was initially designed to supply a power of 9 MW. However, only 6 MW are able to be supplied and this become possible after process optimisation. The annual production of electricity is 50 GWh, which corresponds to the ¼ of the plant's energy needs.

9.3.2 Cogeneration with the Organic Rankine Cycle (ORC) process – cement plant in Lengfurt in Germany

Steam from organic motive medium such as pentane is used instead of steam coming from water, as its boiling point occurs at a much lower temperature than water. Refrigeration techniques use principles similar to the ORC process and it has been found a very promising technique regarding energy savings. Figure 10 shows a typical flow diagram of the very first ORC technique used in the cement industry, in Lengfurt, Germany.

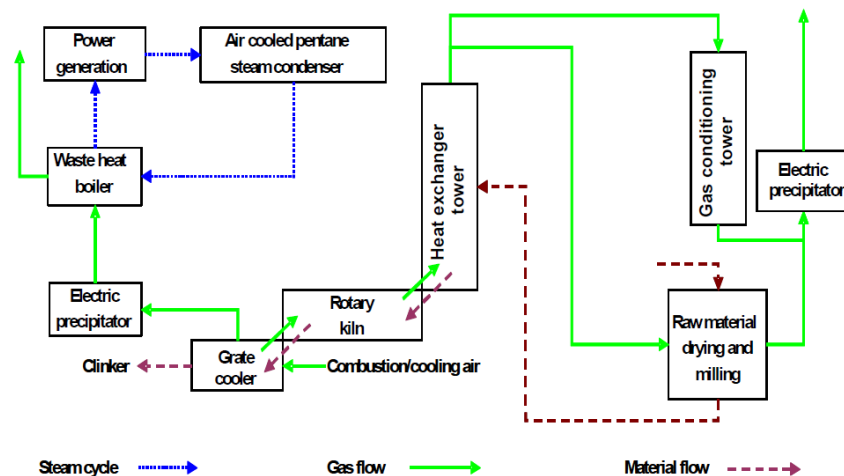


Figure 18: Flow diagram of a pentane based waste heat recovery system for power cogeneration at the Lengfurt plant in Germany (Frauke, Kourti, Scalet, Roudier, & Sancho, 2013)

Due to the pentane used as the motive medium a high level of efficiency is achieved with heat sources operating at temperatures less than 275°C. The plant is able to generate electrical power of 1.0 MW. An amount of 14 MW of waste heat output belongs to the clinker cooler via the clinker cooler exhaust air. The temperature of the exhaust gas varies from 300 °C to 350 °C and an average of 9 MW out of 14 MW is extracted.

10 Production of Chlor-alkali

10.1 Description of industry

The main products produced by the chlor-alkali industry are chlorine, sodium/potassium hydroxide (aka caustic soda/potash) and hydrogen. Electrolysis of brine forms the main process for producing such products.

In 2012, the world's chlorine production was recorded at 77 Mt approx. Figure 1.1 shows the share of installed production capacities per region in 2012.

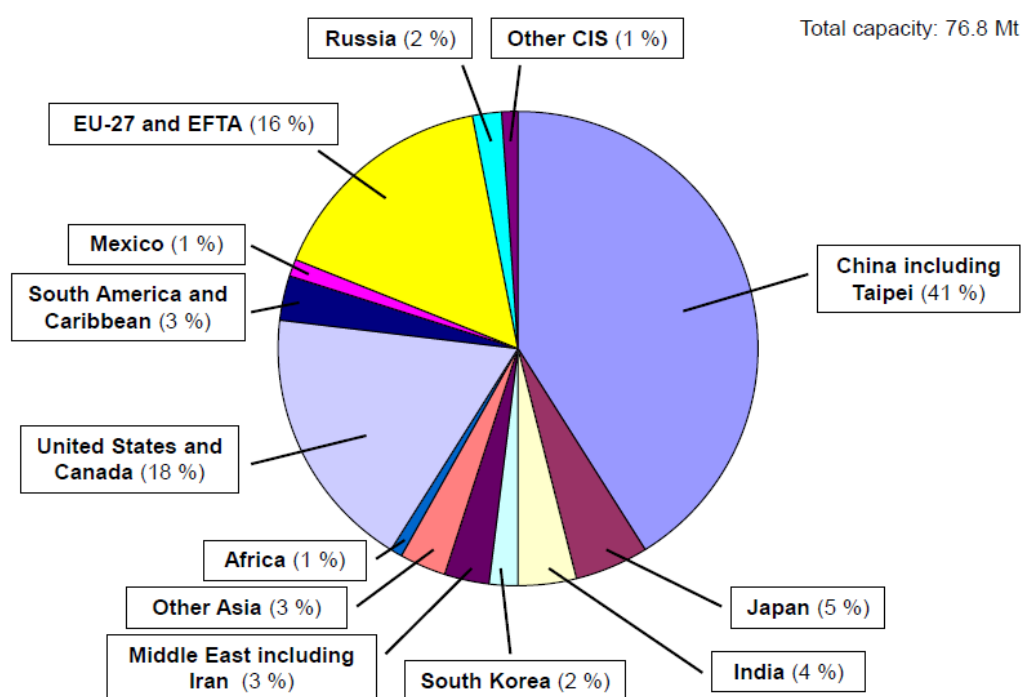


Figure19: Share per region of world chlorine production capacities in 2012 (Brinkmann, Santonja, Schorcht, Roudier, & Sancho, 2014)

Maximum global sales on chlor-alkali products occurred in 2007. However, in 2008 – 2009 the industry experienced a negative growth rate due to the economic crisis with a growth occurring again in 2010. In developing countries, a fair growth is also observed and a higher capacity is expected.

10.2 Processes used involving heat

- *The mercury cell technique*

This technique contains an electrolysis cell and either a horizontal or a vertical decomposer. The flow of brine (25% sodium chloride) occurs in an elongated trough inside an electrolysis cell, which is maintained at 60 – 70 °C. This temperature is achievable while preheating the saturated brine. The temperature increases in the cell with the aid of Joule heating and its range varies between 75°C and 85°C. Finally, the air of the cell room needs to change from 10

to 25 times per hour – based on the building’s design facilities – as it is necessary to provide the required heat during electrolysis and amalgam decomposition.

- *The diaphragm cell technique*

In this process, the reactions occur in one cell in which dissolved salt and caustic soda are contained. The chlorine released at the anode is distinguished with the aid of a diaphragm. Furthermore, the production of the hydrogen and the caustic soda occur at the cathode. The saturated brine (25 % NaCl) is decomposed inside the diaphragm cell by 50 % approx. An electrical current flowing through the liquids causes the temperature of the electrolyte to rise to 80 – 99 °C. Most of the metals resist the dry chlorine at temperatures less than 100 °C. Spontaneous ignition occurs at temperatures between 150 °C and 250 °C, depending on the metal’s particle size.

- *Chlorine processing, storage and handling*

Before the commercialisation of the chlorine cooling, cleaning, drying, compression and liquefaction are required. Hot and wet cell gas is cooled down and converted into a dry gas, during the chlorine process. The Chlorine leaves the electrolyzers in gaseous form and at temperature ranges between 80 – 90 °C. Finally, the chlorine is soaked with the aid of water vapour.

11 Production of Polymers

11.1 Description of industry

Polymers come from the Greek words 'poly', meaning many, and 'meros', meaning parts. Consequently, polymers form a group of chemical products sharing a common building principle. Different types of polymers exist such as:

- natural polymers (for example wool, silk, wood, cotton)
- half synthetic polymers (natural polymers chemically modified – e.g. casein plastics, cellulose plastics)
- synthetic polymers

Nowadays, crude oil or natural gas are mainly used for producing monomers with the only exemption being the cellulosic materials. Such products are produced with the aid of cotton, wood fibres or biodegradable products made by renewable raw materials.

A variety of processes are used to reform the initial shape of raw polymers to the required shape of the final product. The different processing technologies used are listed below.

- extrusion for pipes, profiles, sheets and cable insulation
- injection moulding for products of different, often very complex shapes like machine parts, electrical plugs and medical equipment such as syringes; thermoplastics and thermosets
- blow moulding for bottles, containers and films
- calendaring for films and sheeting
- rotomoulding for large shapes
- pultrusion for rods, tubes, etc.
- blown film for thermoplastics
- cast film for thermoplastics
- coating for thin layers on different substrates
- pressing for resins
- spinning for fibres
- transfer moulding for thermosets
- compression moulding for thermosets
- vulcanisation for rubbers
- blending generally applicable technique

Polymerisation, polycondensation and polyaddition compose the three main reactions for the production of polymers. Steps included in these three reactions are preparation, the reaction itself and products' separation. It can be found in most of the cases that cooling, heating, or vacuum or pressure are used, since they are necessary. Waste streams are recovered or disposed of as waste in the case they cannot be recovered.

11.2 Processes used involving heat

- *Applied processes and techniques in the production of polystyrene*

One or a series of reactors are used for the polystyrene production process. Temperature, pressure and convention rate are the main reactor's parameters controlled, during the production process. The heat of the reactor is removed by means of heat transfer such as transfer to the new material entering the reactor, the evaporation of solvent and/or circulating oil. The crude product coming out from the reactor is about 60 – 90 % solid and needs to be heated to 220 – 260 °C and go through a high vacuum. This allows the removal of the unconverted monomer and solvent. This process is so called the devolatilisation step may contain either one or two stages. At the end, the cleaned and high purity polymer is granulated. The strip and recycling of both the monomer and solvent occur in the devolatilisation section and within the process, respectively.

- *General purpose polystyrene (GPPS) process*

Styrene and processing aid correspond to the main raw materials, which enter the reactor. The reactors are maintained at temperatures between 110 and 180 °C. At the end of the process, the styrene monomer is about 60 – 90 % of solid polystyrene product. A devolatilisation section is then used with one or two flashes (one or two devolatilisation vessels). At this stage the polymer is distinguished from unreacted materials. The operation of devolatilisers occurs at 220 – 260 °C and less than 40 mbar.

- *High impact polystyrene (HIPS) process*

The difference in this process compared to the GPPS is the addition of rubber element. Polybutadiene rubber is initially found in bales weighing 35 kg and it is then ground into small chips. The reactors are maintained at the same temperatures as in the GPPS process and continuous stirred tank reactors (CSTR) and/or plug flow reactors (PFR) are found in the reactor train. Once again, devolatilisation occurs at 220 – 260 °C and a high vacuum of less than 40 mbar.

- *Ortho and isophthalic polyester production*

- Reaction

In this process, heating continually occurs until the temperature rises to 200 °C. Specifically, the glycols and diacids (or anhydrides) undergo an esterification reaction while heated with initial rates of 70 – 90 °C per hour – where water begins to distillate – and then further heated with rates of around 15 - 25 °C per hour.

- *Dicyclopentadiene (DCPD) polyester production process*

- Saturation of epoxy groups

Adding methacrylic acid to the epoxy resin leads to the saturation of the epoxy groups. This process occurs in a stirred batch reactor. The epoxy resin enters the reactor and heated up to 115 °C. An addition of catalyst and inhibitor is also made. Methacrylic acid is then constantly added to the reactor and at this stage the reactor's temperature is maintained at a temperature less than 120 °C. Cooling coils are used in which water flows in order to remove the heat out of the reactor.

12 Processing of Ferrous Metals

12.1 Description of industry

Processing of Ferrous Metals corresponds to the different steps/methods followed in the two main processes called hot and cold forming. Many methods exist for these two processes; however, three of them will be described. These methods are the hot rolling, the cold rolling and the wire production, which is a multistep process.

Some products manufactured using the three main methods mentioned above are:

- Hot rolled Flat Products
- Hot rolled Long Products
- Wire
- Cold drawn Long products
- Cold rolled flat products
- Tubes

Table 3 shows the world's and Europe's production of hot rolling products, hot rolled long products, wire and tubes made by steel, in 2014. The further processing of the hot roll products makes the production of cold rolling products and thus, such products are not shown in the table.

Table 86: Hot Forming production of steel

Product	Production ('000 tonnes)	
	World	EU
Hot Rolled Flat	1,608,425	154,726
Hot rolled long	837,600	58,667
Wired Rod	204,898	19,113
Tubes	44,042	4,890

Source: (Steel Statistical Yearbook, 2015)

Obviously, hot rolled flat products dominate in the global market in which EU shares the 9.6% approx. On the other hand, the production of tubes has the lowest share in the global market with the EU sharing the 11% approx.

12.2 Processes used involving heat

- *Hot Rolling*

In hot rolling process, which is a downstream process after the main furnace – the hot rolled mills powered by electricity change the size, shape and properties of products such as steel slabs, blooms, billets or ingots. During this process, the metal is continually pressed and its temperature varies from 1050 – 1300 °C.

- *Plate mills*

Plate mills are used for the production of heavy metals with a typical thickness range between 5.0 – 380 mm and a width not greater than 5.2 m. Once the metal exits the furnace, a plate mill stand is used to hot roll the product and downstream hot and/or cold levellers are used to straighten the product. Then, the flat plate goes is cooled down to room temperature or at 500 °C max. before passing through the finishing shops where it takes the final size and shape.

- *Reheating- and Heat Treatment Furnaces*

Before the metal passes through hot rolling, it has to be preheated to a uniform temperature between 1050 and 1300 °C. Different types of preheating furnaces are used. Such furnaces are pit furnaces, pusher type furnaces, walking beam furnaces, rotary hearth furnaces or others. Nevertheless, the right choice for the preheating furnace depends on the material and the hot rolling process used. The main fuels firing these furnaces are oil, natural gas, Cabot Oil & Gas (COG) or Blast Furnace Gas (BFG). Due to these fuels – and of course based on the material and process used – waste gas emissions such as SO_x and NO_x may occur.

- *Cold Rolling*

Cold rolling is identical to hot rolling except the fact that no preheating applies to the metal before the rolling process.

- *Pickling of Low Alloy and Alloy Hot Rolling (HR) Steel*

The oxides contained in the hot rolled coil must be removed before the cold rolling process. The removal is done with the aid of hydrochloric acid or sulphuric acid at temperatures between 75 and 95 °C.

- *Annealing of Low Alloy and Alloy Steel*

Temperature profile is the most important parameter, which is monitored and controlled during the whole process. This process may take place in batch or continuous furnaces which of course affect the temperature profile. The three main steps followed in this process are listed below.

- Heating to annealing temperature (above 650 °C)
- Holding at annealing temperature

- Cooling
- *Continuous Annealing*

During the continuous annealing process, the joint of the coils occurs takes place at the entry site of the plant. The steps followed are as below.

- Alkaline/electrolytic cleaning of the strips.
- Heating and holding at the required annealing temperature.
- Cooling (slow jet cooling, high gas jet cooling (using cooling rates up to 150 °C/s, hot water quench (HOWAQ), overaging, roll cooling, final cooling, misting jet cooling).

The steel passes through a furnace either gas fired or electrically heated. The furnace contains multizones such as heating chamber, annealing chamber, cooling zone, tempering zone and second cooling zone. The initial heat applied to the steel strip varies between 650 and 830 °C. Afterwards, the metal is cooled down with the aid of gas jets, gas-water sprays, contact rolls or water quenching.

- *Wire Plants*

Wire manufacture is a complex process as it contains a typically large number and complex steps. The main processes and steps followed for the production of wire are shown in Figure 12.

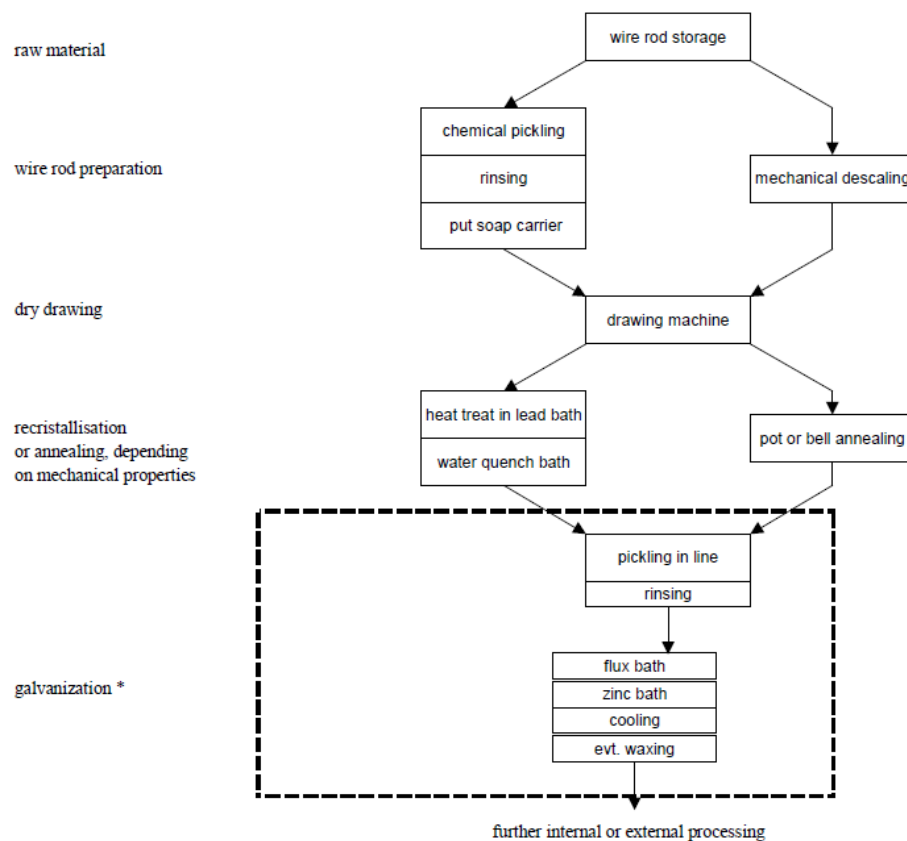


Figure20: Production of low carbon galvanized wire (Hunter, 2001)

➤ Heat Treatment of Wire

The aim of the heat treatment of wire depends on the type of steel used such as low carbon, high carbon or stainless and its end usage. Hence, there are different types of heat treatment processes as listed below. Their heat streams are also listed. For further information on the processes see (Hunter, 2001).

- Batch Annealing of Low Carbon Steel Wire (700 °C)
- Continuous (In-Line) Annealing of Low Carbon Steel Wire (500 – 700 °C)
- Continuous (In-Line) Annealing of Stainless Steel Wire (700 – 1100 °C)
- Patenting (850 – 1000 °C)
- Oil Hardening and Tempering 850 – 1000 °C and 300 – 500 °C reheating)
- Stress-relieving (200 - 500 °C)

12.3 Data available for waste heat recovery• *Waste Heat Boiler*

The installation can take place between the furnace exit and the chimney or in between the recuperator and the stack. When the waste gas is released it goes through the waste heat boiler and produces steam with the gas cooled down to 200 °C. Table 4 shows typical energy and NO_x reduction when a waste heat boiler is used.

Table 87: Typically achievable and cost data for waste heat boilers

Waste Heat Boiler	Reduction [%]		Investment Costs [M ECU]	
	NO _x	Energy	New facilities	Existing Facilities
	15	15	4	4

• *Feedstock Preheating*

A feedstock preheating is installed before the 2 pusher-type furnaces. These furnaces are fired by regenerative burners. At the beginning, heat is recovered from the exhaust gas in a waste heat boiler and the gas cools down to 500 – 600 °C. As the gas is still hot, it is used to heat the slabs to 400 °C through a preheater and as a result the gas further cools down to 300 °C. With the aid of heat exchangers, the still hot gas preheats the combustion air of the furnace's regenerative burners 150 °C approx. finally, the waste gas is disposed to 200 °C approx.

13 Production of Pulp, Paper and Board

13.1 Description of the industry

Europe plays an important role in the global pulp and paper industry, as it is the second largest producer and the third largest consumer of paper and board worldwide. The pulp and paper industry supplies an essential product – paper – to over 5 billion people worldwide. Originally, papermaking was a slow and labour-intensive process. Although, nowadays pulping and papermaking are driven by capital-intensive technical equipment and high-tech and high-speed paper machines that produce rolls of paper at a high speed that may reach 2000 m/min, with a web width that may exceed eight meters.

The pulp for papermaking may be produced from virgin fibre by chemical or mechanical means or may be produced by the repulping of paper for recycling (RCF). In Europe, wood is the main original raw material – paper for recycling accounts for about 50 % of the fibres used – but in a few cases straw, hemp, grass, cotton and other cellulose-bearing material can be used. Figure 21 shows an overview of the pulping and papermaking process.

