EU-MERCI

EU coordinated **ME**thods and procedures based on **R**eal **C**ases for the effective implementation of policies and measures supporting energy efficiency in the **I**ndustry

HORIZON 2020 Project Nr. 693845

Technical analysis –Ceramic sector (NACE C23.2-23.4)

WP4: Picture of efficiency projects implemented by the Industry sector-by-sector and process-by-process

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1 Introduction

According to NACE classification, Ceramic manufacturing and processing is included in NACE C23 Manufacture of other non-metallic mineral products and can be a part of the following subsectors:

- NACE C23.2 Manufacture of refractoryproducts
- NACE C23.3 Manufacture of clay building materials
- NACE C23.4 Manufacture of other porcelain and ceramic products
- NACE C23.9 Manufacture of abrasive products and non-metallic mineral products n.e.c

The total production of the sector in 2015 in Europe was about 28 billion euros which can be divided by products:

- Wall and floor tiles 32%
- Bricks and roof tiles 19%
- Refractories 15%
- Technical ceramics 11%
- Abrasives 9%
- Table and ornamentalware 6%
- Sanitaryware 5%
- Clay pipes 1%
- Expanded clay 1%
- Porcelain enamel 1%

2 Process analysis

Main ceramic products are:

- wall and floor tiles
- bricks and roof tiles
- table- and ornamentalware (household ceramics)
- refractory products
- sanitaryware
- technical ceramics
- vitrified clay pipes
- expanded clay aggregates
- inorganic bonded abrasives.

Main processes of ceramic production are:

- selection and preparation of raw materials
- shaping of ware
- drying of ware and coating
- firing
- subsequent treatment and packaging.

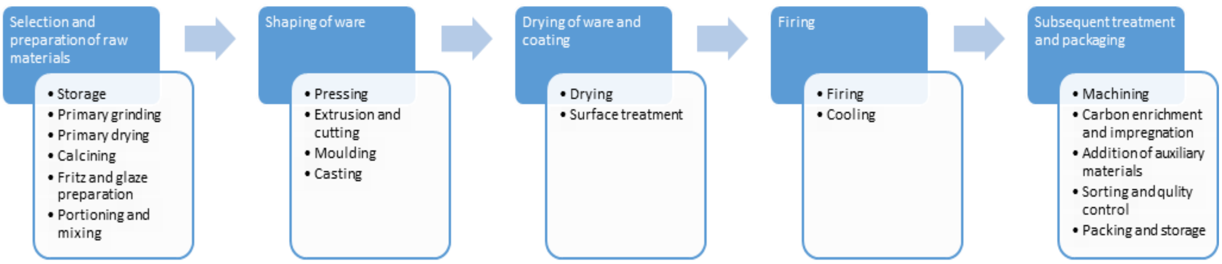

Figure 1: Main phases of manufacturing process.

