This PhD work deals with the upgrading of RDF (refuse derived fuel) and the use of two kinds of ashes, bioash from cocombustion of wood/straw and fly ash from municipal solid waste incineration (MSWI), in the production of bricks. The overall aim is to use these secondary resources prior to natural resources, and by the upgrading to reduce adverse environmental effects caused by the brick making process and at the same time to have a high material quality of the bricks. Two Danish bioashes from co-combustion of straw and wood were studied. They were collected from Enstedværket and Vordingborg Kraftvarme A/S, both combined heat and power plants. The bioashes had Cd concentrations of 9.0-9.7 mg/kg TS, which exceeds the limiting value of 5 mg/kg TS for the ash for agriculture purposes. The use of the ashes directly in brick production results in a loss of plant nutrients, mainly potassium. Potassium is generally present in the water-soluble fraction, which is in practice already being recovered from e.g. straw ash for use as fertilizer by water leaching and other chemical treatments to precipitate dissolved heavy metals prior to use. The scope of this PhD work is on using the water washed ash as resource. The water washed bioashes had a Cd concentration varying between 20 and 67 mg/kg TS. The enrichment of other heavy metals, such as As, Cr, Ni, Pb and Zn, was also observed due to the high ash dissolution ranging from 75% to 88% of the initial mass. Considering the enrichment effect of water washing on heavy metals, recycling of the washed bioashes is problematic from an environmental point of view. Removal of heavy metals from the washed ashes was carried out by electrodialytic remediation (EDR). The results showed that the Cd bound in the two studied bioashes was EDR extractable. After 10-14 days electrodialytic extraction, the Cd concentration in both the raw and the washed ashes originating from Enstedværket CHP was reduced to below 2 mg/kg (with removal rate >95%); and, after 7 days EDR, the Cd concentration in the washed bioash originating from Vordingborg CHP was reduced from 63.7 to 21.4 mg/kg TS. Pb had a removal rate ranging between 12% and 67% from the Enstedværket CHP ash, which shows that Pb in the bioashes was harder to remove than Cd. A two-compartment electrodialytic cell with anode placed in the ash suspension was tested and facilitated the extraction of Pb by creating a faster acidification process. The results showed that prewash with water before EDR stabilized the ash properties, and the removal of Cd resulted in good separation of e.g. Cd, Pb and Ni by hindering the formation of chloride complexes. The XRD analysis showed that the ashes from Enstedværket CHP underwent dramatic changes in the main mineral compositions: from KCl and K2SO4 in the raw ashes, to quartz and carbonates and sulfates after water washing, and finally to mainly quartz in the ashes after EDR treatment. In relation to the use of the treated bioashes in the production of bricks at sintering temperature 1000 °C, substituting 25% clay in the small brick pellets (~2 g) with the washing-EDR treated bioashes resulted in pellets with higher porosity, higher water absorption, and less total shrinkage compared to the pure clay pellets. The water absorption of the pellets increased with increasing ash content, but decreased with increasing sintering temperature. Increasing sintering temperature also led to the decrease in porosity and the increase in bulk density. In addition, by increasing sintering temperature the leaching of heavy metals from the fired pellets containing bioash, in particular As and Cr, could also be minimized to a level that allows the clay pellets to be reused or landfilled as nonhazardous waste at the end of service life. The bricks also had good material qualities. For instance, when fired at 1100 °C for 1 h, the pellets with 25% treated fly ash from Enstedværket CHP met the water absorption requirement for building bricks in accordance with ASTM C62-13a. When fired at 1100 °C, the pellets with 20% treated ash from Vordingborg CHP showed acceptable leaching of heavy metals such as As, Cd, Cr, Ni, Pb and Zn, allowing the bricks to be used in construction work. The use of the bioashes in the production of clay bricks is technically possible, after being treated first by water washing to extract plant nutrients, and then by EDR to extract easily mobilized Cd and the mobile fraction of other heavy metals to lower the leaching to acceptable low