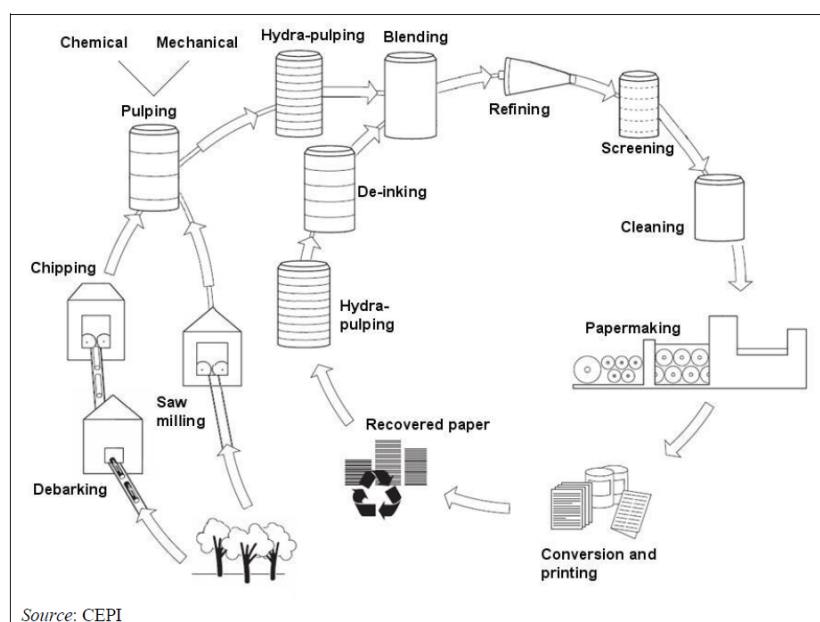


Figure 21: The papermaking process (CEPI, 2007)

In the papermaking process, wood logs are first debarked and chipped into small pieces. Then water and heat are added, and by mechanical or chemical means, the wood is separated into individual fibres (pulping). After screening, cleaning and sometimes refining, the fibres are mixed with water. Then this pulp slurry is sprayed onto a flat wire screen, which moves very quickly through the paper machine. Water drains out, and the fibres bond together. The web of paper is pressed between rolls which squeeze out more water and press it to make a smooth surface. Heated cylinders then dry the paper, and the paper is slit into smaller rolls, and sometimes into sheets.

13.2 Processes used involving heat

- *The Kraft (sulphate) pulping process (chemical pulping)*

Today the kraft process is the principal chemical pulping process worldwide due to the superior pulp strength properties compared with the sulphite process, its applicability to all wood species, as well as to the efficient chemical recovery systems that have been developed and implemented. But the chemistry of the kraft process carries with it an inherent potential problem in the form of malodorous compounds. However, modern mills with an optimised gas collection system can be limit unpleasant odours in the neighbourhood to process disturbances or other than normal operating conditions.

- *Lime kiln*

In the lime reburning process the calcium carbonate formed during the recausticising process is thermally converted back to calcium oxide. The reaction takes place in a rotary kiln where wet lime mud is dried, heated up to the reaction temperature, calcinated and cooled again. The calcination reaction starts at 800 °C and to complete the reaction temperatures up to 1 000 – 1100 °C are required in the hot end of the kiln. The cooling is done by air in heat exchangers.

- *Cooking and delignification*

The cooking can also be carried out in a continuous digester where the wood/chemical charge and retention time, as well as the temperature in the cooking zone, define the resulting lignin content. The chips are preheated by steam before entering the continuous digester in order to remove air which interferes with the impregnation. Before entering the main digester, the chips are impregnated with cooking liquor in an impregnator vessel. After that the temperature is raised to 155 – 175 °C. The cooking time at the maximum temperature is in the range of 1 – 2 hours.

- *Oxygen delignification*

After cooking, delignification can be continued with oxygen in one or two stages and with or without intermediate washing. Oxygen delignification can be combined with conventional and extended cooking. Oxygen delignification takes place in alkaline conditions. In order to maintain the sodium balance of the mill, the oxygen stage normally uses the oxidised white liquor, where sodium hydroxide is the main alkaline chemical and sodium sulphide (Na₂S) has been oxidised to thiosulphate (Na₂S₂O₃). Due to the relatively low solubility of oxygen to the alkaline liquor, the delignification reactor is pressurised and the temperature is elevated to about 90 – 100 °C.

- *The Sulphate pulping process (chemical pulping)*

The production of sulphite pulp is much smaller than the production of kraft pulp. In many respects the kraft and sulphite processes have similarities, not least regarding the possibilities of taking different internal and external measures to reduce emissions to the environment.

Due to these similarities, only some process steps for sulphite pulping technology are discussed in detail. The common process steps are the wood handling, the washing and screening, the bleached stock screening and the drying.

- *Mechanical pulping and Chemimechanical pulping*

In mechanical pulping the wood fibres are separated from one another by mechanical energy applied to the wood matrix causing the bonds between the fibres to break gradually and fibre bundles, single fibres and fibre fragments to be released. It is the mixture of fibres and fibre fragments that gives mechanical pulp its favourable printing properties. In mechanical pulping, the objective is to maintain the main part of the lignin in order to achieve a high yield with acceptable strength properties and brightness. Mechanical pulps have a low resistance to ageing which results in a tendency to discolour.

The main processes and techniques are the production of groundwood pulp (GW), pressure groundwood pulp (PGW), thermomechanical pulp (TMP), chemimechanical pulp (CMP) or chemithermomechanical pulp (CTMP).

- Grinding- Pressure Groundwood pulping (PGW)

The PGW process was developed where the grinding process takes place at overpressure (up to around 3 bar). This allows the process to be operated with white water temperatures of 95 °C and grinder pit temperatures of 125 °C.

- Chemithermomechanical (CTMP) and chemimechanical pulping (CMP)

The CMP process developed as the high yield process for hardwood species, mostly for board, tissue and fine paper. With stronger chemical treatment and refining at atmospheric pressure, pulps with high strength properties can be produced from both softwood and in particular hardwood. After chemical impregnation, the chips are cooked at a temperature ranging from 70 °C to 170 °C. The cooking time depends on the process and can vary between 15 minutes and a couple of hours.

- Bleaching of mechanical pulps

A suitable pH value is 5.6 to 6.5 and a temperature of up to 70 °C accelerates the bleaching process (Finnish BAT Report, 1997).

- *Processing of paper for recycling (with and without deinking)*

Recovered fibre has become an indispensable raw material for the paper manufacturing industry, accounting for more than 40 % of the total raw materials, because of the favourable price of recovered fibres in comparison to the corresponding grades of market pulp and because of the promotion of waste paper recycling by many European countries. In Europe the average utilisation rate of paper for recycling is around 50 %. The maintenance of the fibre

cycle relies on the feed of a certain amount of primary fibres to ensure the strength and other properties of the paper to be produced.

The system for processing paper for recycling varies according to the paper grade and the type of furnish used. Generally, the processing of recycled fibers (RCF) can be divided into two main categories: (i) processes using exclusively mechanical cleaning, i.e. without deinking, comprising products like Testliner, corrugating medium, uncoated board and cartonboard; (ii) processes using mechanical cleaning and deinking comprising products like newsprint, tissue, printing and copy paper, magazine papers (SC/LWC), coated board and cartonboard or market DIP.

- *LWC/SC paper*

The washing filtrate is cleaned in the dissolved air flotation unit with the addition of cationic flocculants. Ash and fines are removed and the water is returned to the system. The stock is heated by means of a heating screw and treated in a disperger that separates any ink still adhering to the fibres and simultaneously mixes in the bleaching additives (oxidative or reductive bleaching is applied here).

13.2.1 Papermaking and related processes

- *Paper machine*

The paper web passes into a press section supported on felts between rollers and through vacuum sections to remove more water and then through the drying section. The drying is normally done using steam-heated cylinders enclosed in a hood. In the dryer section, the web is dried to the final dry content of 90 – 95 %. Practically all the heat used for drying ends up in the hood as exhaust air. The temperature of the exhaust air is normally 80 – 85 °C and the humidity is 140 – 160 g H₂O/kg dry air. A part of the moisture (about 1 – 1.5 m³/t of paper) is driven off to the atmosphere. For economic reasons, all paper mills have installed heat recovery systems. Figure 22 shows a schematic picture of an example of the drying and heat recovery section of a paper machine.

In the first heat exchanger of the heat recovery system, heat is recovered in order to heat the incoming supplied air. The next heat exchanger is for the heating of incoming fresh water. In some cases, heat is also recovered to the wire pit water to compensate for the heat losses at the wet end. The last heat exchanger is for circulation water. The circulation water is used to heat the incoming ventilation air. The supply air and shower water are heated to their final temperatures (90 – 95 °C and 45 – 60 °C respectively) using steam.

- *Coated wood-free printing tissue process with conventional Yankee dryer*

Because of the high moisture, the sheet is moved to a second fabric using a vacuum. To obtain the bulkier characteristics, the sheet is dried by passing it over one or two TAD (through-air drying process) dryers where hot air (>350 °C) is blown through the sheet. Finally, the sheet may be transferred onto a Yankee cylinder for further drying with steam and hot air.

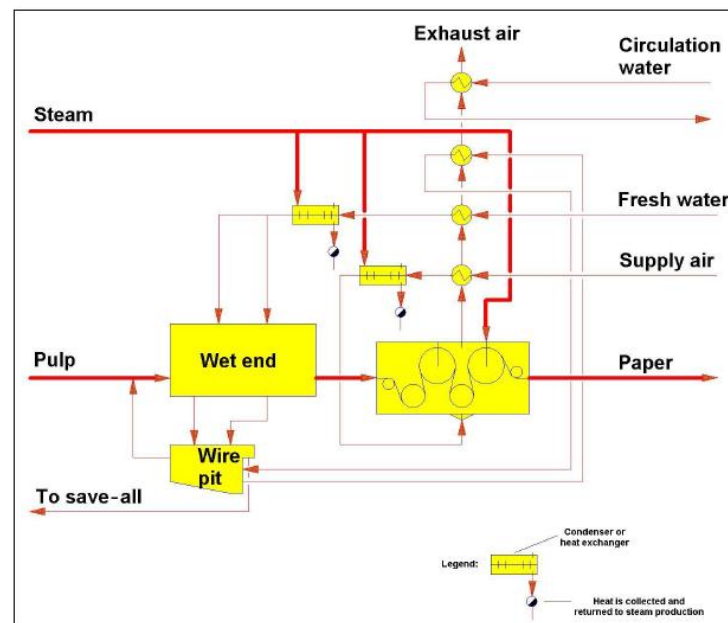


Figure 22: Paper machine heat recovery system

13.3 Data available for waste heat recovery

- *Heat recovery from radial blowers used in vacuum systems*

Due to the compression process in the vacuum blower(s), the exhaust air from the blowers reaches temperatures of 130 – 160 °C. This hot air can be passed through air-to-air heat exchangers, enabling the recuperation of up to 75 % of the power absorbed by the vacuum blowers. Radial blowers are used for wire and felt dewatering across all grades and are normally installed in larger paper machines. By reusing the recovered heat, the steam demand in the drying section of the paper machine can be reduced. The waste heat from the exhaust air can be used to heat the supply air of the drying hood, resulting in savings of direct steam. (Blum, Maur, & Öller, 2007).

- *Recovery of heat from infrared exhaust hot air (for drying of the applied coating colors).*
- *Kraft (sulphate) pulping process*
- *Black liquor recovery boiler*

The recovery boiler is fed with the concentrated black liquor, a by-product from the kraft pulping process that contains valuable cooking chemicals (Na and S). The main purpose of the black liquor recovery boiler is to recover valuable pulping chemicals and to produce energy from the organic residues in the black liquor. The used cooking chemicals are recovered in the form of the inorganic melt.

➤ *Lime kiln*

In the lime reburning process the calcium carbonate formed during the recausticising process is thermally converted back to calcium oxide according the reaction equation $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. The reaction takes place in a rotary kiln where wet lime mud is dried, heated up to the reaction temperature, calcinated and cooled again. The calcination reaction starts at 800 °C and to complete the reaction temperatures up to 1000 – 1100 °C are required in the hot end of the kiln. The cooling is done by air in heat exchangers.

➤ *Flue-gas heat recovery*

The hot flue-gases are used to generate steam in a waste-heat boiler and the resulting high-pressure steam generates additional power in a steam turbine.

13.3.1 Mechanical pulping and Chemimechanical pulping

- *Extensive recovery of secondary heat from TMP and CTMP refiners and reuse of recovered steam in paper or pulp drying*

The working efficiency of a TMP refiner is relatively poor. Nearly all electrical energy put into the refining process is transformed into heat. The majority of the energy is bound in the plate gap containing a specific latent heat for the vaporisation of water (the generation of steam). Heat is also bound to heated water and heated fibre material. 'Heat recovery' means the reuse of all of the heat which is created in a TMP process. A TMP plant consists of main line refiners, which might be just one main line refiner (e.g. RTS process) or two or three in series, and reject refiners, which usually number one or two. (Nilsson, Puurunen, Vasara, & Jouttijärvi, 2007), (Blum, Maur, & Öller, 2007)

- *Processing of paper for recycling*

Recovery operations are considered the preferred waste treatment option. Possibilities to reduce the amount of waste to be landfilled should be identified and put into practice, where feasible. Incineration combined with power and steam generation is regarded as an environmentally sound solution. Different technical options (pretreatment, boilers,

abatement techniques) for the incineration of residues with energy recovery are realised in European paper mills. Four of them are described below.

- *Papermaking and related processes*
- *Steam condensate recovery and use of efficient exhaust air heat recovery systems*

The normal arrangement in heat recovery is first to recover heat to the supply air of the dryer section, and then to the circulation water or fresh water. The recovered heat in the circulation water, is mainly used to heat the building ventilation air. Another major heat recovery use is for the heating of process water and wire pit water. The heating of wire pit water does not apply to TMP mills but for instance to recycled fibre-processing mills. Supply air to the dryer section is always heated by the heat recovery system.

For heat recovery, air-to-air heat exchangers or air-to-water heat exchangers, plate heat exchangers and in some cases scrubbers for warming process water with recovered heat are used. The plate heat exchangers are mainly used for heating hood supply air and machine room ventilation air. The most common application for air-to-water heat exchangers is the heating of circulation water and process water. These heat exchangers are part of heat recovery towers (Blum, Maur, & Öller, 2007).

14 Production of Specialty Inorganic Chemicals

14.1 Description of the industry

In 2002, the EU-15 was the world's leading exporter and importer of chemicals accounting for half of global trade. The key trading regions are the EU, Asia, and North America. Germany is the largest producer of chemicals in Europe, followed by France, Italy and the UK. Together, these four countries produce 64 % of EU-15 chemicals output. Adding Belgium, Spain, the Netherlands and Ireland raises the share to nearly 93 %.

Speciality Inorganic Chemicals are, in general, produced in smaller volumes (typically from a few tonnes to 100 kilotonnes per year) and sold with a higher profit margin than commodity or bulk chemicals, although this may vary widely for different types of speciality chemicals (high margins have eroded for the long established SIC substances). SIC substances tend to be more consumer orientated and less subject to cyclical demand. Production of SIC in Europe is generally highly automated and computer-controlled (although this is not generally the case for the production of SIC explosives and pigments). A SIC substance is often produced in several grades and forms (e.g. powder, granules, paste, solution) depending on the customers' needs.

14.2 Processes used involving heat

As this document does not provide a comprehensive description of all SIC processes, it is important to understand the generic principles of process steps, site infrastructure, energy, and management systems. These fundamental elements should enable a basic understanding of any SIC production process, its potential environmental impact, and suitable techniques in particular for preventing and controlling emissions.

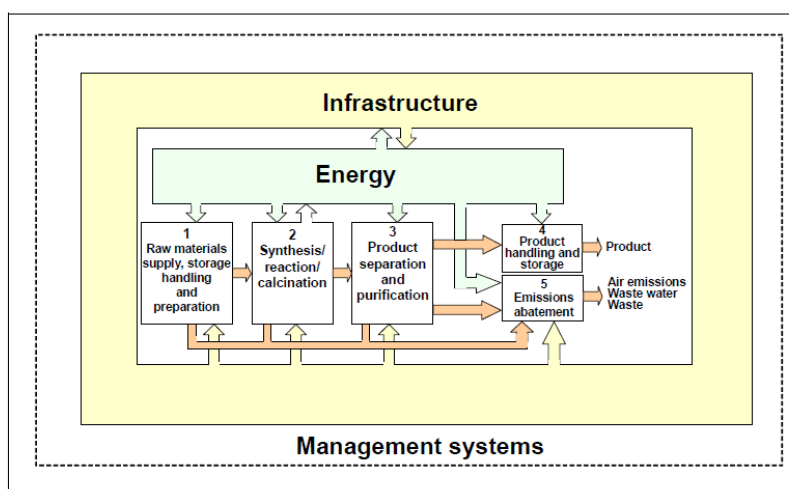


Figure 23: Schematic representation of a SIC production process

- **Calcination**

Calcination is an endothermic process that requires heat to decompose chemical compounds.

Combustion processes involve exothermic oxidation or 'burning' of the feed material. Roasting processes use elevated temperatures and controlled furnace atmospheres to effect the desired chemical reactions in the furnace charge; roasting reactions may be either endothermic or exothermic. Although many furnace technologies exist, current industrial practice favors the rotary kiln and the fluidised-bed reactor for these applications.

- *Drying*

The vaporisation of liquids requires the supply of heat. The product that is to be dried is denoted as the moist solid (e.g. moist cyanide crystals), or simply as the solid. The substance that carries the necessary heat is called the drying agent. This substance could be air, an inert gas, or superheated steam. Heat could also be supplied by radiation, by hot surfaces, or by microwaves (Decker, 2001).

- *Raw material storage and handling*

Storage tanks are maintained at a heated temperature of approximately 60 °C to ensure that the elemental phosphorus remains in a liquid form.

The illustrative SIC families are: specialty inorganic pigments, phosphorus compounds, silicones, inorganic explosives and cyanides.

- *Dry calcination process –specialty inorganic pigments*

Calcination can be divided into thermal decomposition/conversion and high temperature reaction. In thermal decomposition/conversion, the raw material is decomposed at high temperatures (between approximately 150 and 1300 °C), e.g. oxidation of iron sulphate with oxygen to form Fe_2O_3 and SO_3 . This process requires the strict monitoring of the temperature/time curve of the reaction. In the high temperature reaction, the raw materials react with each other in a so-called solid phase reaction, which leads to the formation of the desired pigments. The reaction takes place at temperatures between 500 and 1400 °C, below the individual melting temperatures of the raw materials. The raw materials used are essentially metal oxides, hydroxides or carbonates, and only exceptionally other metal compounds. In some cases, mineralisers (such as sulphates, chlorides and fluorides) are used in minor amounts, which give rise to emissions of such substances into the air. Gaseous reaction products leave the reaction chamber through the same emission point (not necessarily at the same time) as the off-gas in both thermal decomposition/conversion and high temperature reaction processes.

- *Complex Inorganic Coloured (CIC) pigments*

The production process of rutile and spinel pigments consists of a reaction of fine metal oxides, hydroxides or carbonates at temperatures of between 800 and 1400 °C. The reaction process is accelerated by the selection of finely dispersed reaction materials. The starting materials in the manufacture of CIC pigments are weighed, intimately mixed and calcined either in a rotary or tunnel kiln (continuously) or in a chamber kiln (discontinuously). After the

calcination process, the clinker obtained needs, in some cases, to be purified from soluble substances by intensive wet grinding, then dried and, if necessary, milled again.

- *Production of PCl_3 by the gas-liquid reaction process -Phosphorus compounds*

The heat of the reaction, about ten times the heat of evaporation, keeps the system at its boiling point, and the phosphorus trichloride distils off. The vapours are fractionated as reflux takes place, and PCl_3 condenses at 75.5 °C in air-cooled or water-cooled condensers.

- *Production of PCl_3 by the gas phase reaction process-Phosphorus compounds*

In another process, phosphorus and gaseous chlorine are reacted in a combustion chamber to form phosphorus trichloride at about 1800 °C.

- *Drying of SIC explosives -Specialty inorganic chemical (SIC) explosives*

For safety reasons, the drying area is located at some distance from the reactor's room (prevention of the 'domino effect'). The drying area consists of built-in closets where the trays are deposited. Hot air (65 – 70 °C) circulates in the closets through the trays and dries the moist crystals (steam is used as the source of energy to heat the circulating air).