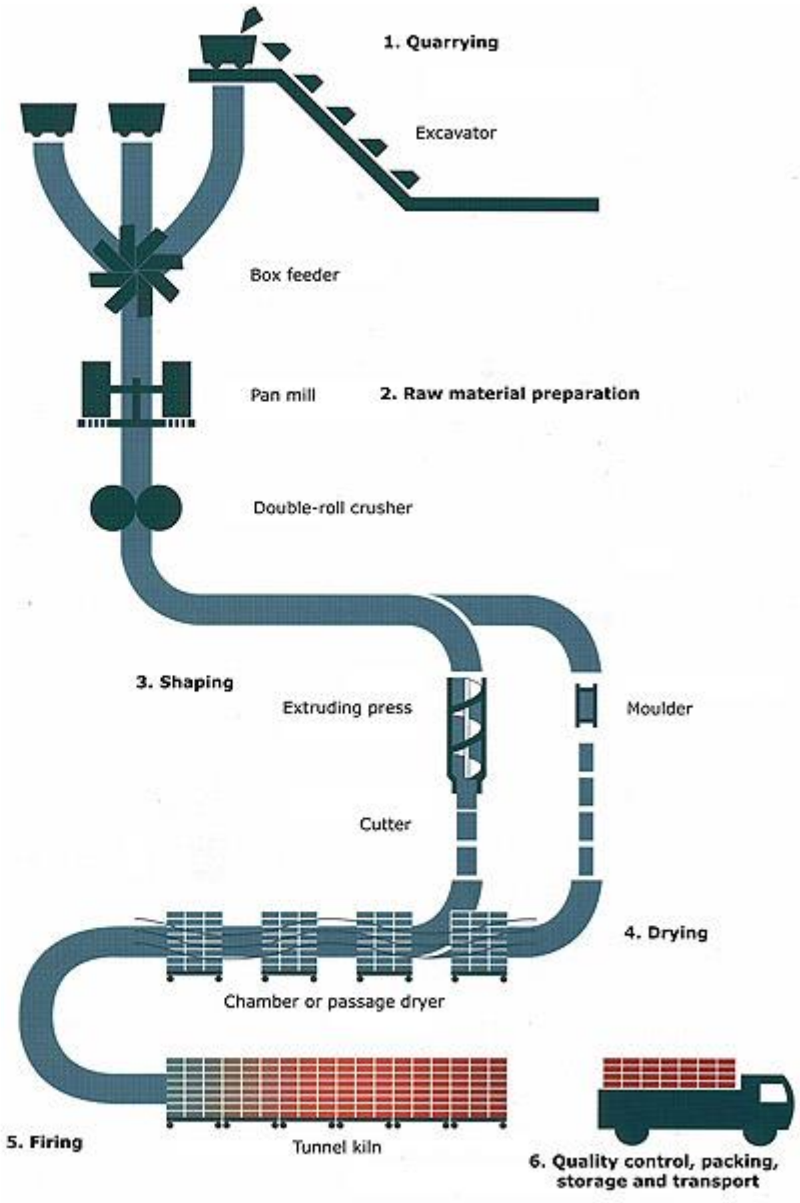

Figure 2. Example scheme of manufaturing process of bricks.

2.1 Selection and preparation of raw materials

Most materials used in the process are obtained from places located near the production plant. Materials like clay, kaolin, clayey materials, feldspar, quartz and most of the other raw materials are then transported to the production plant usually by railway or truck, sometimes also conveyor belts are used for transportation. The materials are stored in different ways depending on their characteristics. Usually open stockpiles, warehouses which are subdivided into boxes, large volume feeders, tempering silos, ageing silos, souring silos or dry silos are used for storage. Depending on the state of raw materials obtained from the mining/quarrying process the materials need further preparation. Than the materials are mixed together to create a product ready for further working. Main techniques used for preparation of raw materials are:

- Pre-drying
- Pre-blending
- Weathering/souring
- Primary and secondary crushing, grinding and screening
- Dry or wet milling
- Dry screening/air classification
- Spray drying
- Calcining
- Fritz and glaze preparation

Fluidised bed technology and rotary dryers are used for pre-drying. In many cases pre-drying is not necessary due to the dry state of raw materials delivered by the supplier. Blending may also start in the mining process and is continued in the primary and secondary crushing, grinding and screening phase. Some of the materials improve their workability during the storage phase. This process is called souring and may take a few months. The most effective weathering takes place during the winter period.

The primary crushing usually takes place near the quarry. Relatively dry/brittle clays are effected by large toothed kibbler rollers or by large jaw-crushers. Hard and large sized materials need jaw or cone-crushers for crushing. Hammer mills, edge runner mills, crushing rollers, clay shredders, roller mills and impact rotor crushers are used for further crushing, grinding and screening, depending on the material and the state of it needed in next phases of the process.

Dry or wet milling enables to furtherly reduce the size of the particles achieved by previously mentioned technologies, which are usually able to decrease the size of particles down to 2 mm. Smaller particle size is usually required during the process of wall and floor tiles, refractory products and tableware. Dry or wet roller mills may reduce the size of particles to 1 mm or less. It is even possible to further reduce it using continuous or batch ball mills.

Dry screening using electrically heated screens optimises properties of materials like for example density. Air classifiers may be used for dry powder sizing. If the particles do not reach the necessary size limit for dry screening or air classification they are taken back to the grinding process.

Spray drying produces highly uniform, more or less spherical hollow granules. The aqueous suspension of raw material which is the product of wet ball milling is sprayed under pressure to contact a hot air steam and produce dry droplets. This process may take place in a specific plant which produces spray dried powder and sells it to the ceramic industry factories.