levels. The recycling of MSWI fly ash faces challenges from technical, legislative, environmental and economical aspects. Thus, identifying options allowing use of the resources retained in the ash is necessary. Direct use of MSWI fly ash in the production of bricks leads to air pollution (e.g. the emission of volatile heavy metals) and the loss of metal resources (e.g. Zn), and also causes heavy metal leaching from the bricks themselves. Zn was the metal with the highest concentration in the MSWI fly ash studied, followed by Pb. Water washing was also applied to remove the soluble salts in the MSWI fly ash in the present work. Approximately 19% of the ash was dissolved in water. It was found that Pb and Zn had relatively higher concentrations in the leachate after washing than the other heavy metals, probably due to the presence of chloride complexes of Pb and Zn in the ash. The raw MSWI fly ash and the washed ash were alkaline; whereas EDR could lower pH to the acidic range, resulting in elevated leaching of Cd and Zn after EDR. At same time, the Cr leaching could be reduced, which was related to the pH and redox potential of the treated ash. Up to 59% of Zn and 6% of Pb were extracted by EDR for 7-12 days compared to less than 0.6% extraction by water washing. However, the extraction of Cr was generally low, because Cr was strongly bound in the ash. The major fraction of Cr remained bound in the ash even after different EDR treatments including one, two and three step treatments, involving ash suspension alkalization by the cathode reaction and acidification by the anode reaction and/or water splitting. The Cr extraction rate was improved by combining different electrodialytic cells to achieve first acidification (especially to pH below 4) and then alkalinization generation. The improvement was mainly due to the combined extraction of Cr(III) at low/oxidizing condition (e.g. anode reaction taking place in the ash suspension) and extraction of Cr(VI) at high pH/low oxidizing condition (e.g. cathode reaction taking place in the ash suspension). Thermal treatment was conducted on the pure EDR-treated ash at 1000 °C for 1 h. The results showed that during thermal treatment the slightly acidic to neutral ashes (pH 5-6.5) were realkalinized. The thermal treatment reduced the leaching of most heavy metals by solidification, and possibly also by evaporation; however, the leaching of As and Cr were still problematic and did not meet the limiting values for the ash being reused in construction work. It was found that the removal of Ca by EDR resulted in a decrease in the leaching of Cr after thermal treatment, but an increase in As leaching. However, minimizing leaching from the thermally treated ash (especially of Cr) could be obtained when optimizing the combined water washing and EDR prior to the thermal treatment. In addition, the evaporation of especially Pb during thermal treatment was significantly reduced by water washing and EDR pre-treatment. Handmade bricks (50 mm × 50 mm × 50 mm) incorporating the MSWI fly ash treated after water washing and EDR, had
higher porosity, lower compressive strength and higher soluble salts content compared to the 100% clay brick when sintered at 1000 °C for 6 h. Still the washing-EDR treatment significantly improved the properties of the fired fly ash-clay bricks compared to the properties of the bricks incorporating the untreated ash. The results indicated that the MSWI fly ash could be fit for the studied clay replacement at low substitution ratio i.e. 5%, as the bricks with this substitution met the technical requirements for bricks (properties: weight loss during firing 11.3%; density 1.63 g/cm3; apparent porosity 41%; water absorption 25.5%; and compressive strength 8 N/mm2). The leaching of heavy metals from all the bricks with ash content up to 20% sintered at 1000 °C for 6 h met the requirement for landfilling as mineral waste. Even better was that the fly ash-clay brick with 5% ash content might be reused in construction work at the end of service life as the heavy metal leaching was low enough to allow this, and thus these bricks could be reused directly. Even though washing-EDR treatment reduced the Cr leaching from the fired bricks compared to that from the bricks with the untreated ash, the fine fraction in the ash was shown to significantly contribute to the leaching of Cr. Thus, fractionation of the treated MSWI fly ash was beneficial to its recycling in particular of the less toxic fraction.