- *Neutralisation/crystallisation - Cyanides*

Simultaneously to the neutralisation reaction or in a second step, water is vaporised under reduced pressure and the alkali metal cyanide is precipitated below 100 °C (crystallisation). The shorter the residence time of the cyanide in solution, the cleaner the product and the lower the content of hydrolysis products and iron impurities will be (Decker, 2001).

- *Drying- Cyanides*

The moist NaCN crystals (which still contain about 12 % water) are dried (at about 300 °C) with hot, CO₂ free air which circulates in a closed loop within the process.

14.3 Data available for waste heat recovery

- *Cooling and refrigeration systems*

Cooling systems typically involve some form of heat exchanger to remove heat from the process, a heat transfer medium and a mechanism for dissipating heat into the environment. A wide variety of cooling technologies are available and as these technologies are used in common ways across industry, they are covered in detail in the dedicated horizontal BREF on Industrial Cooling Systems (European IPPC Bureau, Reference Document on the application of Best Available Techniques to Industrial Cooling Systems, 2000). Cooling can be carried out directly or indirectly. Direct cooling is carried out by injecting water, usually to cool down vapour phases. Indirect cooling is provided by heat exchangers (condensers), where the cooling medium (e.g. water, brines) is pumped in a separate circle (European IPPC Bureau, Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector, 2003).

- *Separators*

The waste gas stream is passed into a chamber where the dust, aerosols and/or droplets are separated from the gas under the influence of gravity/mass inertia, the effect increased by reducing the gas velocity by design means, e.g. baffles, lamellae or metal gauze. A separator is usually installed as a preliminary step to various dust filter systems, scrubbers, cooling towers, etc. It is used, e.g. to prevent entrainment of the washing liquid with the purified waste gas and/or to remove abrasive particles. It is not applicable to treat particulates in flue gas. For additional information on the description, application, advantages/disadvantages and limits/restrictions of the technique, please refer to the CWW BREF (European IPPC Bureau, Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector, 2003). Performance rate 10 – 90% (Dependent on PM size)

- *Condensation and cryogenic condensation*

Condensation is a technique that eliminates solvent vapors from a waste gas stream by reducing its temperature below its dew point. Condensation is carried out by means of direct (i.e. contact between gas and cooling liquid) or indirect cooling (i.e. cooling via heat exchanger). Indirect condensation is preferred because direct condensation needs an additional separation stage. Recovery systems vary from simple, single condensers to more complex, multi-condenser systems designed to maximise energy and vapor recovery. For additional information on the description, application, advantages/disadvantages and limits/restrictions of the technique, please refer to the CWW BREF (European IPPC Bureau, Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector, 2003).

- *Twin-bed oxidiser systems*

The oxidiser consists of a reinforced, insulated twin-bed chamber filled with ceramic heat exchanger media. The gas flow is automatically controlled by a zero leakage poppet valve mechanism that changes the direction of the gas flow at regular intervals via an integral Programmable Logic Control (PLC) system with remote modem-based telemetry diagnostics. Due to the abundant oxygen content of the process gas, complete combustion readily occurs when the ignition point is reached in the oxidiser (typically 870 to 927 °C for RTO and 316 to 427 °C for RCO – Regenerative Catalytic Oxidation). Process hydrocarbons are converted to carbon dioxide and water vapor.

- *Catalytic oxidation*

Catalytic oxidisers operate in a very similar way to thermal oxidisers, with the main difference that the gas, after passing through the flame area, passes through a catalyst bed. The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal oxidation units. Catalysts, therefore, also allow smaller oxidisers to be used. The waste gas is heated by auxiliary burners to approximately 300 – 500 °C before entering the catalyst bed. The maximum design exhaust temperature of the catalyst is typically 500 – 700 °C (European IPPC Bureau, Reference Document on Best Available Techniques in Common Waste Water and Waste Gas Treatment / Management Systems in the Chemical Sector, 2003).

- *Waste gas treatment techniques to abate gaseous pollutants in combustion exhaust gases*

Sorbent injection for abating acid gases and fluorides

Selective reduction of NOX (SNCR and SCR)

Wet SO₂ abatement techniques

- *Thermal oxidation of off-gases containing light hydrocarbons and chlorinated organic compounds*

Off-gases containing light hydrocarbons and chlorinated compounds from the production of silicones are treated in a thermal oxidiser. The thermal oxidiser must be authorised to burn chlorinated compounds. The amount of VOC, methyl chloride and chlorosilane emissions to the air are directly related to the reliability of the thermal oxidiser. To reduce chloride emissions, a scrubber is necessary after thermal oxidation.

- *Incineration of process air containing volatile organic compounds (VOCs)*

The heat recovered from incineration is used to dry the cyanide crystals.

- *Utilisation of industrial waste and especially petrochemical residues for power generation with low emissions*

The concept is based on a confidential combustion system combined with a two-step, dry fluegas treatment system and an existing boiler. The combustor is composed of a high swirl, sub-stoichiometric combustion chamber, followed by an after combustion chamber, to which secondary air is added ensuring a residence time of 0.3 s and a temperature of 1200 °C. The particular geometry, together with the flow pattern lead to complete combustion, with low formation levels of NOX, CO and dioxins. The flue-gas is desulphurised by the injection of crushed limestone, together with recirculated flue-gas to reduce the temperature to a level of 1100 – 1150 °C. After heat recovery, lime powder and steam are added for HCl removal.

Finally, the flue-gas is cleaned using bag filters (European Commission, n.d.), (Boenke, 2005).

15 Refining of Mineral Oil and Gas

15.1 Description of the industry

The purpose of refining is to convert natural raw materials such as crude oil and natural gas into useful saleable products. Crude oil and natural gas are naturally occurring hydrocarbons found in many areas of the world, in varying quantities and compositions. In refineries, these are transformed into different products such as:

- fuels for cars, trucks, aeroplanes, ships and other forms of transport;
- combustion fuels for the generation of heat and power for industry and commercial and domestic use;
- raw materials for the petrochemical and chemical industries;
- speciality products such as lubricating oils, paraffins/waxes and bitumen;
- energy as a by-product in the form of heat (steam) and power (electricity).

In order to manufacture these products, these raw materials are handled and processed in a number of different refining facilities, alone or as a mixture with biofuels. The combination of these processing units which convert crude oil and natural gas into products, including supporting units and facilities, is called a refinery. The market demand for the type of products, the available crude quality and certain requirements set by authorities influence the size, configuration and complexity of a refinery. As these factors vary from location to location, no two refineries are identical.

15.2 Processes used involving heat

- *Bitumen production*

Where the bitumen feed is received from storage, an additional fired heater may be required to preheat the feed to a temperature of about 200 – 250 °C, but it can be up to 550 °C. With a batch-operated BBU, a feed buffer vessel is usually included to store the hot feed stream from the vacuum unit. The residue feed stream is pumped into the top of the oxidation vessel. As air is sparged into the base of the vessel, oxidation of the residue takes place, resulting in heat. The temperature in the oxidation vessel, which determines to a certain extent the bitumen grade, is normally controlled between 260°C and 300°C.

The remaining gas, consisting mainly of light hydrocarbons, N₂, O₂, CO₂ and SO₂, is incinerated at high temperatures (about 800 °C) to ensure complete destruction of minor components such as H₂S, complex aldehydes and organic acids and phenolic compounds, which have a highly unpleasant odour.

- *Catalytic cracking*

In the FCC (Fluid Catalytic Cracking) process, oil and oil vapour preheated to 250 – 425 °C come into contact with hot catalyst at about 680 – 730 °C in the riser reactor. To enhance vaporisation and subsequent cracking, the feed is atomised with steam. The cracking process takes place at temperatures between 500 °C and 540 °C and a pressure of 1.5 – 2.0 barg.

In the moving bed process, oil is heated to 400 – 700 °C and is passed under pressure through the reactor, where it comes into contact with a catalyst flow in the form of beads or pellets.

(Kooottungal, 2008), (Hydrocarbon Processing, 2011)

- *Catalytic reforming*

Continuous catalytic regeneration (CCR) reforming process → 500-550 °C

Semi-regenerative reforming process → 400 – 560° C

- *Coking processes*

Delayed and fluid coking → 440-450 °C

Calciner → The coke is calcinated at up to 1 380 °C, driving off volatile matter and burning it within the kiln. Exhaust gases discharge from the feed end and are incinerated to burn off residuals and coke fines. Hot flue-gases pass through a waste heat boiler and gas cleaning by multi-cyclones. Collected fines from the cyclones are pneumatically conveyed to a silo with exit air filters. The calcined coke discharges to a rotary direct water injection. Off-gases from the cooler pass to gas cleaning by multi-cyclones and the water scrubber. Collected cyclone fines may be recycled to product, which is oil sprayed as a dust suppressant, or may be incinerated or sold as a fuel.

Flexicoking → The flexicoking process uses three major vessels: the reactor, the heater and the gasifier. As auxiliary facilities, the system includes a heater overhead cooling system and a fines removal system, a coke gas sulphur recovery unit and reactor overhead scrubber. The preheated vacuum residue feed is sprayed into the reactor, where it is thermally cracked, typically at 510 – 540 °C. The freshly formed coke is deposited on the surface of the fluidised recirculated coke particles. In the gasifier, the coke is reacted at elevated temperatures, typically 850 – 1000 °C, with air and steam to form coke gas, a mixture of hydrogen, carbon monoxide and dioxide and nitrogen.

- *Desalting*

After preheating to 115 – 150 °C, the oily feedstock is mixed with water (fresh and reused water) in order to dissolve and wash out the salts.

- *Etherification: 60-90 °C*
- *Gas separation processes: 55-112°C*
- *Hydrogen-consuming processes*

Hydrotreating and hydroprocessing → 320 – 380 °C

Hydrocracking → 280 - 475 °C

- *Hydrogen production*

Steam reforming → 750 – 1 000°C

- *Isomerisation: 250 – 280 °C*
- *Primary distillation units*

Atmospheric distillation → 300 – 400 °C

Vacuum distillation → 355-400 °C

- *Visbreaking and other thermal conversions*

Visbreaking: There are two types of visbreaker operations, ‘coil or furnace cracking’ and ‘soaker cracking’. Coil cracking uses higher furnace outlet temperatures (470 – 500 °C) and reaction times from one to three minutes, while soaker cracking uses lower furnace outlet temperatures (430 – 440 °C) and longer reaction times.

15.3 Data available for waste heat recovery

Waste heat is abundant at refineries, and so is low/medium-pressure, low-temperature steam. Any effort to recover waste heat as low-pressure/low-temperature steam is pointless if there is no additional use for the extra steam produced. Options for using that heat need to be carefully quantified and qualified. Heat exchangers require space. The identification and use or opportunities or synergy for sharing use of energy outside the refinery is sometimes difficult and requires finding partners.

- Gas-heated reforming (GHR)

The gas-heated reforming (GHR) technique generally uses a compact unit heated by high-temperature waste heat from the raw synthesis gas, often by means of a heat exchanger-type reactor downstream of the conventional synthesis gas generator. In other examples, the GHR can also be fully integrated into the synthesis gas generator. The recovered heat is used in the

GHR to drive the endothermic reforming reactions instead of solely using this heat for steam generation in a steam boiler. Consequently, a hydrogen production plant with a GHR unit produces less excess steam than a conventional synthesis gas production plant based on a steam reformer or partial oxidation reactor.

- Heat integration of crude distillation units

There is a tendency towards improved heat integration with crude and other units. The high energy consumption of the CDU makes heat integration very relevant. To optimise heat recovery from the atmospheric distillation column, two or three reflux streams are normally kept in continuous circulation at several points per top and middle pumparounds. In modern designs, integration with the high vacuum unit and sometimes the thermal cracker is achieved.

16 Slaughterhouses and Animals By-products Industries

16.1 Description of the industry

The relationships between the activities downstream from the slaughterhouse are illustrated in a very simplified and general form in Figure 24. The final use or disposal route for many of the individual by-products of slaughter and of the treatment of waste water from slaughterhouses and animal by-products installations varies geographically and also from time to time. This depends on whether the by-products are considered, within food and veterinary legislation, to be fit for use as food for humans, pet food or animal feed; on economic factors and on local/national traditions and preferences. Local/national tradition is a significant factor with respect to, e.g. the choice between the use of landfill, incineration and biogas alternatives and it may be determined by local legislation.

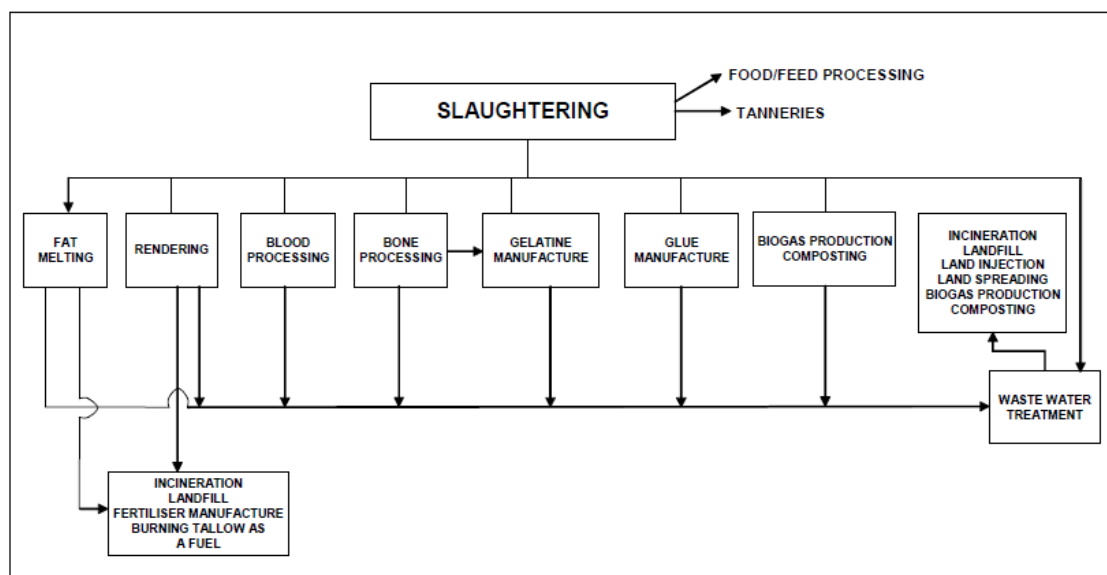


Figure 24: Relationships between slaughterhouses and downstream activities (summary)

16.2 Processes used involving heat

16.2.1 Slaughter of large animals

- *Pig scalding*

Traditionally the pig carcase is passed through a static or rotary scalding tank filled with water between 58 °C and 65 °C for 3 – 6 minutes to loosen the bristles and toenails.

- *Pig singeing*

The degree of singeing is controlled by the amount of energy supplied. Singeing temperatures are around 900 - 1000 °C (WS Atkins-EA, 2000), (Nordic States, 2001), (Filstrup, 1976).

16.2.2 Slaughter of poultry

- *Scalding*

After stunning and bleeding, the birds are immersed in a scalding tank to loosen the feathers to facilitate de-feathering. Birds destined to be sold frozen are usually 'hard scalded' at 56 - 58 °C. Carcasses to be air-chilled, for fresh sale, are most often 'soft scalded' at 50 - 52 °C to avoid damage to the cuticle and resultant skin discolouration. In the Nordic countries, chickens for freezing are scalded at approximately 58 – 60 °C and chickens for chilled distribution are scalded at approximately 50 - 51 °C.

- *De-feathering*

Some slaughterhouses have equipment for cleaning the feet for human consumption. The feet are cleaned with water at 80 °C. The equipment is only used when there is a viable market for this product.

16.2.3 Animal by-products installations

- *Fat melting*

Batch wet fat melting is the oldest method of fat melting. An autoclave is filled with precut raw material and is then closed. Live steam is then injected into the raw material at a pressure corresponding to a saturation temperature of about 140 °C. To minimise the heating time, the cooking vessels are not too large and are equipped with agitators.

Continuous processing combines mechanical and thermal treatments in order to minimise the processing time. The raw material is first passed through a mincer. It is then conveyed to an airtight section, where it is heated in two stages to about 60 °C and 90 °C respectively, in a matter of a few minutes.

- *Rendering of carcasses and waste*

The by-products, which have been reduced in size to no greater than 50 mm, are sterilised at 133 °C, for at least 20 minutes without interruption at a pressure (absolute) of at least 3 bar (300 kPa) produced by saturated steam.

Current continuous sterilisers consist of a system of preheaters, heaters, and a holding device.

These can be constructed horizontally in series, or vertically as a compact system. The raw material is conveyed from the loading equipment, where fat may be mixed into it, into a piston

pump, which presses the material at high pressure through the entire system. In the preheaters, which consist of a cylindrical container containing heated pipes, the raw material is heated to approximately 75 - 80 °C, using the exhaust vapour from the sterilisation. In a second stage, i.e. the heater stage, the material is brought to a temperature of 133 °C through the indirect supply of steam. The heater is also a heat-exchanger containing heated pipes. The third stage is the holding device, which must be sized for the maximum throughput volume. The pressure of 3 bar (300 kPa) is guaranteed by the pressure keeping system installed at the end of the holding device, which only opens at a pressure of 3 bar (300 kPa). The mixing of the raw material is ensured within the pipe system. After discharge of the sterilised material, the exhaust vapour steam is separated in a cyclone and used again for the preheating.

- *Rendering of feathers and pig hair*

The processes can be carried out in batches in dry rendering cookers, where the keratin containing material is exposed to high temperature (135 - 145 °C) and pressure for 30 -60 minutes. The pressure is then released and the product is dried and milled. This can eliminate the need for mechanical dewatering.

- *Fish-meal and fish-oil production*

Fish are 70 - 75 % water. They are indirect-steam cooked for 20 minutes in their own water at 90 - 100 °C. The protein coagulates and it is this which forms the press cake.

- *Blood processing - plasma and dried red cell production*

The air circulating through the drying chamber is atmospheric air, finely filtered and warmed by passing through a steam heater or an indirect gas heater. A centrifugal ventilator moves the heated air into the circulation system. The inlet temperature at one installation is reported to be 240 °C. The minimum contact time is 15 seconds at that same installation. It may be up to 30 seconds in other plants. The outlet temperature is 90 °C. The temperature for spray drying the red cells is higher than that for plasma, i.e. > 250 °C.

16.2.4 Gelatine manufacture

- *Degreasing*

Drying at 85 °C takes 45 minutes. The product temperature reached in the drier is about 110 °C, for at least 45 minutes. The tallow/water mix is separated using centrifuges to give purified tallow and process water. The liquids are maintained at a temperature of 85 °C for 30 minutes during separation. Fine solids removed from the liquid during separation, together with fine solids from the pressing of the sinew are combined and dried to give a moisture content typically < 10 %. The product temperature achieved in the drier is around 110 °C for at least 45 minutes.

Bone chips are graded by density, using a hydrocyclone, because high-density bones require more processing than low-density bones, both to demineralise and to extract the gelatine. They are then dried in a band oven, with a starting air temperature of around 350 °C and an exit temperature of 150 °C. The chips are only in contact with the hot air for a short time and they are also cooled by the evaporation of the water, so their temperature will not normally exceed 85 °C. The drying time varies from 20 – 60 minutes.

- *Extraction*

The gelatine is extracted from the neutralised ossein, pretreated hides or pig skins, with hot water. This involves about 5 steps, at progressively higher temperatures, usually with no more than 10 °C difference between steps and typically ranging between 50 - 60 °C and 100 °C. The gelatine concentration of the extract is normally 3 - 8 %.

- *Sterilisation*

The concentrated gelatine solution is sterilised either by direct steam injection, such that the temperature is raised to 138 - 140 °C, or by operating the final effect, known as a finisher, at a temperature of about 120 - 140 °C. The increase in temperature is achieved by injecting steam from another source.

- *Autoclaving and extraction*

133 - 135 °C

- *Gasification of meat and bone meal*

The gasification process involves partial combustion in a reduced oxygen environment. The MBM is fed by a vertical screw conveyor to a ring shaped combustion chamber, where process room air is added at sub-stoichiometric quantities compared to the fuel load at a temperature of 1300 - 1500 °C. The fuel is recirculated back to the gasifier, in the form of partially carbonized material. Syngas is the product of the low oxygen combustion process. The syngas has a lower heating value of 4605 kJ/m³(NTP). The gasification process is endothermic and the syngas is thereby cooled to between 680 °C and 850 °C. The syngas then passes through a cyclone and a heat-exchanger to cool it further to 500 - 550 °C, for combustion in a thermal oxidiser and boiler.