Calcining process reduces the plastic shrinkage of materials to which clays are added. It enables to control the size of final products and reduce the time for firing the products. The raw materials are usually pre-fired in rotary kilns, tunnel kilns or shaft kilns. There are specific plants for producing prefabricated materials that use calcining.

Frits are vitreous compounds, insoluble in water, prepared from crystalline materials. They are used for ceramic wall and floor tile glazing. Frits are created and supplied by specific manufacturers. Other product commonly used for glazing are silica, materials that are used as fluxes (alkalis, alkaline earths, boron, lead, etc.), opacifiers (zirconium, titanium, etc.) and as colouring agents (iron, chromium, cobalt, manganese, etc.). These materials are ground in discontinuous drum ball mills until a pre-set reject is obtained and then glaze is passed through vibrating sieves. The glaze is then adjusted to the needs of further process.

After the additives are prepared they are then mixed. The process of mixing depends highly on the specific product created during the process. The amount of minor additives, water content and the properties of each and every material are defined for every product specifically. Portioning of the product is usually done automatically with computer control. Double and single shaft mixers are often used for continuous mixing. It is also possible to mix some of the materials and additives during the crushing, grinding and screening phase in pan mills, clay shredders and impact rotor crushers. For batch mixing the most common technologies are: the Z-blade mixers (dough mixer), drum mixers, rotating pan mixers, rotating shaft mixers (blungers) and stirred tanks.

2.2 Shaping of ware

The formerly prepared materials are then shaped into the form similar to the final product. The ways of shaping depend on what the final product is. The main technologies used for shaping are:

- Pressing
- Extrusion
- Moulding
- Slip casting
- Fusion casting

Pressing of the materials can be done in different ways. The main technologies are: mechanical pressing, hydraulic pressing, impact pressing, friction pressing and isostatic pressing. Mechanical pressing is used in process of brick and refractory products manufacturing. Hydraulic pressing is characterized by high compaction force, high productivity, consistency and easy adjustment process. It is used to form complex refractory shapes especially useful in shaping of tiles. The impact pressing is used in forming of special refractory products. Friction pressing is used for producing refractory shapes and is often replaced with hydraulic pressing. Isostatic pressing enables to create high quality products. It is used in the refractory and technical ceramics sectors as well as for the manufacture of tiles and tableware.

Extrusion is used during the manufacture process of clay bricks and blocks, vitrified clay pipes and ceramic floor and wall tiles. It is also used for preparation of semi-products. The raw material for extrusion needs to be plastic. Before the extrusion the plastic material is tempered to the required consistency with water and then forced through the extruder. The plastic body is also de-aired before entering the auger of the extruder. The product is then cut into required pieces.

Moulding is the process that used to be the most common for production of bricks. It requires less energy consumption but the product requires more energy consumption for next phases of the whole ceramic production. It is often used for manufacturing bricks of specific aesthetic characteristics. The process is similar to the modern ways of forming the product, but uses much softer mix. The mix is cast into a mould. During the vibro-casting forming process mix is vibrated using vibrating pokers. This process is not always applied during moulding.

Slip casting is employed extensively for the manufacture of sanitaryware and household ceramicks and for manufacturing special and complicated refractory products and technical ceramics. The material is mixed with water to produce clay slip. It is poured to a mould. The liquid is drawn from the slurry in the mould by the capillary suction to form a solid cast on the inner surface of the mould. The process last so long as to achieve necessary level of solidification.

Fusion casting demands high energy consumption and financial costs thus it is used for specialized ceramic production. The material for fusion casting is pre-melted and poured into moulds. The product than requires controlled cooling and solidification to avoid fractions and achieve planned characteristics of the product during the crystallisation process.

2.3 Drying of ware and coating

Drying process requires high control of specific parameters. The humidity, temperature and air circulation and heating rates have to be controlled. This part of the process can be often optimized and therefore reduce costs of the process and upgrade the efficiency of it. Usually the time of drying, the thermal efficiency and production of wastes can be optimized. The heat for the process is usually supplied by gas burners or recovered from cooling kilns. It is also possible to obtain the heat from cogeneration or using other fuels such as coal, biomass, biogas or petroleum coke. The process of removing the water from the ceramics is carried out by the dryers of different forms. The most common technologies for the dryers are: hot floor dryers, chamber dryers (intermittent), tunnel dryers (continuous), vertical ‘basket’ dryers, horizontal multi-deck roller dryers, dehumidifying dryers, infrared and microwave dryers.

Some of the ceramic products require surface treatment. For example the specific texture needs to be applied to non-slip floor tiles. Most of the ceramic products apply surface treatment for aesthetic reasons. To achieve specific colour of the product the surface coating inside the moulds can be added or it can be done using granular minerals delivered to specific surfaces by compressed air blasting guns. Some of the ceramics need the application of glaze on their surfaces. The process of applying glaze is often executed by spraying, waterfall glazing, dry glazing or decorating. The surface of the ceramic can also be engobed. The application process of engobe usually takes place during the drying phase. The engobe is applied by dipping or pouring the non-transparent layer on ceramic mass. The surface of the ceramic products can be modified also by screen printing. The ink is forced into glazing lanes inside the mask which covers the surface and protects it, enabling the application of a specific patterns. There are more decorating techniques such as the gravure technique and flexo space printing. They enable to apply the pattern directly on the surface and edges.

2.4 Firing

The firing process is vital for the ceramic product to achieve specific properties. Firing increases mechanical strength, abrasion resistance, dimensional stability, resistance to water and chemicals and fire resistance. The firing process is executed by kilns of different kinds depending on the preparation process or the product requirements. Main types of kilns are:

- Intermittent (periodic) kilns,
- Continuous kilns.

Other technologies used in the firing process are:

- clamp firing,
- rotary kilns,
- fluidised beds.

The intermittent kilns use a single chamber charged with pre-dried ceramic products. The main types are shuttle and hood-type kilns. The gas burners allow to control temperature and oxidising or reducing in the kiln atmosphere. There are also specific kilns for the manufacture of technical ceramics that use electricity. The main types of electricity supplied kilns are: hot isostatic pressing, high temperature kilns and kilns with a protective atmosphere.

The continuous kilns types used in ceramic industry are: chamber (Hoffmann) kilns, tunnel kilns, roller hearth kilns, sliding bat kilns. Chamber (Hoffmann) kilns consist of a series of linked chambers. During the firing process the dry ware is sealed inside one chamber fired with hot gases, which are then drawn to the next chamber. The system connecting chambers allows the increase of efficiency compared to the intermittent kilns. Most of chamber kilns are gas-fired but there is also possibility to use oil or coal. Tunnel kilns consist of refractory tunnels served by rail tracks carrying kiln-cars. The carts go through the kilns in specific intervals set. The cars are pushed in the opposite direction to the flow of air drown by fans to the exhaust duct. The air is preheated during the cooling phase of the ware and therefore is prepared for firing process. The hot gasses drown from the firing process can be applied to the drying process significantly reducing fuel needs. The tunnel kilns are usually gas-fired. The kilns are usually sealed mechanically or by water in order to reduce energy consumptions. Roller hearth kilns are commonly used for wall and floor tile production. It is also possible to use roller hearth kilns for the manufacturing process of clay roof tiles, vitrified clay pipes, sanitaryware and tableware. In the kilns, the ceramic ware is transported over driven rollers and heated using gas-fired burners located at the sides of the kiln. Sliding bat kilns work similarly to roller hearth kilns but the ware is transported refractory carriages on wheels borne by tracks outside of kilns. Due to the different method of transportation sliding bat kilns can transport ware of different and irregular shapes.

Clamp firing is used for the manufacture of limited number of the ceramic products such as bricks as it is a not efficient traditional way. This method uses specifically prepared ware with a component of solid additive fuel such as fine coke. The bricks are formed into piles called clamps and set on the foundation of fired bricks. Flues in the base layers are used to initiate firing. The bricks ignite slowly. The whole process of firing and cooling takes a few weeks. Then the bricks are sorted manually.

Rotary kilns are used mainly for manufacture of expanded clay aggregates. The kilns are formed into long cylinders which rotate about the axis and are fired by a burner set axially at the lower end.

Fluidised beds use suspension of solid particles and maintain the particles in gas thus the particles behave rather like fluids. The base supporting the ceramic powder is porous enabling the gas to be fed under pressure to the powder. The fluidised beds enable the ceramic powder to be both dried and calcined.

After the firing stage the ceramic ware needs cooling. The process is usually carried out using the circulating air soon after firing. The heated air from cooling process can be used in other phases like drying. The air flow can be transported using set of fans.