16.3 Data available for waste heat recovery

When the factory represented in the schematic diagram produces surplus heat, it is conducted through the heat-exchanger to a district heating system, if required. Only a few fish-meal factories supply heat in this way. During operation, a surplus of condensate is continuously produced at the primary side of the heat-exchanger. This surplus is channeled away. The heat exchanger can also receive heat from other sources of condensate, but this is not shown on the figure, to preserve clarity.

- *Heat recovery from pig singeing exhaust gases, to preheat water*

Temperatures in the singeing unit can be as high as 900 - 1000 °C and if heat is not recovered gases can be emitted at 600 - 800 °C. A heat recovery system can be used to heat the water.

- *Incineration of malodorous air, with heat recovery*
- *General techniques applicable in slaughterhouses and animal by-products installations*

Heat can be recovered in rendering plants and used in the rendering process, for other on-site activities or for off-site activities, such as district heating. The recovered heat can be used for space heating, feedstock heating and water heating (Finnish Environment Institute and Finnish Food and Drink Industries' Federation, 2001).

17 Smitheries and Foundries Industry

17.1 Description of the industry

Foundries melt ferrous and non-ferrous metals and alloys and reshape them into products at or near their finished shape through the pouring and solidification of the molten metal or alloy into a mould. The foundry industry is a differentiated and diverse industry. It consists of a wide range of installations, from small to very large; each with a combination of technologies and unit operations selected to suit the input, size of series and types of product produced in the specific installation. The organisation within the sector is based on the type of metal input, with the main distinction being made between ferrous and non-ferrous foundries.

The European foundry industry is the third largest in the world for ferrous castings and the second largest for non-ferrous. Germany, France and Italy are the top three production countries in Europe, with a total annual production of over two million tonnes of castings each. In recent years Spain has taken over the fourth position from Great Britain, with both having a production of over one million tonnes of castings. Together, the top five countries produce more than 80 % of the total European production.

17.2 Processes used involving heat

- *Magnesium casting*

Pressure die-casting is the most commonly used casting process, due to the low casting temperature (650 – 700 °C); both hot chamber and cold chamber die-casting machines are used.

- *Casting of superalloys*

The superalloys are typically Ni, Ni-Fe, and Co based alloys with Cr, Ti, W, Al additions. They were originally used for high temperature applications (over 810 °C) or in severe corrosive media. Superalloys can be distinguished from high alloyed steels.

17.2.1 Melting and metal treatment- furnaces

- *Cupola furnaces*

Hot blast cupola furnace → Two methods of heating are:

- *Recuperative heating*: This involves the transfer of the residual (“latent”) heat of the flue gases to the combustion air. The flue-gases are collected at the top of the furnace, mixed with sufficient air and then burned in a post combustion unit. This provokes the exothermic oxidation of CO. The burnt gases are led through a heat-exchanger (recuperator) where the heat is transferred to the combustion air. Typically, the blast air is heated at temperatures of

500 to 600 °C. Above these temperatures, problems arise with the sintering of furnace dust on the surface of the recuperator.

- *External heating*: Here the combustion air is heated by some external means, e.g. by a gas or fuel burner, by electrical resistance or by a plasma torch.

The combination of these two heating methods, permits the superheating of the blast air up to 1000 °C. These high temperatures, however, require the use of more expensive refractory materials and may cause too high a melt temperature.

17.2.2 Mould and core production

- *Moulding with unbonded sand (V-process)*

a thin film of polyethylene vinyl acetate (PEVA), 75 to 100 microns thick, is heated up to 85 °C

- *Moulding and core-making with chemically-bonded sand*
 - **Alkyd oil, unbaked (Cold-setting processes)** → 150 °C
 - Hot-box, phenolic and/or furan based → 230 °C to 290 °C
 - **Warm-box** → 150 - 170 °C

Raw materials

Chromite sand → theoretical melting point: 2180 °C, but the presence of impurities can lower this to 1800 °C

Zircon sand → melting point: higher than 2000 °C

Olivine sand → melting point: forsterite: 1890 °C, fayalite: 1205 °C

Iron foundries require metal of a controlled composition and temperature, supplied at a rate sufficient to match the varying demand of the moulding line. The metallic charge to be melted usually consists of foundry returns, iron and steel foundry scrap and pig iron, with alloying additions such as e.g. ferrosilicon, ferrophosphorus or ferromanganese. The charge is usually melted in a cupola or in an electric induction furnace. Induction furnaces are gradually gaining higher market preference compared to the cupola type. Coreless induction furnaces are used for melting. Channel induction furnaces are only used for holding, their main application being in combination with the cupola furnace, in the so-called duplex configuration. Gas-fired and oil-fired rotary furnaces can also be used, although their use is less common. Short-term holding, transport and metal treatment are performed in ladles.

Steel is melted in both electric arc and induction furnaces. Large steel foundries may use electric arc furnaces, but induction furnaces are more commonly used. Arc furnaces are capable of using low cost scrap charges, since refining takes place in the furnace. However, they have the limitation that there is always some carbon pick-up from the graphite

electrodes, so very low carbon stainless steels (<0.03 % C) cannot be made. In the induction furnace, refining is not possible, so a carefully selected charge must be used. However, any type of steel may be melted. Short-term holding, transport and metal treatment are performed in ladles.

The melting furnace used in non-ferrous melting is dependent on the foundry size. Non-ferrous foundries often use a variety of different alloys and/or have a limited melting capacity. Melting is done in small volume furnaces, for which the crucible furnace is most suited. Additionally, die-casting is the major casting technique. In this case, there often is no need for a centralized melting, as the melting (and holding) furnace is integrated into the casting machine. Non-ferrous foundries with a higher capacity and a need (or reason) for centralised melting typically use induction, hearth type or shaft furnaces for melting, and then distribute the molten metal to holding furnaces and casting crucibles (Brown, 2000).

17.3 Data available for waste heat recovery

- *Cooling - Cupola furnace*

In the hot blast operation, the heat recovered from cooling may be used for preheating the blast air.

Several options are possible for cooling the collected gases, including:

- *Using tube coolers:* Running the collected gases through long ducts, decreases the temperature by natural convection and radiation. This system is simple but takes up a lot of space and does not offer controlled cooling (therefore there is a risk of condensation)
- *Using a forced air/gas heat-exchanger:* Cold ambient air is forced through an arrangement of tubes or plates to cool down the gases. Dust collection and the subsequent need for cleaning the heat-exchanging surfaces may lead to a complex and expensive design of the system. One advantage of this system is the possible use of the heated air for external heating purposes. Recuperative hot blast cupolas are equipped with a post combustion unit and a heat-exchanger (recuperator) to heat the blast air
- *Using an oil/gas heat-exchanger:* This is similar to the above system but more expensive because of the need for a secondary cooling system. The heat-exchanger is generally cooled with a circulation of mineral oil. Cooling with a water/gas heat-exchanger is not (or only very rarely) practised
- *Saturation with water:* Here the gases are cooled by the evaporation of the water sprayed into the gas stream. Wet scrubbers perform better if the gases are cooled in a saturation chamber prior to cleaning. When using fabric filters only, partial saturation is possible to prevent clogging of the fabric due to the condensation of water. A good control system is necessary to guarantee correct functioning of the system. Quenching the gases has the advantage that rapid cooling reduces the risk of dioxin formation.

Post combustion

Post combustion of the waste gases is used to optimise heat recovery (chemically bonded as CO) and to provide cleaner exhaust gases. In burning CO, any residual carbonaceous material is simultaneously oxidised to CO₂ and H₂O. The generated heat can be recovered using a heat exchanger and then transported to an internal user (e.g. blast air preheating).

Exhaust capture and cleaning is a necessary measure to reduce the emission products from coke combustion such as NO_x, SO₂, HF, PCDD/F, and dust. The post combustion of CO allows (additional) heat recovery from the cupola off-gas. Additionally, it allows the melting of scrap contaminated with oil and grease without additional environmental effects and thus stimulates the recycling of metals. Post combustion without heat recovery shows a negative environmental balance.

- *Post combustion in an HBC combustion chamber*

Heat is used for blast air preheating and goes to a further heat recovery, before leaving through the stack at a temperature of 220 °C.

- *Off-gas collection and waste gas cleaning - Rotary furnace*

recuperative incinerator: combustion with a heat recovery for preheating the combustion air, resulting in a higher thermal efficiency and lower fuel consumption.

- *Induction furnace: waste heat utilisation*

18 Surface Treatment of Metals and Plastics

18.1 Description of the industry

The surface treatment of and by metals dates back to early man using gold decoratively before 4000 BC. Gold and silver plating (including their deposit from amalgams) was well-known by the 13th century AD, and tin plating of iron was carried out in Bohemia in 1200 AD. In the mid-19th century, the electrodeposition of metals was discovered enabling new possibilities, which are still being extended. Currently, the main areas of application are: automotive and transportation, packaging, building and construction.

Plastics are now widely used in their own right and not only to replace metals. However, although they can be easily formed, may be flexible or rigid, and are corrosion-resistant and insulating, they lack other desirable properties.

18.2 Processes used involving heat

Despite this complexity and the range of activities described in this section, all workpieces or substrates pass along a common route of activities. The first activity onsite is the delivery and storage of incoming workpieces, substrates and raw materials. Workpieces or components are loaded onto the appropriate transport systems prior to pretreatment, such as degreasing. Most workpieces or substrates are given more than one pretreatment, and some of these may be prior to loading to a process line. The workpieces or substrates are then surface treated with one or more of the activities described in core processes. Rinsing is usually carried out between processes steps, whether they are pretreatment and/or core processing steps. Treatment is followed by after treatments such as drying and the workpieces or substrates are stored and dispatched.

- *Workpiece or substrate pretreatment*
 - *Electropolishing with electric discharge (also known as plasma-electrolytic polishing)*

In this process, the used electric potential between anode and cathode is in the range of 200 – 400 V DC depending on the solution and temperature (40 –95 °C) used.

- *Electrolytic and chemical polishing processes for aluminium*

Hot, highly concentrated acid mixtures are normally used, especially phosphoric acid, sulphuric acid and sometimes nitric acid. The temperature is >80 °C.

- *Core activities*
 - *Hot sealing (Sealing following anodising)*

With hot sealing, the pores in the oxide layer are closed by hydrating the aluminium oxide to boehmite: the pores are close by the increased volume of the boehmite structure. The sealing process is carried out by dipping the anodised parts in hot or boiling (minimum 95- 96 °C)

deionised water for three minutes per μm thickness. Sealing with steam achieves the same effect.

- *Trivalent chromium (Cr(III)) conversion coatings on aluminium and electroplated zinc*

(Chromium conversion coatings) 200 °C

- *Chemical blacking – oxide coatings*

Steel may be blackened in a high temperature bath containing 480 – 840 g/l of a mixture of about 75 wt % sodium hydroxide and 25 wt % sodium nitrate. The solution is operated at the boil between 121 – 149 °C. Instead of 25 wt % sodium nitrate, a mixture of 12 wt % sodium nitrate and 13 wt % sodium nitrite may also be used.

Stainless steel can also be blackened in molten sodium/potassium dichromate at about 370 °C provided the parts are not adversely affected by the high temperature. The resulting oxide has good corrosion resistance, and the procedure is covered by military specifications. The 'Inox' process, dipping in chromic acid and sulphate at 60 – 90 °C can be used, and chromium-nickel steel can be coloured black by dipping in NaOH/NaNO₂ at 125 - 130 °C.

Copper may be blackened in a bath containing 120 g/l of a mixture of 75 wt % sodium hydroxide and 25 wt % sodium chlorite at 93 – 100 °C. The black copper (II) oxide produced has a fuzzy appearance. On bright finished parts, this fuzzy nap disappears when lacquer is applied, restoring the lustrous appearance, or it may be laid down (not removed) by gentle buffing or tumbling in sawdust or other soft abrasives.

Brass may be blackened in the same solution but may not respond, depending on the zinc content and metallurgical history. Activation may be carried out by immersion in a bath containing 120 g/l of a mixture of 85 wt % sodium hydroxide and 15 wt % sodium chlorite operated at 93 - 100 °C for 5 - 10 min to dezincify the surface, after which the blackening bath will usually function normally.

- *Chemical milling*

temperature: 80 °C for older processes, types up to 110 °C for high speed processes

18.2.1 After treatment activities

- *Drying using hot water*

The water temperature needs to be carefully controlled. The temperature must be limited to 60 °C for plated plastic components in order to avoid deformation. Zinc plated and passivated components also are limited to 60 °C to avoid dehydration of the coating and loss of corrosion protection of the passivate film. Chrome plated components can be dried at up to 90 °C Drying 100-120°C.

- *Drying using hot air*

Drying in automated jig plants is most easily accomplished on automatic lines using hot air. The jigs are placed in a tank-shaped drier at the end of the process line; the tank has the same dimensions as the vats in the line to fit into the transporter system. Hot air is evenly recirculated from the top to the bottom of the tank at temperatures of 60 – 80 °C. Hot air escaping from the top of the drier tank makes the equipment thermally inefficient. In some cases, such as the new thick film passivations or to reduce drying times, it is necessary to heat the substrate or workpieces to 80 °C and higher. The temperature of the air circulating in the tank-shaped driers then needs to be above 100 °C. The air is normally heated by circulation or heat-exchangers using steam or hot oil. Direct heating systems are an alternative, using a special gas burner with an open gas flame in the circulating air. The burning gas heats the air directly with an efficiency of nearly 100 % of the energy input.

18.3 Data available for waste heat recovery

Waste gas treatments

The following cleaning systems are used:

- droplet separators which use a fill material to condense aerosols and droplets.

Condensate is usually treated in a waste water treatment plant.

- exhaust air wet scrubbers. These may be:
 - fibrous packing scrubbers with mats of fibrous packing
 - moving bed scrubbers with a zone of mobile packing, usually low density plastic

spheres which are free to move between support grids

- packed bed scrubbers containing a fixed bed of variously shaped packing material
- impingement plate scrubbers
- spray towers

Heated process tanks can be insulated to reduce heating losses by:

- using double skinned tanks
- using pre-insulated tanks
- applying insulation
- *Cleaning and recirculation of degreasing baths - Maintenance of process solutions*

Spent degreasing solution is cleaned; the oil residues out of the regeneration devices are recovered for heat recovery; the treated degreasing bath is recycled within the degreasing section.

19 Surface Treatment Using Organic Solvents

19.1 Description of the industry

Organic solvents are largely derived from the petroleum industry and made by established producers. 4.5 million tons of solvents are sold and used in Europe and by far the largest demand for solvents comes from the paint and coatings industry. However, this has decreased from about 46% in 1998 to 27% in 2003. This is probably already due to a large shift to water-based and powder technologies, where these are technically feasible. Of the remainder, 7% are used in printing ink formulations and 4% in adhesives formulations. It is not possible to provide a further breakdown, as solvents producers do not know, for example, which type of formulations the solvents are used in, or if they are used for cleaning, etc.

The historic solvents sales data show a marginal average growth of 0.1% per year over the last 10 years, below GDP growth. Projections of future consumption estimate no growth. The declining trend over the last years is linked to:

- increasing environmental legislation
- increased penetration of water-based or alternative technologies, where feasible
- solvent recycling and more effective use of solvents.

Organic solvents are usually categorized into classes of products. The most important classes are:

- oxygenated solvents: this includes esters, ketones, alcohols and glycol ethers (and their acetate derivatives)
- hydrocarbon solvents: aromatic (e.g. toluene, xylene), aliphatic and paraffinic hydrocarbon solvents
- chlorinated solvents (not included in these statistics)

Within the solvents family, there has been a tendency to move away from aromatic and white spirit types of solvents, and to use less volatile products (less combustible, less potential exposure, less VOC release) where possible.

19.2 Processes used involving heat

- *Printing*

The printing industry is one of the largest of the European Union's manufacturing industries, being in the top ten of such industries in most countries. It is an industry which serves all sectors of the economy including public authorities, financial services, publishers, distributive services and manufacturing industries. Its customers range from major institutions to the smallest business.

Actual plants can vary widely with production parameters such as ink coverage, run length, type of paper etc. However, in general, waste gas treatment usually operates at 700 - 800 °C.

The waste gas treatment is done by a regenerative thermal oxidation (thermoreactor) and combustion chamber approx. 900 °C, VOC destruction efficiency: 99 %. Purified gas exit temperature at 140 °C; heat recovery: 93 % thermal efficiency.

The waste gases of heatset presses tend to smell offensively. In many cases, this was the original driving force for installing incinerators in this part of the printing industry. For air emissions control, a catalytic waste gas treatment system with heat recovery is installed. The extraction systems of the printing presses are equipped with circulating air techniques which are controlled by measuring the solvent concentration.

The hot steam desorption generates about 3 – 6 m³ per kg of recovered solvent. In flexible packaging, solvent recovery through adsorption to activated carbon is also applied; frequently in Italy, rarely elsewhere. Where solvent recovery is applied, solvent consumption is limited as far as technically possible to ethyl acetate, in order to reduce the size of the adsorption unit, reduce dehydration problems and reduce the occurrence of azeotropic mixtures of ethylacetate with ethanol and MEK. Hot steam desorption is used less and less in flexible packaging, and currently inert gas desorption is usual. Recovery rates are generally 95 to 95.5 %, with a waste gas concentration of 50 to 150 mg C/m³.

- *Manufacturing of Winding Wire*

The processes involving heat are described below.

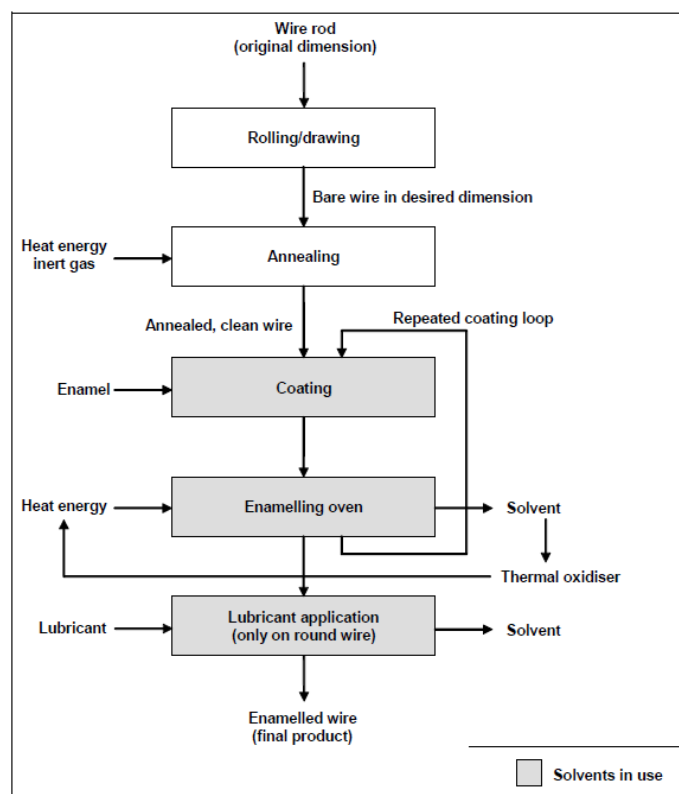


Figure 25: Typical manufacturing process for enamelled wires (EWWG, 2004).

- *Rolling and drawing*

These are deformation processes. Rolling is a continuous or stepwise forming process under compressive conditions. The material can be rolled at ambient or elevated temperatures.

- *Annealing*

The wire drawing process is followed by annealing where the wire passes through heated tubes (containing an inert atmosphere to prevent oxidation) and leading to recrystallisation and softening of the wire.

- *Drying and curing*

The coated wire then passes into the enamelling chamber, which consists of a heated chamber (horizontally or vertically arranged) where the solvent is evaporated before moving into a higher temperature zone (400 - 700°C) where the film is cured.

Using electrical heating, the solvent-laden air is passed over heating elements to reach a temperature in excess of 500°C. This is generally sufficient to achieve complete oxidation. In all cases, electrically heated machines use precious metal catalysts. The efficiency of oxidation is sufficient to ensure that emission control limits for VOC emissions are always achieved. After thermal or catalytic oxidation of the solvents, the air stream is recirculated to provide complete or partial heating of the enamelling chamber.

- *Hot melt enamel coatings*

A thermosetting material is applied to the copper conductor. This substitute is thermoplastic until 100°C, and then the resin is maintained as liquid at approximately 80°C and can be applied with dies onto the copper conductor.