2.5 Subsequent treatment and packaging

The final product needs further machine operations in order to adjust it to the defined standards. Some of the products have specific dimensional tolerance not able to fit by formerly mentioned processes. To reach these tolerances the ceramic products are machined in processes such as: grinding, drilling and sawing.

Grinding can use wet and dry method. Wet grinding is a batch process which uses diamond machine heads for reaching the highest standards of dimensional tolerances. The products are fixed to a table which moves under the head. Dry grinding uses diamond wheels to facilitate bonding the product with a thin layer of mortar. Drilling is used when the level of accuracy of dimensions of holes required in the product is not possible to achieve during the preparation processes. The sawing is used when the shapes of ceramic brick cannot be effectively produced during the pressing phase. In this process, the pressured and fired oversized bricks are sawn into pieces of required dimensions.

Many of the ceramic products need additional operations for surface adjustment. Polishing is used especially for porcelain tiles. Tumbling of facing bricks is done to obtain an antique look. Tumbling is usually done by passing the ware through a rubber-lined rotating inclined drum. The sharp edges are softened in this process and additional pigment application can be done during the process.

Some refectory products need carbon enrichment to be fitted to work in a hostile environment. In specific cases the fire ware needs to be impregnated with petroleum-based pitch. The process usually takes place in three upright cylindrical vessels. In the first vessel the ware is heated via hot steam of air. The basket with ware is transported to second vessel which enables to maintain temperature. The liquid pitch is poured into a sealed and evacuated vessel. The vacuum is released from the vessel and then the nitrogen is applied to a vessel at an elevated pressure. Dried contents are transferred to third vessel where the cooling phase takes place. At the final stage the impregnated ware is transported to a heating oven where in a heating process a high proportion of pitch volatiles is removed.

At a last stage of manufacturing process addition of auxiliary materials is needed. Most common additives are: jointing materials, silicones/water repellents, insulation materials, carding and plating (refractory bricks) and adhesives. The methods of application vary; the most common ones are spraying, dripping, burning in or mechanical mounting.

The ready products are then sorted and controlled to avoid broken or damaged ware. This process can be done manually but is mostly done by automatic systems. These systems can determine the quality of the product taking under consideration even the colour of it. The ceramic ware is strapped into standard sized packs. The product is wrapped for safety and the packs may be palletised. More fragile objects are held in metal drums or separate boxes.

3 Energy intensity of key processes

Scheme of main phases with mass and energy flows is reported below.