- *Waste Gas Treatment from enamelling*

Air used for drying (e.g. evaporation or curing process) of the enamel coating on the wire, is extracted and sent to a catalytical oxidiser. The treated hot air is routed back to the enamelling oven. The solvent destruction provides approximately 50% of the energy required for the enamelling process. A certain proportion of this cleaned air is continually vented to the air. The combustion temperature is normally in the range of 500 - 750°C.

More energy is saved if the extracted hot air is utilised by heat regenerators for heating:

- the incoming laden room air at the entrance of the curing oven
- the bare wire annealed
- the steam generator

The waste gas from the abatement technique connected to the enamelling ovens for reducing VOC may contain high levels of NOX. However, no abatement techniques are applied, as they are not currently considered technically or economically viable in the sector.

- *Manufacturing of Abrasives*

Grinding is one of the oldest production processes. A principal characteristic of grinding is the effect of numerous, non-orientated cutting materials in the workpiece. Contemporary abrasive materials are synthetic corundum or silicon carbide often cubic boron nitride (CBN) or diamond.

A large variety of workpiece materials can be processed such as ferrous and non-ferrous metals, glass, ceramics, natural stone, concrete, plastics and wood. The application field of grinding is wide and includes activities such as rough grinding of cast iron or high accuracy grinding of tubular needles for medical purposes. Numerous products in tool manufacturing, construction of vehicles, aircraft, power plants or furniture only obtain their finish and high quality surface through grinding.

For this process, pre drying is performed at temperatures 50-130 °C, the second drier operates at temperature of 35 to 100°C and for the exhaust air treatment, dust separators and thermal or regenerative post combustion at 700°C is used, with or without heat recovery. The heat recovery need depends on the onsite specific circumstances and energy or heat demand of the industry.

- *Coil Coating industries*

The definition of a coil coating process according to EN-10169-1:1996 is as follows: 'A method in which an organic coating is applied on a metal strip in a continuous process. This process includes cleaning and chemical pretreatment of the metal surface and either one-side or two-side, one or multiple application(s) of (liquid) paints or coating powders which are subsequently cured, or laminating with plastic films'.

Natural gas is normally used as the fuel source for the paint curing ovens and for the oxidiser (combustion process). Commonly, a regenerative or recuperative oxidiser is applied. The heat generated can eventually be used in the process or can be used for steam generation or hot water.

After each lacquering operation, the cans immediately pass gas fired multiple zone ovens at typical drying temperatures of 180 - 200 °C. The emissions of the curing process are collected in a duct and exhausted by fans to the air or to abatement equipment. In general, the volatile gases created in the lacquer application machines are captured as well. The waste gases containing VOC from driers and also coating application units are generally treated via regenerative, thermal combustion. The process heat can be used via heat exchangers, e.g. for the cleaning process.

Curing of solvent-based coatings and inks takes place in thermal ovens at rates of up to 8000 sheets per hour at temperatures of between 150 and 220 °C. Speeds and temperatures are dependent on sheet sizes, thickness and the coating specification.

19.3 Data available for waste heat recovery

The printing process involves heat recovery systems with 93% thermal efficiency. The temperature of the process is between 700 and 800°C.

High temperatures are obtained from the other processes also. However, the recovery of the waste gas is not considered as economical and viable. The waste gas from the various techniques is connected to the enamelling ovens for reducing VOC which contain high levels of NOX. However, no abatement techniques are applied, as they are not currently considered technically or economically viable in the sector.

The BAT describes all the processes has to be followed to treat the waste gas and reduce the amount of VOC. These processes are; the increase of the internal solvent concentration, containment and collection of waste gases, dry filter systems, thermal oxidation, regenerative thermal oxidation, and biological treatment.

20 Tanning of Hides and Skins

20.1 Description of the industry

The leather making operation consists of converting the raw hide or skin, a highly putrescible material, into leather, a stable material, which can be used in the manufacture of a wide range of products. The whole process involves a sequence of complex chemical reactions and mechanical processes. Amongst these, tanning is the fundamental stage, which gives leather its stability and essential character. Preserving hides and skins by tanning and performing various steps of preparation and finishing, generates a final product with specific properties: stability, appearance, water resistance, temperature resistance, elasticity and permeability for perspiration and air, etc. Next figure shows the process steps in leather making production. There is considerable variation between tanneries, depending on the type of leather being produced.

Leather is a material used in the manufacture of a variety of products, for which it is often the major material input. These include shoes, clothing, leather goods, furniture, upholstery for cars, boats and aircraft, and many other items in daily use. These different applications require different types of leather. The processing of hides and skins also generates by-products, which find outlets in several industry sectors such as pet and animal food production, fine chemicals including those used in photography and cosmetics, and soil conditioning and fertilisers.

Most of the basic stages of leather making are still the same, but the industry has undergone important changes and with respect to environmental protection, major improvements have been made. Provisions for pollution control, waste minimisation and disposal, the correct use of chemicals, and accident prevention are essential for minimising the potential impact on air, water, and soil from the processing of hides and skins.

20.2 Processes used involving heat

Drying Process uses Energy and Biocides as inputs and the emissions outputs are heat and acid fumes. The objective of drying is to dry the leather whilst optimising the quality and area yield. There is a wide range of drying techniques and some may be used in combination. Each technique has a specific influence on the characteristics of the leather. Drying techniques include samming, setting, hang drying, vacuum drying, toggle drying and paste drying. Generally samming and setting are used to reduce the moisture content mechanically before another drying technique is used to dry the leather further. After drying, the leather may be referred to as crust. Crust is a tradable intermediate product.

The rest processes produce waste water, organic solvents, particulate matter, coarse material and filter materials. The shrinkage temperature of the skins must be at least 20 °C higher than the operation degreasing temperature, which can be up to 60 °C. The degreasing process where water is used, consists of breaking the emulsion of fat and surfactant at temperature 90 °C. Waste water recovery systems are taking place in lot of stages for the process.

For emissions to the air, data are only available for VOCs in general (often giving only the consumption of organic solvents and using different monitoring systems). Volatile halogenated hydrocarbons require special attention, as some of these constitute a high environmental risk. Relevant air emissions are: sulphides from the beamhouse and waste water treatment; ammonia from the beamhouse; tanning and post-tanning operations; sulphur dioxide from post-tanning operations; dust/total particulate from the storage and handling of powdery chemicals, dry shaving, buffing, milling drums and staking. Emissions from on-site incineration processes are controlled by laws implementing Directive 2000/76/EEC on waste incineration.

20.3 Data available for waste heat recovery

Energy savings can be achieved by heat pumps incorporating recovery systems. Waste heat can be used from and for other processes. From drying process, up to 75 % of waste heat may be recovered.

By means of heat exchangers, energy can be recovered from the waste process water, from condensate from vacuum dryers, from evaporated water from high frequency drying, or from exhaust air from drying.

21 Textiles industry

21.1 Description of the industry

The textile industry is one of the longest and most complicated industrial chains in manufacturing industry. It is a fragmented and heterogeneous sector dominated by a majority of Small and Medium Enterprises, with a demand largely driven by three main end-uses: clothing, home furnishing and industrial use.

The textile and clothing chain is composed of a wide number of sub-sectors covering the entire production cycle from the production of raw materials (man-made fibres) to semi-processed materials (yarns, woven and knitted fabrics with their finishing process) and final/consumer products (carpets, home textiles, clothing and industrial use textiles).

21.2 Processes used involving heat

The textile chain begins with the production or harvest of raw fibre. The basic steps in this chain are schematically represented in the following diagram.

Finishing processes (that is pretreatment, dyeing, printing, finishing and coating, including washing and drying) can take place at different stages of the production process. the substrates for finishing can be fabrics, yarns or loose fibres.

“Textile finishing” cannot be defined as a standard sequence of treatments, but rather is a combination of unit processes that can be applied within the production of a textile product, depending on the requirements of the final user.

- *Dirt removal/grease recovery loops*

The technique involves the closed-loop treatment of wool scouring effluents by vaporation/incineration with recovery of water and energy.

A seven-stage steam-heated falling film evaporator is installed. The steam used for heating is produced in a boiler which uses waste heat from the incinerator. The boiler also powers a steam turbine, producing electricity. The integrated evaporator/incinerator/boiler system is selfsufficient in energy, all the energy used to be derived from the sludge.

The condensate from the evaporator is treated in a steam stripper to remove ammonia, then passed through a fixed bed aerobic bioreactor, which removes residual odorous compounds and 90 % of steam-volatile ectoparasiticides, before the water is recycled to the rinse section of the scour. The ammonia is used in a catalytic reactor to reduce the NO_x content of the incinerator flue gases.

The evaporator concentrate entering the incinerator has a calorific value of 9.5 MJ/kg and its combustion is self-supporting (no fuel added from external sources). The operating temperature of the incinerator is 1200°C in order to destroy the polychloro-dioxins and - benzofurans. The exhaust gases are used to heat the boiler, as already stated, and fly ash is

removed from the boiler flue gases in a bag filter system. The ash is extracted with water to recover sodium and potassium carbonate in solution, which is used as a builder in the scour. The extracted ash and the solidified liquid ash from the incinerator are landfilled.

- *Optimisation of cotton warp-yarn pretreatment*

The conventional process consists of five steps, including wetting/scouring, alkaline peroxide bleaching and three subsequent rinsing steps. The last rinsing water is re-used for making the first bath. This process can be further improved by combining wetting, scouring and bleaching in one step and performing rinsing in two steps, re-using the second rinsing bath for making the bleaching/scouring bath.

In addition, the energy consumption of the process has been reduced by heat recovery. The heat from the scouring/bleaching bath (110°C) is recovered (by means of a heat exchanger) and used for heating the fresh water for the first rinsing. The bath is therefore cooled to about 80°C, while the fresh water reaches a temperature of 60 – 70 °C.

- *Dyeing*

Due to the high glass transition point of polyethyleneterephthalate, which is in the range of 80 - 100 °C, the diffusion rate of disperse dyestuff molecules into the standard PES fibres at normal dyeing temperatures is very low. As a result, dyeing conditions typically used for other types of substrates are not applicable. Exhaust dyeing of single polyester and polyester blends can be carried out either in autoclaves at high temperature (HT-dyeing at 130 °C, which is usually applied for pure PES and wool-free PES blends) or at normal dyeing temperatures (95 °C – 100 °C, which is applied for PES/wool blends) with the help of so-called carriers

- *Dyeing of cellulosic with reactive dyes*

The dye liquor is applied to the textile using a padder (cotton is squeezed to about 70 % pick-up and iscosed to about 80 %) and, after a short passage through air, the fabric is fed directly to the dryer (hot-flue), where it remains for 2 minutes.

In the conventional process, urea is used as solvent for the dye in dry heat. Urea melts at 115 °C and binds water above 100 °C, thus allowing penetration of the dyestuff in the fabric during fixation in the steamer. With the referenced process, this is not needed because the conditions in the dryer are set (120 °C and 25 vol.-% steam content) so that the fabric remains at a specific temperature of 68 °C as long as it is damp.

Since highly reactive dyes are used, only a low fabric temperature (68°C), a weak alkali and a short time (2 minutes) are needed for fixation.

- *Oxidation techniques*

The disadvantage of thermal incineration is the high energy consumption for heating the off-gas to at least 750 °C. After incineration, the temperature of the cleaned off-gas is around 200

°C to 450 °C. The textile industry does not have a demand for thermal energy in this sort of amount so most of it would be wasted.

Another problem arises from the gas-air-mixture typical of exhaust air from textile finishing. In the textile industry, most of the emissions to be treated are characterised by high off-gas flows, but relatively low load. Moreover, the characteristics of the off-gases are often subject to fluctuation, leading to inefficient thermal incineration.

In catalytic incineration, phosphorus compounds, halogens, silicones and heavy metals can poison the catalyst. These compounds are quite common in the textile industry, so special care has to be taken when using catalytic oxidation in this sector.

21.3 Data available for waste heat recovery

Exhaust heat recovery can be achieved by using air-to-water heat exchangers. Up to 70 % of energy can be saved. Hot water can be used in dyeing. Electrostatic filtration for off-gas cleaning can optionally be installed. Retrofitting is possible. If hot water is not required, an air-to-air heat exchanger can be used. Efficiencies are generally 50 to 60 %. Approximately 30 % savings in energy can be achieved. An aqueous scrubber alone or with subsequent electrostatic filtration can optionally be installed for off-gas cleaning.

- heat recovery system: counter-flow pipes
- drying temperature: 130°C
- heat setting: 190°C
- off-gas volume flow: 15000 m³/h
- off-gas moisture content (drying): 70 g/m³
- off-gas moisture content (heat-setting): 40 g/m³
- temperature of the fresh water (before heat recovery): 15°C
- efficiency: 70%
- heating value of the gas 9.3 kWh/m³
- cost of the gas: 0.25 euros/m³
- maintenance cost: 1000 euros/yr
- interest rate: 6%

22 Waste incineration

22.1 Description of the industry

Incineration is used as a treatment for a very wide range of wastes. Incineration itself is commonly only one part of a complex waste treatment system that altogether, provides for the overall management of the broad range of wastes that arise in society.

The incineration sector has undergone rapid technological development over the last 10 to 15 years. Much of this change has been driven by legislation specific to the industry and this has, in particular, reduced emissions to air from individual installations. Continual process development is ongoing, with the sector now developing techniques which limit costs, whilst maintaining or improving environmental performance.

The objective of waste incineration is to treat wastes so as to reduce their volume and hazard, whilst capturing (and thus concentrating) or destroying potentially harmful substances that are, or may be, released during incineration. Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content from waste.

Basically, waste incineration is the oxidation of the combustible materials contained in the waste. Waste is generally a highly heterogeneous material, consisting essentially of organic substances, minerals, metals and water. During incineration, flue-gases are created that will contain the majority of the available fuel energy as heat.

The organic fuel substances in the waste will burn when they have reached the necessary ignition temperature and come into contact with oxygen. The actual combustion process takes place in the gas phase in fractions of seconds and simultaneously releases energy where the calorific value of the waste and oxygen supply is sufficient, this can lead to a thermal chain reaction and self-supporting combustion, i.e. there is no need for the addition of other fuels.

The basic linear structure of a waste incineration plant may include the following operations:

- incoming waste reception
- storage of waste and raw materials
- pretreatment of waste (where required, on-site or off-site)
- loading of waste into the process
- thermal treatment of the waste
- energy recovery (e.g. boiler) and conversion
- flue-gas cleaning
- flue-gas cleaning residue management (from flue-gas treatment)
- flue-gas discharge
- emissions monitoring and control
- waste water control and treatment (e.g. from site drainage, flue-gas treatment, storage)
- ash/bottom ash management and treatment (arising from the combustion stage)
- solid residue discharge/disposal.

Each of these stages is generally adapted in terms of design, for the type(s) of waste that are treated at the installation.

22.2 Processes used involving heat

The main stages of incineration process are:

- *Drying and degassing*

Volatile content is evolved (e.g. hydrocarbons and water) at temperatures generally between 100 and 300 °C. The drying and degassing process do not require any oxidising agent and are only dependent on the supplied heat

- *Pyrolysis and gasification*

Pyrolysis is the further decomposition of organic substances in the absence of an oxidising agent at approx. 250 – 700°C, but mostly the temperature range of the pyrolysis stage is between 400-700°C. At lower temperature 250°C other reactions occur to some extent. Gasification of the carbonaceous residues is the reaction of the residues with water vapour and CO₂ at temperatures, typically between 500 and 1000°C, but can occur at temperatures up to 1600 °C. Thus, solid organic matter is transferred to the gaseous phase. In addition to the temperature, water, steam and oxygen support this reaction.

Figure 26 shows the structure of the pyrolysis plant for municipal waste treatment and Figure 27 shows a fluidised bed gasifier with high temperature slagging furnace.

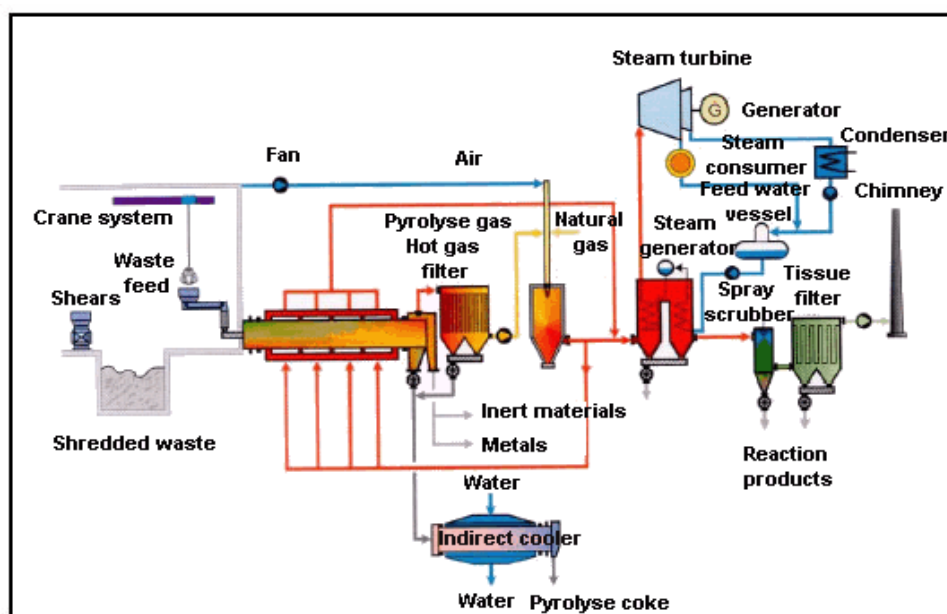


Figure 26: Structure of the pyrolysis plant for municipal waste treatment (UBA, 2001).

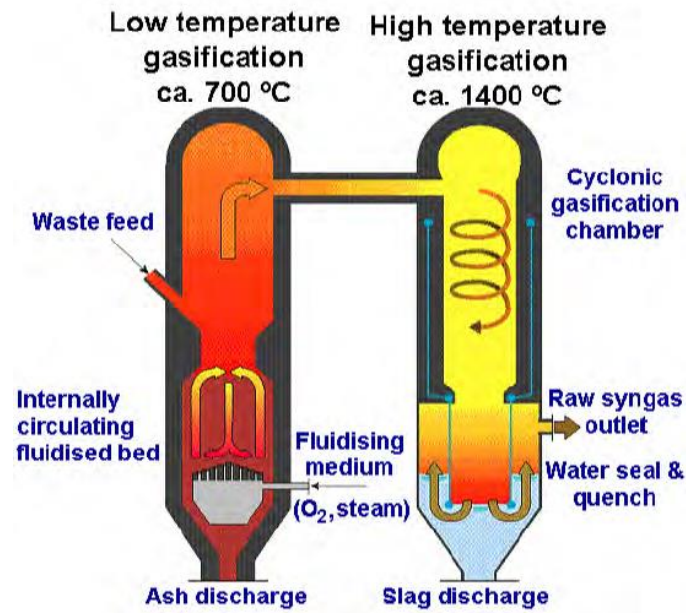


Figure 27: Fluidised bed gasifier with high temperature slagging furnace (Ebara, 2003).

- *Incineration – Oxidation (Full oxidative combustion)*

The combustible gases created in the previous stages are oxidised, depending on the selected incineration method, at flue-gas temperatures generally between 800 and 1450 °C. The products from this process is air with CO₂, H₂O, O₂ and N₂.

Combustion takes place above the grate in the incineration chamber (see Figure 8). As a whole, the incineration chamber typically consists of a grate situated at the bottom, cooled and non-cooled walls on the furnace sides, and a ceiling or boiler surface heater at the top. As municipal waste generally has a high volatile content, the volatile gases are driven off and only a small part of the actual incineration takes place on or near the grate.

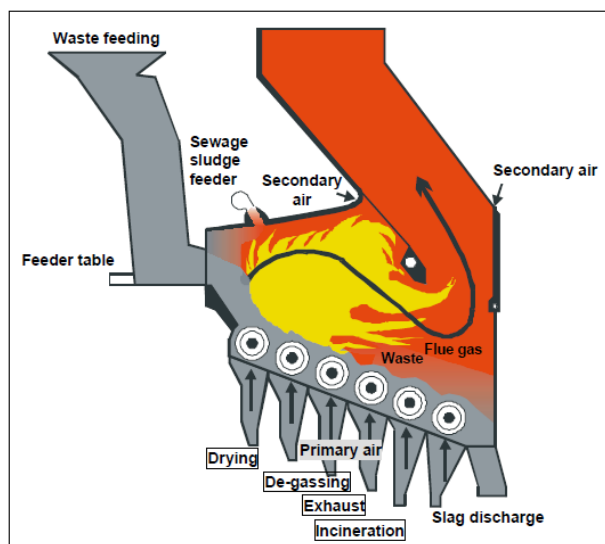


Figure28: Incineration chamber (UBA, 2001).

22.3 Data available for waste heat recovery

Different types of thermal treatments are applied to the different types of wastes, however not all thermal treatments are suited to all wastes:

- grate incinerators
- rotary kilns
- fluidised beds
- pyrolysis and gasification systems.

Incineration of sewage sludge - this takes place in rotary kilns, multiple hearth, or fluidized bed incinerators. Co-combustion in grate-firing systems, coal combustion plants and industrial processes is also applied. Sewage sludge often has a high water content and therefore usually requires drying, or the addition of supplementary fuels to ensure stable and efficient combustion.

Incineration of hazardous and medical waste - rotary kilns are most commonly used, but grate incinerators (including co-firing with other wastes) are also sometimes applied to solid wastes, and fluidised bed incinerators to some pretreated materials. Static furnaces are also widely applied at on-site facilities at chemical plants.

Other processes have been developed that are based on the de-coupling of the phases which also take place in an incinerator: drying, volatilisation, pyrolysis, carbonisation and oxidation of the waste. Gasification using gasifying agents such as, steam, air, carbon-oxides or oxygen is also applied. These processes aim to reduce flue-gas volumes and associated flue-gas treatment costs. Some of these developments met technical and economic problems when they were scaled-up to commercial, industrial sizes, and are therefore pursued no longer. Some are used on a commercial basis (e.g. in Japan) and others are being tested in

demonstration plants throughout Europe, but still have only a small share of the overall treatment capacity when compared to incineration.

Combustion is an exothermic (heat generating) process. The majority of the energy produced during combustion is transferred to the flue-gases. Cooling of the flue-gas allows:

- the recovery of the energy from the hot flue-gases and
- cleaning of flue-gases before they are released to the atmosphere.

In plants without heat recovery, the gases are normally cooled by the injection of water, air, or both. In the majority of cases a boiler is used.

In waste incineration plants, the boiler has two interconnected functions:

- to cool the flue-gases
- to transfer the heat from the flue-gases to another fluid, usually water which, most often, is transformed inside the boiler into steam.

The characteristics of the steam (pressure and temperature) or of the hot water are determined by the local energy requirements and operational limitations.

The design of the boiler will mainly depend on:

- the steam characteristics
- the flue-gas characteristics (corrosion, erosion and fouling potentials).

The flue-gas characteristics are themselves highly dependent upon the waste content. Hazardous wastes for example, tend to have very wide variations in composition and, at times, very high concentrations of corrosive substances (e.g. chlorides) in the raw gas. This has a significant impact on the possible energy recovery techniques that may be employed. In particular, the boiler can suffer significant corrosion, and steam pressures may need to be reduced with such wastes.

Similarly, the thermal cycle (steam-water cycle) will depend on the objective, for example:

- the highest electrical outputs require the most sophisticated cycles, but
- simpler cycles suit other situations e.g. supply of heat.

Heat recovery boilers in hazardous waste incineration installations:

The hot combustion gases are cooled in a steam generator (or boiler) with a capacity of between 16MW and 35MW depending on the installation. Figure 29 shows an illustration of individual heat surface areas in a steam generator. The steam that is produced has a pressure of 13 bar to 40 bar with a temperature between 207 and 385 °C. As a guideline, a fully equipped installation normally produces an average of 4 – 5 tonnes of steam per tonne of incinerated waste, thereby attaining a thermal efficiency of 70 – 80 % (energy in steam versus

energy in waste). Most installations are equipped with an economiser device and a superheater if electricity is produced. A range of factors influence the efficiency of the steam generators used in hazardous waste incinerators, including the composition of the gas and the potential for deposition to occur on the heat-exchange surfaces. This has a significant influence on the construction materials used and on the design, as well as on the operational life and performance of the equipment.

For some installations, the steam is used in a turbine to produce electricity. The electricity is used by the incineration plant for its own purposes or exported. Alternatively, steam may be transported for direct use in industrial processes, e.g. the production of chemicals, or to other waste treatment processes or fed into a district heating system. Combinations of these are also applied.

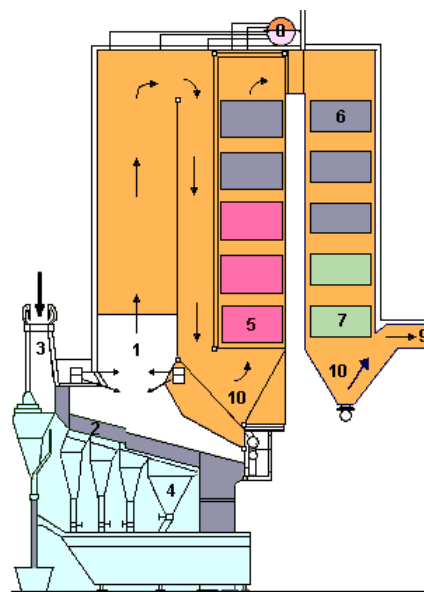


Figure 29: Illustration of individual heat surface areas in a steam generator (UBA, 2001).

Different boiler concepts can be used in waste incineration plants (from left to right in Figure 30):

- horizontal boilers
- combination of vertical and horizontal boilers
- vertical boilers

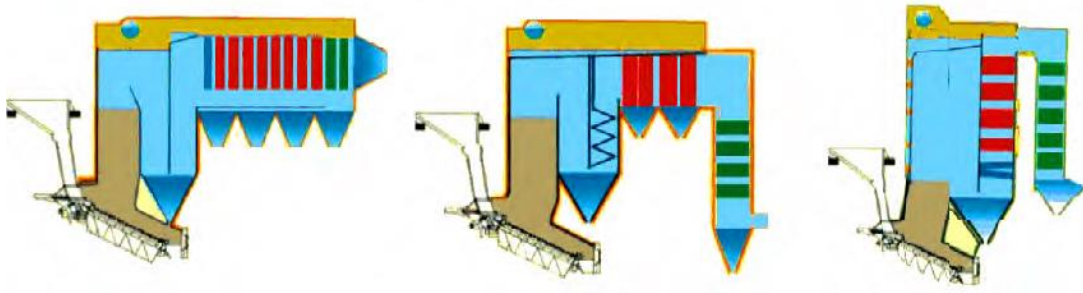


Figure 30: Various boiler systems: horizontal, combination and vertical (UBA, 2001).

23 Waste Treatment

23.1 Description of the industry

Secondary products are inherent to any industrial process and normally cannot be avoided. In addition, the use of products by society leads to residues. In many cases, these types of materials (both secondary products and residues) cannot be re-used by other means and may become not marketable. These materials are typically given to third parties for further treatment.

The reason for treating waste is not always the same and often depends on the type of waste and the nature of its subsequent fate. Some waste treatments and installations are multipurpose. In this document, the basic reasons for treating waste are:

- to reduce the hazardous nature of the waste
- to separate the waste into its individual components, some or all of which can then be put to further use/treatment
- to reduce the amount of waste which has to be finally sent for disposal
- to transform the waste into a useful material.

The waste treatment processes may involve the displacement and transfer of substances between media. For example, some treatment processes result in a liquid effluent sent to sewer and a solid waste sent to landfill, and others result in emissions to air mainly due to incineration. Alternatively, the waste may be rendered suitable for another treatment route, such as in the combustion of recovered fuel oil. There are also a number of important ancillary activities associated with treatment, such as waste acceptance and storage, either pending treatment on site or removal off site.

Some waste treatment installations are not standalone installations only containing a single type of treatment. Some of them are designed to provide a wide variety of services, and they are designed to treat a great variety of waste types. Figure 31. Shows an example of an integrated waste treatment installation.

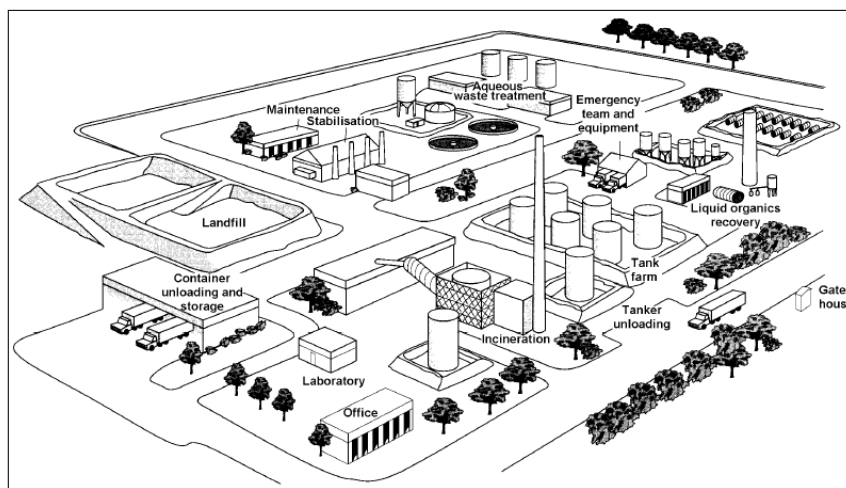


Figure 31: Example of an integrated waste treatment installation (LaGrega, Buckingham, & Evans, 1994).

23.2 Processes used involving heat

- *Thermal Treatment*

Thermal treatment of FGT (Flue gas treatment) waste from combustion processes is used extensively in a few countries, mainly to reduce the volume and to improve their leaching properties.

High temperature treatments use heat in order to melt waste and initiate vitrification and ceramisation processes. Thermal treatments can be grouped into three categories: vitrification, smelting and sintering. The differences between these processes chiefly relate to the characteristics and properties of the final material:

- vitrification is a process where wastes are mixed with glass precursor materials and then combined at high temperatures into a single-phase amorphous, glassy output. Typical vitrification temperatures are 1300 to 1500 °C. The retention mechanisms are chemical bonding of inorganic species in the waste with glass-forming materials, such as silica, and encapsulation of the constituents by a layer of glassy material
- melting is similar to vitrifying, but this process does not include the addition of glass materials and results in a multiple-phased product. Often several molten metal phases are generated. It is possible to separate specific metal phases from the melted output and recycle these metals, possibly after refinement. Temperatures are similar to those used in vitrifying
- sintering involves heating the waste to a level where a bonding of the particles occurs and chemical phases in the wastes reconfigure. This leads to a denser output with less porosity and a higher strength than the original waste. Typical temperatures are around 900 °C. Temperatures for sintering bottom ash from MSW incinerators can be up to 1200 °C.

Most commonly, FGT wastes are treated thermally in combination with bottom ashes. Regardless of the process, the thermal treatment of FGT waste in most cases results in a more homogeneous, denser product with improved leaching properties. Vitrifying also adds the benefits of the physical encapsulation of contaminants in the glass matrix.

The thermal treatment of FGT waste requires substantial off gas treatment, thus creating a new solid residue to be treated. Also the high salts concentrations in FGT waste can cause corrosion problems in off-gas treatment systems.

- *High temperature drying*

The aims of the process are the following:

- removal of the water content from the wastes; making recycling economically viable
- concentration of the waste components (e.g. metal compounds); the heating value is considerably raised
- elimination of the problems with handling paste-like substances, as drying the waste transforms it into granulate material
- use of the waste heat in other processes, e.g. distillation
- the dissipated plume gives the necessary moisture to the biofilter.

The input substances that are to be dried are provided by the gathering chain conveyor and put into the revolving tube drum in single portions. The residence time of the input substances in the drier and thus the dryness of the granulated product can be regulated by hydraulic adjustment of the tube angle. The energy required for the drying process is drawn from the waste heat of the incinerator. The air needed for cooling the flue-gases is cooled down to 150 °C in air-air heat exchangers.

Up to 30000 m³/h drying air (maximum 100 °C) flow through the revolving tube counter currently to the moist input. The heat is used for the evaporation of the water. The plume is extracted by suction via a dust filter and directly transferred to the biofilter. Hereby, a slight negative pressure is created in the dryer who prevents effectively the leakage of dust into the environment. The granulated dry product is discharged automatically by the rotation of the drum and filled into big bags or other containers.

- *Regeneration of activated carbon*

To treat the spent activated carbon to produce a material with properties and qualities very similar to the original activated carbon.

Thermal treatments are the main processes used for regeneration. During the process, drying, thermal desorption and heat treatment are carried out.

Activated carbon is commercially available in three forms: extruded, granular and powder. Since powdered carbon is extremely difficult to regenerate, this activity is not carried out on powdered carbon. Only the first two forms are therefore considered in this section.

Regeneration is normally carried out thermally and is typically composed of the following operations:

- Receipt, handling and dewatering
- Spent activated carbon is normally received on site as a drained solid in tankers. Water is added at the regeneration site in order to turn the carbon into slurry, which is fed to a tank where it is dewatered and charged into a kiln to be regenerated.
- Thermal regeneration. After separation from the water, the moist carbon is fed into the furnace for regeneration. During thermal regeneration, drying, thermal desorption (i.e. removal of the organic chemicals) and high temperature (650 to 1000 °C) heat treatment in a slightly oxidising controlled atmosphere are carried out.

The types of equipment generally used are multiple hearth furnaces, directly fired rotary kiln furnaces and indirectly fired rotary kiln furnaces. Fluid bed furnaces and infrared furnaces may also be used.

- *Incineration*

In the decontamination of thermal exhaust air, the exhaust air is treated in a combustion chamber at temperatures of up to 850 °C and for a minimum residence time of at least 2 seconds. Within this space of time, the harmful substances will be totally oxidised and the cleaned gas can then be released to the air. In biological treatment plants, incineration can be differentiated into post-combustion, with or without heat recovery. As in thermal post-combustion, the carbohydrates are oxidised to carbon dioxide and water in a combustion chamber.

Used for VOC control and will usually require the addition of supplementary fuel to support the combustion process. The operator can offset the cost of the supplementary fuel when there is a requirement elsewhere on site for the waste heat that is generated. Values of less than 50 g of VOC per tonne of waste can be achieved with this technique.

In biological treatment plants, by using special heat-exchangers, high quality heat recovery of up to 98 % may be achieved. These high rates of heat recovery are based on the use of special ceramic heat-exchangers, which combine a high mass and a large surface area in an ideal way.

Usually requires the addition of supplementary fuel to support the combustion process. The flowrate is 1500 Nm³/h and the operating temperature is 1050 – 1200 °C. The specification of 850 °C with 2 seconds residence time may be justified in waste incineration when a complete flue-gas treatment installation achieves the full removal of residual contaminants. The burning conditions are more extreme (e.g. 1100 °C with 2 seconds residence time) to completely

- *Catalytic combustion*

In biological treatment plants, catalytic combustion may be used to remove TOC (total organic carbon) from the exhaust gas. The pollutants are oxidised at temperatures between 200 and 500 °C using noble-metal or metal oxide catalysts.

Achieved environmental benefits

- low fuel consumption
- complete destruction of VOC (volatile organic compound)
- efficiencies range from 95 to 99.9 %
- output concentrations of 5 – 50 mg C/Nm³ are achievable. The actual range depends on the type of compound and the input concentration.

In biological treatment plants, among the disrupting substances are catalyst toxins, such as organometallic compounds, organic silicon compounds and arsenic compounds. The treatment of halogenated compounds, organic sulphur compounds and organic nitrogen compounds is possible only to a limited degree. Methane can be catalytically reduced to CO₂ only under certain conditions. High temperatures of over 600 °C are necessary for the catalytic oxidation of methane. The energy use of a thermal treatment without heat recovery is very high. The catalytic-thermal oxidation in biological treatment (MBT) is, therefore, questioned under both an economical and environmental point of view.

24 Wood-based panels production

24.1 Description of the industry

The wood-based panel products described in this document all relate to Section 6.1(c) of Annex I to the Industrial Emissions Directive (IED). The production capacity threshold in the definition given therein is 600 m³/day of wood-based panels.

All the main process steps, from the storage of raw material to the storage of finished product, take place at the wood-based panel installation. More than 50 % of the raw boards are further processed, to give them added value, at the installation prior to dispatch.

The production of wood-based panels is a continuous process, where the core processes, drying and pressing, are especially interlinked. The production depends on the functionality of all the intermediary steps. While the preparation of wood particles can run with an overproduction and intermediary storage of prepared chips before the drying step, there are generally only a few hours of storage capacity for dried wood particles, to keep the mat forming station and panel press running continuously.

24.2 Processes used involving heat

- *Drying of wood particles and fibres*

The drying of the prepared wood material, in the form of chips, flakes, strands or fibres, is the core element of the dry manufacturing process for panels, in the sense that the wood particles need a prescribed moisture content to obtain the desired level of curing of added resin and the desired properties of the panel in the press. This is achieved by an active drying process that is similar to drying processes in other industrial sectors. The drying process is also the process with the highest energy demand in panel production, and the reason why combustion plants of different configurations can be found on almost all sites.

The choice and configuration of dryers depends on the heat sources available, the available space, the required throughput, the emissions generated and their abatement as well as the overall cost of investment, operation and maintenance.

The drying of fibres for dry process fibreboards takes place under different conditions and with different equipment.

Dryers have a rather long lifetime, but the energy efficiency and quality of the dried product can be improved through various choices of retrofits, such as improved dryer configuration, choice of energy source, management of waste gases and by taking advantage of the heat energy in waste gases.

- *Drying of wood particles for particle board and OSB*

Raw wood particles have a moisture content of between 20 % and 140 % depending on the source and conditions of the wood. Humidity can be as high as 140 % in very fresh wood and

during wet periods. Chips, slabs and sawdust are less humid than roundwood. Roundwood and other virgin wood stored and used during winter periods holds more moisture than in summer. Recycled wood is the driest material, but its moisture content can also vary depending on the composition and prior conditions.

The moisture content should not drop too low either during drying, as the drier the material becomes, the more resin is consumed. Drying to a low humidity is also avoided because of the fire risk of hot, dry wood dust in the dryer, in the sorting of particles after the dryer and of collected dust in a bag filter for example. The higher the drying temperature applied and the drier the wood particles, the higher the potential for burnt fines. Any burnt fines cause a rise in the condensable dust emissions and a rise in emissions of polycyclic aromatic hydrocarbons (PAHs).

Dryers can be single-pass or triple-pass; in a single-pass dryer, the wood particles travel from the entrance of the dryer to the outlet in one pass. In a triple-pass dryer, the wood particles are dried subsequently in three different chambers of the dryer, each with a temperature lower than the previous one. Single-pass dryers are only applied for directly heated dryers, according to the data collection. Single-pass and triple-pass dryers apply hot gas temperatures from 200 °C to more than 370 °C at the inlet of the dryer.

Other types of rotary dryers are drum dryers and tubular dryers. The temperature applied in a drum dryer can be as high as 500 °C at the inlet of the dryer.

The drying time or residence time varies from 5 to 30 minutes. Short drying residence times are achieved when applying two drying stages, where the first stage is a directly heated flash dryer, and the second stage a traditional rotary dryer. Between the two stages, cyclones can be applied to distribute and feed the second dryer. The temperature in the first dryer stage is higher than in the second dryer stage. In theory, the main dust and VOC emissions arise from the first dryer stage. In Figure 5, a selection of dryer types is shown.

The outlet temperature of the waste gas lies between 100 °C and 130 °C for directly heated dryers and between 80 °C and 120 °C for indirectly heated dryers.

- *Drying of wood fibres*

When the fibres leave the refiner unit, they enter a blowline of 20–30 m in length and with a small diameter, where the fibre mix is uniformed and wetted. The blowline also serves the purpose of adding resins, hardening agents and additives. All are added as aqueous solutions into the blowline. Only in a few MDF production lines are the resins added after drying. The drying of fibres for dry process rigidboard and flexboard is identical, but while hardening agents and additives are added in the blowline, the resin is added after drying.

From the blowline, the fibres enter the dryer, where they are dried and thereafter continuously fed to the mat forming station. The fibre dryers applied are mainly directly heated tube dryers of 150–180 m in length. The tube dryers can also be indirectly heated by

steam coils or by a combination of indirect heating and additional hot gas. The fibres remain in the tube for 3–10 seconds and the drying inlet temperature is between 120 °C and 140 °C, occasionally up to 220 °C, which is generally slightly lower than that applied for PB chips and OSB strands. The outlet temperature is also lower and lies between 60 °C and around 100 °C.