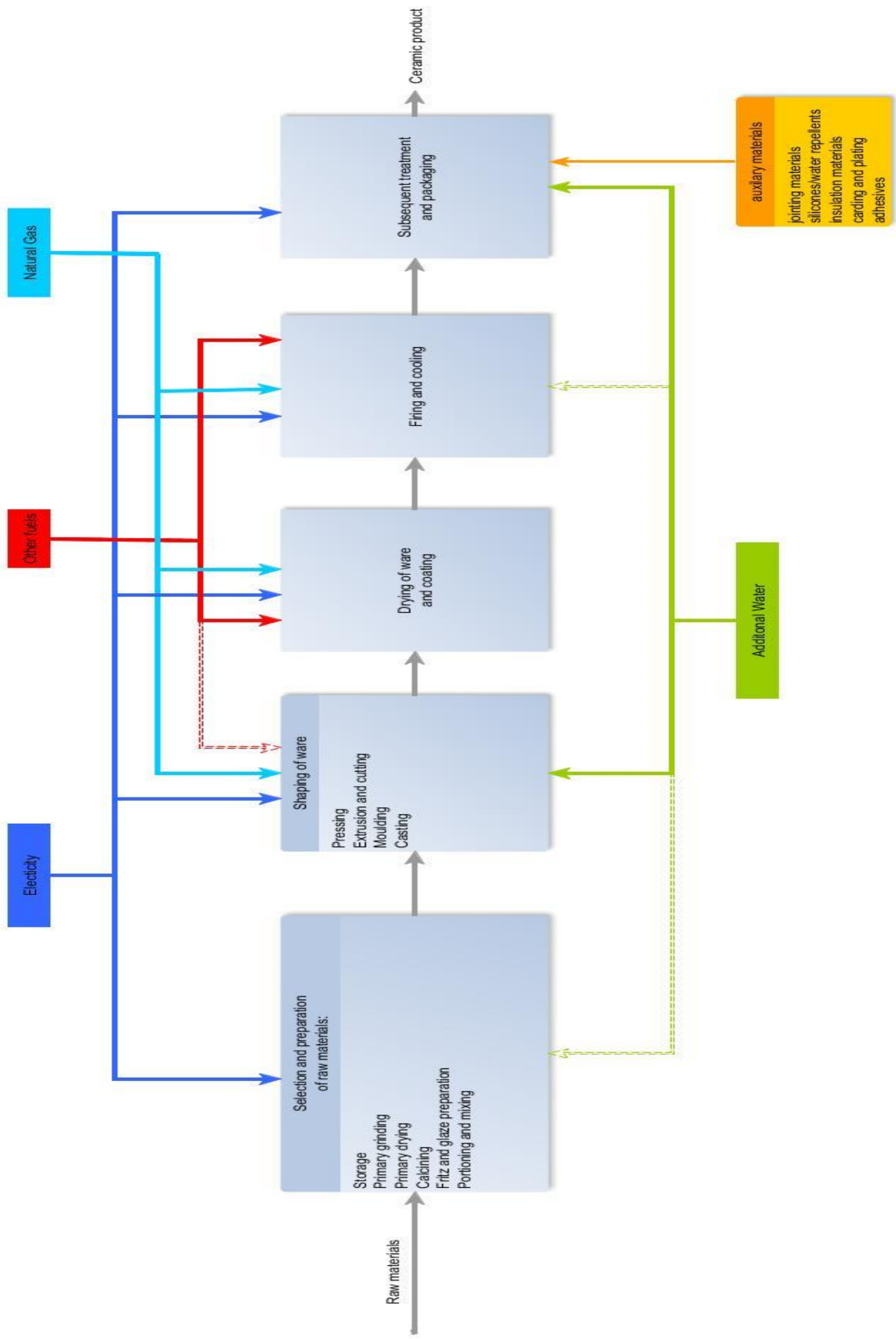

Figure 3: Fuel use for Ceramic production processes.

Table 1: Energy consumption of sub-sectors.

Product	**Energy use** [GJ/t]	**Share of energy consumption per sector**
Wall and floor tiles	5.6	42%
Bricks and roof tiles	2.31	38%
Table- and ornamentalware	45.18	6%
Refractory products	5.57	7%
Sanitary ware	21.87	3%
Technical ceramics	50.39	2%
Vitrified clay pipes	5.23	1%

Natural gas is the main energy source in ceramic industry. The consumption of natural gas in kilns in the process of firing and drying reaches approximately 85% of the whole of energy consumption in the manufacturing process. The consumption differs for different final product but the structure mainly based on natural gas for firing and drying is similar for every type of final product.

Electrical energy is used mainly for comminution, mixing and forming. It stands for approximately 15% of energy consumption in sector. In some cases, electrical energy can be used in drying and firing process. In tabelware and technical ceramics sectors electrical energy is employed for kiln firing in order to achieve required quality. Some manufacturers may also use electricity for transportation.

4 Efficient technologies according to BREF/BAT

A full list and description of efficient technologies according to BREF/BAT can be found in EU-MERCI Portal. However, a summary is here below reported:

1. Improved design of kilns and dryers:
    - automatic control of dryer circuits
    - automatic control of humidity and temperature within the dryer
    - in dryers, installation of impulsion fans distributed in zones with an independent thermal contribution
    - better sealing of kilns, e.g. metal casing and sand or water seals for tunnel kilns and intermittent kilns
    - improved thermal insulation of kilns, e.g. by use of insulating refractory linings or ceramic fibres (mineral wool)
    - improved refractory kiln linings and kiln-car decks
    - the use of high velocity burners
    - replacing old kilns with new (e.g. fast firing kilns)
    - interactive computer control of kiln firing regimes
    - reduced use of firing auxiliaries and/or use of firing auxiliaries made of SiC/super alloys
    - optimisation (minimisation) of the passage between dryer and kiln and also using the preheating zone of the kiln for finishing the drying process
    - reducing the amount of airflow through the rotary kiln
2. Recovery of excess heat from kilns
3. Cogeneration/combined heat and power plants
4. Substitution of heavy fuel oil and solid fuels by low emission fuels
5. Modification of ceramic bodies