The heat energy for drying comes from similar sources to those mentioned for drying wood particles and strands for PB and OSB.

After the mat forming station, the production process is similar to the production of PB and OSB.

- *Pressing*

The raw panel is produced in the press by applying high pressure and high temperature for a sufficient amount of time to compress the mat to the required thickness and to densify and fixate the particles or fibres by resin curing. The temperature at the core of the panel needs to reach a certain level depending on the resin, normally above 100 °C, in order for water to evaporate.

Before entering the press, the mat leaving the mat forming station is normally pre-pressed at ambient temperature in a roller press to remove air from the mat, and the sides of the panel are trimmed. Pre-pressing is not necessary in OSB production. If the main press is a multi-opening press, the pre-pressed panel is cut to fit and be loaded individually to the press.

The press belts in a continuous press or the press plates in a multi-opening press are heated with thermal oil with a contact temperature normally not exceeding 260 °C. Press plates in a multi-opening press generally operate with a lower temperature.

- *Lamination*

Lamination is often connected to the panel production plant in terms of sharing energy sources for heating thermal oil for the cyclic presses. Thermal oil rings are used at some plants to serve both panel presses and lamination presses. Lamination lines are often situated next to the storage areas for the finished product. The cyclic press laminates one panel at a time, either on one face only or on both sides. A cyclic tandem press laminates two panels for each cycle and continuous presses are also available. As indicated, the most commonly used paper is melamine-impregnated paper. The melamine thermosetting resin in the paper becomes liquid upon heating and sets and cures onto the panel and creates a thin cured layer of resin on the surface. The press time is between 15 and 40 seconds. The presses are often heated with thermal oil. The curing and lamination takes place at temperatures between 130 °C and 200 °C, which is lower than in presses used in panel production. The pressure is also lower than that used in panel production.

24.3 Data available for waste heat recovery

Waste gases from drying are collected and generally conducted into a dust abatement system.

The flue-gases from biomass combustion used for direct drying and also for steam generation for indirect drying are sometimes treated before entering the dryer. This will depend on the fuel, the combustion unit and the combustion process.

The formation of nitrogen oxides (NOX) depends on the fuel-bound nitrogen content and the combustion temperature. The combustion temperatures for biomass are lower than for gaseous or liquid fuels, so the conditions for creation of thermal NOX are not so favourable. The fuel-bound nitrogen content in wood-based biomass varies between 0.2 % and 0.5 %, depending on the wood source, which is lower than for liquid fuels.

The staged combustion obtained in fluidised bed combustion or by air staging in moving grate furnaces is widely applied and can minimise NOX and CO levels. Reduction of NOX is applied at some biomass-fired combustion plants, using selective non catalytic reduction (SNCR) in the combustion chamber. When using SNCR the potential related emissions of ammonia (NH₃) would be subject to control. The combustion plants are mainly stand-alone plants and few examples have been identified for hot gas production for directly heated dryers.

Emissions of sulphur oxides (SOX) depend on the fuel-bound sulphur content and liquid fossil fuels can contain sulphur, which gives high SOX emissions. The majority of sulphur oxides are produced as sulphur dioxide (SO₂). High SOX emissions are generally not an issue when using biomass as a fuel, but there are examples of dry sorbent injection to prevent elevated SOX emissions. The design of the combustion unit is decisive for the use of specific SOX abatement techniques.

The dust emitted during the burning of the biomass arises almost entirely from the mineral fraction of the fuel. A small proportion of the dust may consist of very small particles formed by the condensation of compounds volatilised during combustion. Moving grate boilers, which are the most commonly applied type in the sector, produce a relatively small amount of fly ash (20–40 % of total ash). The combustion of liquid fuels is also a source of particulate emissions, in the form of soot particles, and is related to poor combustion conditions.

The abatement of dust emissions in the hot gases before they are used for direct drying is carried out at a few combustion plants that use biomass as a fuel, where fabric filters and ESP applications are the most common abatement techniques. These are generally only used in combustion plants/units over 20 MW.

Bark fuel has a high mineral content (2–3 %) and a tannin content of more than 20 %. If the combustion is not complete, the flue-gases will contain resinous tar and contribute to the dust emissions in the dryer waste gas. In order to complete the combustion and thermal decomposition of the tannins, temperatures above 1200 °C are needed together with an efficient recirculation of the flue-gases for post-combustion.

25 Ceramic Manufacturing Industry

25.1 Description of the industry

Generally the term 'ceramics' (ceramic products) is used for inorganic materials (with possibly some organic content), made up of non-metallic compounds and made permanent by a firing process. In addition to clay based materials, today ceramics include a multitude of products with a small fraction of clay or none at all. Ceramics can be glazed or unglazed, porous or vitrified. The term 'ceramics' is derived from the Greek 'keramos' meaning 'burned earth' and is used to describe materials of the pottery industry.

Firing of ceramic bodies induces time-temperature transformation of the constituent minerals, usually into a mixture of new minerals and glassy phases. Characteristic properties of ceramic products include high strength, wear resistance, long service life, chemical inertness and nontoxicity, resistance to heat and fire, (usually) electrical resistance and sometimes also a specific porosity.

The main steps in the manufacture of ceramic products are largely independent of the materials used and the final product. The steps are: mining/quarrying of raw materials and transport to the ceramic plant (neither of these two steps is covered in this document), storage of raw materials, preparation of raw materials, shaping, drying, surface treatment, firing and subsequent treatment

25.2 Processes used involving heat

There are various ceramic products and thus various fundamental methods and steps in the production process of each product.

- *Bricks and roof tiles*

Brick products are produced in large quantities, which are used as materials in numerous branches of building and contracting. For the most part, bricks and tiles are not designated according to the shaping technique used, but according to the intended application: building bricks, roof tiles, paving bricks, chimney bricks.

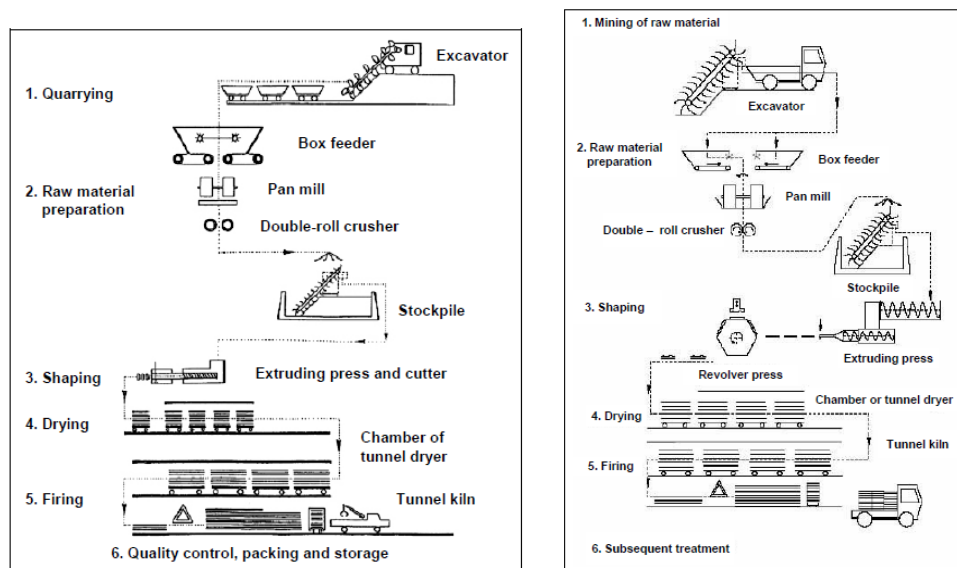


Figure 32: Left: Preparation of extruded bricks, Right: Manufacturing of pressed roof tiles.

- *Drying, glazing and engobing*

Different types of dryers operate in the drying process, depending on the amount of work, the degree of mechanisation and the sensitivity of the mass.

In the manufacture of bricks, chamber and tunnel dryers are usual. In the manufacture of roof tiles, chamber dryers and tunnel dryers are also used. In tunnel and fast dryers, the conditions for drying bricks are between less than 8 up to 72 hours at a temperature of approx. 75 – 90 °C. Fast dryers operate at significantly shorter periods of less than 8 hours for blocks, some facing bricks take up to 72 hours. In chamber dryers the drying period for bricks lasts up to 40 hours at a temperature of approx. 90 °C.

Roof tiles are dried in tunnel dryers or chamber dryers at a temperature of 60 – 90 °C in 12 to 48 hours. The water content of the ware before the firing process in a tunnel kiln is lower than three per cent. Dryers are heated mainly by excess heat from the kiln and, in some cases, by natural gas or fuel oil burners or cogeneration.

- *Firing*

Today, bricks and roof tiles are fired in tunnel kilns mainly in an oxidising atmosphere. The ware to be fired is heated up to a maturing temperature of between 800 and 1300 °C.

Following the necessary body formation time of between two and five hours at maturing temperature, the ware is cooled down according to plan to 50 °C.

- *Vitrified clay pipes*

Vitrified clay pipes and fittings are used for drains and sewers, but also tanks for acids and products for stables. Vitrified clay pipes are manufactured using the following process steps: storage of raw materials, preparation of raw materials, shaping, drying, glazing, firing and subsequent treatment.

- *Drying and glazing*

The rupture-free drying of the green ware takes place in chamber or tunnel dryers at temperatures of up to 100 °C to about two per cent remaining humidity. The drying time of the fittings is between 70 and 100 hours, the drying time of the pipes is between 30 hours (small pipes) and nine days (large pipes).

- *Firing*

Firing takes place in gas heated tunnel kilns predominantly in an oxidising atmosphere. The green ware is fired in a vertical position fixed on firing auxiliaries. Conventional firing temperatures are between 1150 and 1250 °C, the firing time is between 30 and 80 hours.

- *Refractory products*

The resistance of refractory materials to high temperatures is defined so that their softening point is not less than 1500 °C. A classification of 'refractory materials' with a softening point of between 1500 and 1800 °C and 'high refractory materials' with a softening point of more than 1800 °C is commonly used (TWG, 2005).

- *Shaping*

The mixes to be shaped are mixed with a binder sensitive to cold. Next the mixes are poured into moulds and harden at temperatures of below -30 °C.

- *Drying*

For periodically operated dryers (chamber dryers), the operation temperature for the fireclay products is 80°C and the temperature of the flue gas is 60°C. For the silica products, the drying temperature is 100°C and the temperature of the flue-gas is 60°C. Regarding the two tunnel dryers and a climate controller dryer, the drying temperature for the tunnel dryer for fireclay is 100C, for magnesite 150-180°C, and for high alumina in the climate controlled dryer 30-200°C. For the three processes, the flue gas temperature is 40°C, 120°C, 105°C respectively. More details are shown in Tables below.

- *Firing*

Refractory products are fired at temperatures of between 1250 and 1850 °C. Maturing temperatures depend on the composition of the raw materials and reach the beginning of

deformation. The firing temperatures for the most important material groups are in the following ranges:

- fireclay bricks 1250 - 1500 °C
- silica bricks 1450 - 1500 °C
- high alumina bricks 1500 - 1800 °C
- magnesia bricks 1400 - 1800 °C.

The following tables show the operating data of tunnel kilns and shuttle kilns.

- *Special procedures*

Special procedures are applied to manufacture refractory products with special characteristics. The formation of carbon bonding and pitch impregnation are procedures where special auxiliary agents are used. C-bonded bricks are predominantly used in the production of steel. The raw materials are often hot processed and pressed with coal tar, pitch or resins as binders. The bonding of the pressed parts is considerably reinforced by tempering and curing. The binding agent cokes during the tempering under the exclusion of air at temperatures of between 320 and 550 °C. During the hardening process, the products are heated to approx. 150 to 220 °C in electrical kilns. Refractory bricks are impregnated in some cases with coal-tar or bitumen to avoid 'open pores'.

- *Expanded clay aggregates*

Expanded clay aggregates are porous ceramic products with a uniform pore structure of fine, closed cells and with a densely sintered, firm external skin. They are manufactured from raw materials containing clay minerals. The raw material is prepared, moulded and then subjected to a firing process at temperatures of between 1100 and 1300 °C, resulting in a significant increase in volume due to expansion.

25.2.1 Wall and floor tiles

Ceramic tiles (see EN 14411) are thin slabs made from clays and/or other inorganic materials, generally used as coverings for floors and walls. Ceramic tiles are usually shaped by extrusion or dust pressing at room temperature, then dried and subsequently fired at temperatures sufficient to develop the required properties.

- *Preparation of raw materials*

Preparation of raw materials includes different operations and techniques, according to the type or form of body to be produced. Drying is performed at temperatures of between 350 and 450 °C to a water content of between five and nine per cent. The required heat in the spray dryer is produced by natural gas or fuel oil firing.

- *Drying*

The pressed bodies are dried mainly in tunnel dryers, roller dryers or vertical dryers. Waste heat from the kiln or natural gas and fuel oil firing burners are operated to heat the dryer. Drying is performed at temperatures that vary depending on the type of technology, e.g. in vertical dryers between 200 – 220 °C and in tunnel dryers 300 – 350 °C. Drying time is between one and four hours depending on the water content of the green ware. The required residual moisture content is less than one per cent to avoid fissures and glazing errors in the firing process.

- *Firing and glazing*

Tiles are made as glazed or unglazed single fired products or as glazed double or even triple fired products. In the double firing process, the tiles pass the biscuit firing first. Biscuit firing is performed at temperatures of between 1050 and 1150 °C in classic tunnel kilns (in 20 to 50 hours) or in modern roller hearth kilns in one to two hours.

The final firing takes place in roller hearth kilns, tunnel kilns or periodically operated kilns. Glazed tiles are put on firing auxiliaries and are fired at temperatures of between 1050 and 1300 °C in tunnel kilns or in roller hearth kilns without firing auxiliaries. Specially formed tiles are fired in shuttle kilns or tunnel kilns at temperatures of up to 1100 °C. The following table shows examples of operating data of tunnel kilns and roller hearth kilns.

- *Household ceramics*

The manufacture of household ceramics covers tableware, artificial and fancy goods made of porcelain, earthenware and fine stoneware. Typical products are plates, dishes, cups, bowls, jugs and vases. The process of household ceramics manufacture is made up of the following main steps: storage of raw materials, preparation of raw materials, shaping, drying, firing, glazing, decoration and subsequent treatment.

- *Firing, glazing and decoration*

Household ceramics are fired between one and four times, depending on the material and the production technique. In the first step, biscuit firing gives the semi-product the strength and absorbency needed for the glazing. Biscuit firing temperatures are between 900 and 1050 °C, the firing time in classic tunnel kilns is between 18 and 30 hours. Fast firing kilns achieve firing times of between three and seven hours.

The glost firing that follows is performed in an oxidising or reducing atmosphere at temperatures of between 1320 and 1430 °C. Glost firing kilns are tunnel kilns with tunnel kiln cars, (multi-rack) roller hearth kilns, fast firing tunnel kilns with moving firing tables, slab kilns or belt conveyer kilns. Periodic kilns such as chamber kilns, shuttle kilns and hood-type kilns are operated at lower feed rates. The ware to be fired is set on fireproof firing auxiliaries (so called 'kiln furniture'). Glost firing time varies between 25 and 36 hours in the tunnel kiln and between three and a half and five hours in fast-firing kilns without firing auxiliaries.

Tables below show the operating data of a shuttle kiln and tunnel kilns.

Another household ceramics manufacturing process, which is applied in a few cases, involves only one firing process without prefiring. This one-time firing process suffices for undecorated products and for products with decorations applied prior to the glazing. The firing takes 20 hours in shuttle kilns, at a temperature of 1260 °C. Gold, platinum and other metallic colours have to be fired at the lower temperature of 890 °C

Input and output flows in the manufacture of household ceramics

- *Sanitary ware*

Ceramic goods used for sanitary purposes are all included under the collective name sanitary ware. Typical sanitary ceramic products are lavatory bowls, bidets, wash basins, cisterns and drinking fountains. Glazing is applied directly to the clay surface and fired at the appropriate temperature of the product concerned; normally between approximately 1200 – 1210 °C for vitreous china and at about 1220 °C for fireclay.

- *Drying and glazing*

The green ware is dried in two stages. After the leather-hard drying, the green ware is perfectly treated. The following white drying minimises the water content down to less than one per cent.

The drying process takes place in tunnel or chamber dryers. Microwave dryers are built as tunnel dryers and are also used for leather-hard and white drying. The drying temperature is from 60-90°C while the flue gas temperature from 60-150°C.

- *Firing*

Sanitary ware is fired in tunnel kilns and roller hearth kilns at temperatures of between 1250 and 1290 °C in an oxidising atmosphere. Small scale production is carried out in flexible periodically operated kilns such as shuttle kilns. Shuttle kilns are operated to change the product specific firing curve in very short cycles.

For tunnel kilns the firing temperature is from 150 to 1290°C and the flue gas temperature 150-550°C. For the shuttle kilns the firing temperature is from 1210-1250°C and the flue gas temperature 150-550°C.

- *Technical ceramic*

Technical ceramics are applied in many industries and cover both, established products like insulators and new applications. They supply elements for the aerospace and automotive industries (engine parts, catalyst carriers), electronics (capacitors, piezo-electrics), biomedical products (bone replacement), environment protection (filters) and many others.

- *Firing/sintering*

For firing, depending on the wide variety of raw materials and process variants, different types of kilns are used. Small scale production is carried out in flexible periodically operated kilns such as shuttle kilns, which are operated to change the product specific firing curve in very short cycles.

Typical sintering temperatures for technical ceramic materials are shown in the following table.

- *Inorganic bonded abrasives*

A principal characteristic of grinding – one of the oldest known production processes – is the effect of numerous, not orientated cutting materials in the workpiece. Abrasive products, which apply this principal characteristic, are tools widely used in working every kind of materials: not only grinding, but also cutting-off, polishing, dressing, sharpening, etc. for metals, plastics, wood, glass, stones etc.

- *Drying*

As the compressed material is moisturised with water containing glue, the raw workpiece has to be dried. Chamber dryers and vacuum dryers are applied, in which the products are dried at temperatures of between 50 and 150 °C. Long drying times of up to 45 hours are necessary for a crack free drying and the dryers can also be air conditioned (in particular, vacuum dryers are equipped with a humidity control) for a crack free drying

- *Firing*

The firing of inorganic bonded abrasives takes place in natural gas or electrically heated periodically or continuously operated kilns. Example plants operate kilns with capacities of more than 4 m³ (up to 11 m³), firing temperatures of between 850 to 1300 °C and setting densities of between 360 to 1400 kg/m³.

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Part III:

Waste heat potential estimation

1. Definition of waste heat potential

When considering different technologies for using the industrial waste heat potential, it is necessary to first distinguish which potential type is considered (Brueckner *et al.*, 2014): the theoretical or physical potential (Metz *et al.*, 2007), the technical potential or the economic feasible potential (Roth *et al.*, 1996) (Fig. 1.a).

The theoretical potential only considers physical constraints: the heat has to be above ambient temperature, bound in a medium, etc.

Not considered here is whether it is possible to extract the heat from the carrier fluid or whether it is possible to use it. The above-mentioned constraints set the technical potential. In addition, the technical potential depends on the technologies considered. An example of a technical constraint is the required minimum temperature. The technical potential to use waste heat is defined by two major constraints: in addition to the boundary conditions of the technology itself, a heating or cooling demand is necessary.

If we go one step further, then the technical potential can be separated into a theoretical technical potential and an applicable technical potential, which are distinguished by the fact that the first one is calculated using a theoretical/generic process-related analysis, while the second one is calculated by using onsite data with all plant specific parameters taken into consideration (Fig. 1.b).

Accordingly, the feasibility of the technology considered is further analysed using economic criteria/analysis.

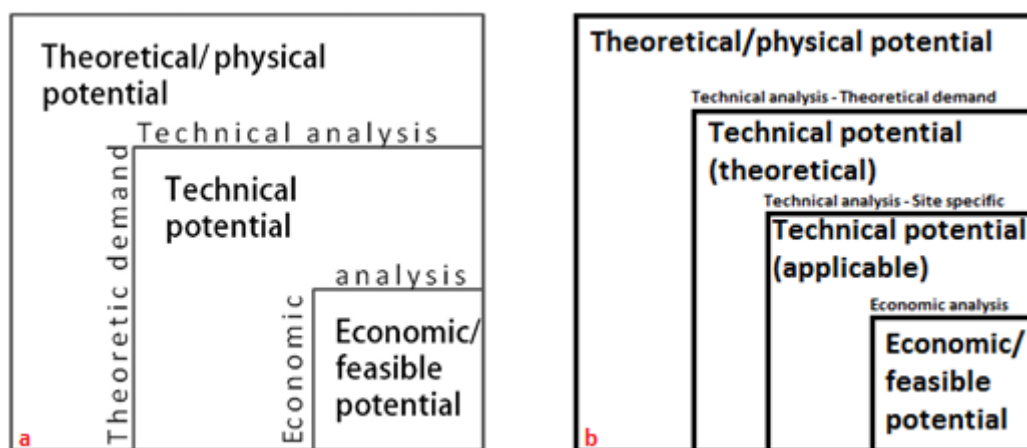


Fig. 1 Types of potential (a: graph based on Brueckner *et al.*, 2014, Metz *et al.*, 2007 and Roth *et al.*, 1996, b: modified)

2. Waste heat potential evaluation

The data used for the estimation of the waste heat potential are those presented by Forman *et al.* (2016). As aforementioned the waste/rejected heat can be further distinguished by its applicability according to the respective temperature range (qualitative analysis).

In terms of Thermodynamic analysis, energy is described as the sum of exergy and anergy, whereby exergy stands for the energy that can be totally turned into technical work. Thus, the exergy content of waste/rejected heat can be calculated by Carnot's theorem, which states that the maximum efficiency of a heat engine is determined by the two available heat reservoirs. Applying the Carnot factor (Eq. 1) to the waste heat amounts and their corresponding waste heat temperatures (T_{high}) gives the respective technical work potential further indicated as Carnot's potential.

$$\eta_{max} = \eta_C = 1 - \frac{T_{low}}{T_{high}} \quad \text{Eq. 1}$$

The waste heat temperature ranges can be distinguished into three categories as follows:

- Low Temperatures (LT): < 100 °C
- Medium Temperatures (MT): 100-299 °C
- High Temperatures (HT): ≥ 300 °C

According to the results of Forman *et al.* (2016) the waste heat potential and Carnot's potential are calculated as the percentage of the consumed energy for each temperature range respectively, as can be seen in the Table 1.

Table 1: Waste heat potential and Carnot's potential according to Forman *et al.* (2016)

Potential	LT	MT	HT
Waste Heat	12.60%	6.00%	11.40%
Carnot's	1.73%	2.00%	6.40%

As expected, waste heat at lower temperature level has a significantly smaller share within Carnot's potential. Thus, Carnot's potential provides a more precise indication on whether waste heat could still perform technical work or, better, be used for heat transfer.

Consequently, by using the data presented in Table 2 concerning the processes used in each industrial sector and their respective waste heat stream temperature range, the waste heat potential and Carnot's potential for each industry are calculated as shown in the Table.

Table 2: *Waste heat and Carnot's potential for each industrial sector*

	Type of Industry	Waste heat potential	Carnot's potential
1	Iron & Steel Industry	11.40%	6.40%
2	Chemical and Petrochemical Industry	11.00%	5.13%
3	Non-ferrous metal industry	9.59%	4.93%
4	Non-metallic minerals (glass, pottery & building materials industry)	11.40%	6.40%
5	Food and Tobacco	8.64%	1.89%
6	Paper, Pulp and Print	10.56%	4.59%
7	Wood and Wood Products	6.00%	2.00%
8	Textile and Leather	11.04%	2.72%
9	Non-Specified industry	10.38%	4.84%

The data presented in Part I for the energy consumption of the industrial sector of each country are consequently combined with the data of Table 2 and the waste heat potential and Carnot's potential of each industrial sector for each country are calculated and presented in Tables 3-4 as it can be seen below. Finally, the total potentials for each country and the EU-28 are calculated and presented in Table 5.

Table 3: Waste heat potential for the industrial sectors of each EU-28 country

Industry	COUNTRY																											
	AU	BE	BG	CR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	GB
Iron & steel industry	4.63	4.41	0.13	0.03	0.00	3.87	0.06	0.00	1.49	10.2	24.9	0.19	0.52	0.00	6.90	0.04	0.00	0.31	0.00	4.35	3.20	0.23	2.22	2.92	0.20	4.24	2.09	5.14
Chemical and Petrochemical industry	1.82	4.98	1.00	0.18	0.01	1.81	0.31	0.10	1.34	9.2	25.4	0.14	0.96	0.29	5.27	0.03	0.39	0.07	0.00	10.7	3.81	0.63	2.11	0.38	0.19	5.13	0.71	4.16
Non-ferrous metal industry	0.31	0.47	0.16	0.02	0.00	0.10	0.00	0.00	0.33	1.7	3.06	0.98	0.17	0.54	0.71	0.00	0.00	0.00	0.00	0.48	0.45	0.03	0.00	0.27	0.17	1.22	0.37	0.61
Non-metallic Minerals (Glass, pottery & building mat. Industry)	1.62	2.42	0.66	0.44	0.18	1.79	0.50	0.23	0.35	7.7	12.0	0.96	0.50	0.40	6.62	0.19	0.25	0.14	0.00	1.02	3.38	1.44	1.05	0.52	0.24	4.48	0.42	3.47
Food and Tobacco	0.79	1.88	0.24	0.22	0.03	0.78	0.63	0.06	0.35	6.9	6.96	0.47	0.51	0.44	2.67	0.09	0.19	0.03	0.00	2.68	1.85	0.42	0.53	0.14	0.06	2.18	0.38	2.69
Paper, Pulp and Print	2.93	1.27	0.31	0.07	0.00	1.00	0.21	0.07	7.23	4.7	10.0	0.12	0.22	0.03	2.48	0.01	0.05	0.01	0.00	1.18	1.93	1.73	0.10	0.53	0.20	2.52	7.18	2.00
Wood and Wood Products	0.67	0.24	0.04	0.02	0.00	0.21	0.06	0.08	0.43	0.5	1.44	0.02	0.04	0.10	0.28	0.25	0.06	0.01	0.00	0.05	0.60	0.07	0.18	0.03	0.03	0.35	0.38	0.00
Textile and Leather	0.16	0.35	0.09	0.04	0.00	0.24	0.03	0.02	0.04	0.5	0.89	0.06	0.05	0.02	1.50	0.01	0.04	0.02	0.00	0.19	0.15	0.37	0.00	0.04	0.03	0.44	0.03	0.93
Non-specified (Industry)	0.43	0.78	0.19	0.00	0.01	0.78	0.17	0.03	0.32	1.6	4.40	0.16	0.30	0.21	1.92	0.02	0.00	0.02	0.01	22.9	0.80	0.16	0.00	0.14	0.09	1.55	0.96	8.44

Table 4: Carnot's potential for the industrial sectors of each EU-28 country

Industry	COUNTRY																											
	AU	BE	BG	CR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	GB
Iron & steel industry	2.60	2.48	0.07	0.02	0.00	2.17	0.03	0.00	0.84	5.78	14.0	0.10	0.29	0.00	3.88	0.02	0.00	0.18	0.00	2.44	1.80	0.13	1.24	1.64	0.11	2.38	1.17	2.88
Chemical and Petrochemical industry	0.85	2.32	0.47	0.08	0.00	0.85	0.15	0.04	0.63	4.33	11.8	0.07	0.45	0.14	2.46	0.01	0.18	0.03	0.00	5.03	1.78	0.30	0.98	0.18	0.09	2.39	0.33	1.94
Non-ferrous metal industry	0.16	0.24	0.08	0.01	0.00	0.05	0.00	0.00	0.17	0.92	1.57	0.51	0.09	0.28	0.37	0.00	0.00	0.00	0.00	0.25	0.23	0.01	0.00	0.14	0.09	0.63	0.19	0.31
Non-metallic Minerals (Glass, pottery & building mat. Industry)	0.91	1.36	0.37	0.25	0.10	1.00	0.28	0.13	0.20	4.35	6.74	0.54	0.28	0.22	3.72	0.11	0.14	0.08	0.00	0.57	1.90	0.81	0.59	0.29	0.13	2.52	0.24	1.95
Food and Tobacco	0.17	0.41	0.05	0.05	0.01	0.17	0.14	0.01	0.08	1.52	1.52	0.10	0.11	0.10	0.58	0.02	0.04	0.01	0.00	0.59	0.40	0.09	0.12	0.03	0.01	0.48	0.08	0.59
Paper, Pulp and Print	1.27	0.55	0.13	0.03	0.00	0.44	0.09	0.03	3.14	2.05	4.35	0.05	0.10	0.01	1.08	0.00	0.02	0.01	0.00	0.51	0.84	0.75	0.04	0.23	0.09	1.09	3.12	0.87
Wood and Wood Products	0.22	0.08	0.01	0.01	0.00	0.07	0.02	0.03	0.14	0.19	0.48	0.01	0.01	0.03	0.09	0.08	0.02	0.00	0.00	0.02	0.20	0.02	0.06	0.01	0.01	0.12	0.13	0.00
Textile and Leather	0.04	0.09	0.02	0.01	0.00	0.06	0.01	0.00	0.01	0.14	0.22	0.01	0.01	0.01	0.37	0.00	0.01	0.01	0.00	0.05	0.04	0.09	0.00	0.01	0.01	0.11	0.01	0.23
Non-specified (Industry)	0.20	0.36	0.09	0.00	0.00	0.37	0.08	0.02	0.15	0.76	2.05	0.08	0.14	0.10	0.89	0.01	0.00	0.01	0.01	10.7	0.37	0.07	0.00	0.06	0.04	0.72	0.45	3.94

Table 5: Total Waste heat and Carnot's potential for each EU-28 country

EU COUNTRY	Potential (TWh)	
	Waste heat	Carnot's
Austria	13.36	6.43
Belgium	16.79	7.89
Bulgaria	2.81	1.30
Croatia	1.02	0.45
Cyprus	0.22	0.11
Czech Republic	10.59	5.18
Denmark	1.96	0.79
Estonia	0.60	0.27
Finland	11.89	5.35
France	43.52	20.03
Germany	89.18	42.82
Greece	3.11	1.47
Hungary	3.27	1.48
Ireland	2.03	0.88
Italy	28.36	13.44
Latvia	0.65	0.26
Lithuania	0.99	0.42
Luxembourg	0.62	0.32
Malta	0.03	0.01
Netherlands	43.72	20.17
Poland	16.17	7.56
Portugal	5.08	2.28
Romania	6.18	3.03
Slovakia	4.96	2.59
Slovenia	1.20	0.58
Spain	22.14	10.45
Sweden	12.52	5.72
UK	27.44	12.71
EU28	370.42	173.98

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Part IV:

**Comparative table with regard to type of industry, processes,
temperature range and heat recovery technologies**

Type of Industry	Processes used	Temperature range (°C)	Temperature range (LT, MT, HT)	Heat recovery technology	Waste heat or gas
Iron and Steel Production	Sinter Process	1300 – 1480	HT	Heat Exchanger	Dust, heavy metals, SO ₂ , NO _x , HCl, HF, CO, org C, PAH, PCDD/F, PCB
	Pelletisation Plants - Induration process	straight grate process: 1300 – 1350 grate kiln process: 1250	HT	Heat Exchanger	Dust, org C, VOC, SO ₂ , NO _x , CO, F, heavy metals, PCDD/F, PCB, PAH
	Coke oven plants – Jewell - Thompson oven	1150 – 1350	HT	Heat Exchanger	Dust, TOC, VOC, H ₂ S, SO ₂ , NH ₃ , HCN, CO, Hg, PAH, BTX, NH ₃
	Blast furnace – Hot Stoves	900 – 1500	HT	Heat Exchanger	Dust, org C, VOC, SO ₂ , NO _x , H ₂ S, CO, heavy metals
	Basic Oxygen Steelmaking	1200	HT	Heat Exchanger	Dust, org C, VOC, SO ₂ , NO _x , CO, heavy metals, PCDD/F, PAH
Large Combustion Plants	Combustion process – Gasification / Liquifaction process	430 – 630	HT	Steam Rankine Cycle	N/A
	Steam process - Boiler	Coal and Lignite fuels: 540-570 Liquid fuels: 120 – 140	HT	Steam Rankine Cycle	N/A
	Co-generation/combined heat and power	100	LT	Thermal Energy Storage	N/A
	Combined cycle plants	430 – 630	HT	Steam Rankine Cycle	N/A
Large Volume Inorganic Chemicals-	Conventional steam reforming - Desulphurization process	350-400	HT	Heat Exchanger	N/A

Ammonia, Acids and Fertilizers	Conventional steam reforming - Primary and Secondary reforming	Primary: 400-600 Secondary: 400-600 Exhaust gas: 1000	HT	Heat Exchanger	N/A
	Ammonia Partial oxidation - Gasification of heavy hydrocarbons and coal	N/A	N/A	Thermal Energy Storage	N/A
	Ammonia Partial oxidation - Sulphur removal	N/A	N/A	Thermal Energy Storage	N/A
	Sulphuric Acid - Sulphur combustion SO ₂ production process	900-1500	HT	Thermal Energy Storage	N/A
	Sulphuric Acid - Regeneration of spent acids SO ₂ production process	400-1000	HT	Thermal Energy Storage	2-15% SO ₂
	Sulphuric Acid - Spent acid from TiO ₂ production and roasting of metal sulphates	850+	HT	Thermal Energy Storage	SO ₂
Large Volume Inorganic Chemicals - Solids and Others industry	Sulphur burning process	145	MT	Heat exchanger	N/A
	Tank furnace process	430-650	HT	Heat exchanger	NO _x : 0 .64 g /Nm ³ , Dust: <20 m g/Nm ³ and CO: 36 .0 mg/Nm ³
	Sodium silicate plant (revolving hearth furnace) process	600	HT	Heat exchanger	Waste gas
Food, Drink and Milk Industry	Seed oil extraction process	65	LT	Heat exchanger	N/A
	Solubilisation/alkalizing process	45-130	MT	Heat exchanger or Thermal Energy Storage	N/A
	Utility processes -CHP	60-115	MT	Thermal Energy Storage	N/A
	Heat recovery from cooling systems	50-60	LT	Heat exchanger	N/A
	Frying	180-200	MT	Heat exchanger	N/A
Production of Glass	Heating the furnaces and primary melting	750 – 1650	HT	Heat exchanger	CO ₂ , NO _x , SO _x , CO, H ₂ S
Production of OFC	Energy Supply	45 – 130	LT	Heat exchanger	N/A
	Thermal oxidation of VOCs and co-incineration of liquid waste	950 – 1000 (SNCR) or SCR	HT	Thermal Energy Storage of Steam Rankine Cycle	Heat

	Recovery and abatement of acetylene	N/A	N/A	Heat exchanger	Radiative Heat
Production of Non-ferrous metals	Primary lead and secondary lead production	200 – 400	MT	Thermal Energy Storage or Heat exchanger	Flue gas
	Smelting Process	400 – 1200	HT	Steam Rankine Cycle	CO
	Zinc sulphide (sphalerite)	900 – 1000	HT	Heat exchanger	SO ₂
Production of Cement, Lime & Magnesium Oxide	Kiln firing	≥2000	HT	Steam Rankine Cycle or Organic Rankine Cycle (ORC)	CO, CO ₂ , Vapour, NO _x , NH ₃ , SO ₂ , SO ₃ , H ₂
				Thermal Energy Storage	
	Clinker burning	1400 – 2000	HT	Heat exchanger	
				Thermal Energy Storage	
Production of Polymers	Thermal treatment of waste water	N/A	N/A	Thermal Energy Storage or Heat exchanger	VOC, CO ₂ , NO _x
Ferrous Metals Processing	Hot rolling mill	1050 – 1300	HT	Thermal Energy Storage or Heat exchanger	NO _x , CO
	Re-heating and heat treatment furnaces	N/A	N/A	Thermal Energy Storage or Heat exchanger	N/A
Pulp, Paper and Board production	Kraft pulping process (chemical pulping) Sulphate pulping process (chemical pulping)	155 – 175 (Cooking and delignification)	MT	Thermal Energy Storage or Heat exchanger	NO _x , SO ₂ , CO, CO ₂ , dust, malodorous reduced sulphur compounds (TRS), VOC, chlorine compounds
		90 – 100 (Oxygen delignification)	LT		
		800 – 1100 (calcination reaction - lime kiln)	HT		
	Mechanical pulping and Chemimechanical pulping	95 – 125 (Grinding-Pressure Groundwood pulping)	LT-MT	Heat exchanger	SO ₂ , NO _x , CO, CO ₂ , HCl, dust VOC, visible plume, odour
		70 – 170			

	Processing of paper for recycling (with and without deinking)	N/A	N/A	Heat exchanger	SO ₂ , NO _x , CO ₂ , CO, HCl, dust VOC, visible plume, odour
	Papermaking and related processes	45 – 90 (Paper machine)	LT	Heat exchanger	SO ₂ , NO _x , CO ₂ , CO, HCl, dust VOC, visible plume, odour
		>350 (Coated wood-free printing tissue process with conventional Yankee dryer)	HT		
Surface Treatment Using Organic Solvents	Printing	700-800	HT	Heat exchanger	Waste gas including VOC.
	Drying and curing	400-700	HT	Heat exchanger	Solvent-laden air
	Waste gas treatment from enamelling	500-750	HT	Heat exchanger	Gas with low levels of NO _x
	Manufacturing of Abrasives	35-110 in the drier	LT	Heat exchanger	Air with NO _x
		700 for the exhaust air treatment	HT		
	Coil coating	150-220	MT	Heat exchanger	waste gases containing VOC from driers
Tanning and Hides and Skins	Drying	60-90	LT	Heat exchanger	Waste heat with VOCs
Textiles industry	Dirt removal	1200	HT	Heat exchanger	Heat, NO _x , ammonia
	Optimisation of cotton warp-yarn	60-110	LT-MT	Heat exchangers	Heat
	Dyeing	80-100	LT	Heat exchangers	Heat
	Oxidation	750	HT	Heat is Not recovered because the industry does not have a demand for thermal energy in this amount-potential use	Waste heat and gas

				with Heat exchangers	
	Drying	130	MT	Heat exchangers	Heat, acid fumes
	Drying and degassing	100-300	MT	Heat exchangers or Thermal Energy storage	Gas with CO, TOC, Cl ₂ , SO ₂ , NO _x , dust, CO ₂ , PCDD/F
Waste Incineration	Pyrolysis	250-700	MT-HT	Steam Rankine Cycle or Organic Rankine Cycle	H ₂ , CO, hydrocarbons, N ₂ O ₂ , N ₂
	Gasification	500-1600	HT	Heat exchanger	H ₂ , CO, CO ₂ , CH ₄ , H ₂ O, N ₂
	Oxidation, Combustion	800-1450	HT	Heat exchanger	CO ₂ , H ₂ O, O ₂ , N ₂
Waste Treatment	Thermal Treatment	Vitrification 1300-1500 Sintering 900-1200	HT	Heat Exchanger	Flue gas
	Drying	100	LT	Heat Exchanger	Steam, H ₂ O
	Regeneration of carbon	650-1000	HT	Heat Exchanger	Heat, H ₂ O
	Incineration	850-1200	HT	Heat Exchanger	Gas with VOC
	Catalytic combustion	200-600	MT-HT	Heat is used to remove TOC from the gas	Gas without VOC, TOC
	Drying of wood particles	200-370 for single pass and triple pass dryers	MT	Heat Exchanger	Gas with VOC at 80-120°C for directly dryers and 80-120 for indirectly dryers
		500 at rotary dryers	HT		
Wood based panels production	Drying of wood fibres	60-220	MT	Heat Exchanger	Heat with dust
	Pressing	100-260	MT	Heat is Not recovered, potential use with Heat Exchanger	Heat with dust
	Lamination	130-200	MT	Heat is Not recovered, potential use with Heat Exchanger	Heat with dust

Notes:

- Temperature ranges:
 - Low Temperatures (LT): $< 100\text{ }^{\circ}\text{C}$
 - Medium Temperatures (MT): $100\text{-}299\text{ }^{\circ}\text{C}$
 - High Temperatures (HT): $\geq 300\text{ }^{\circ}\text{C}$
- Waste heat recovery techniques:
 - Active:
 - Waste heat to heat (WTHH)
 - Mechanical vapour compressor
 - Sorption heat pump
 - Waste heat to cold (WHTC)
 - Sorption chiller
 - Waste heat to power (WHTP)
 - Steam Rankine Cycle
 - Organic Rankine Cycle
 - Kalina cycle
 - Passive:
 - Heat exchangers
 - Thermal energy storage (TES)

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