WASTE 2H2

Waste to Hydrogen

Evolution of the publications in high impact journals in the relevant research fields

Deliverable No.:	D6.2
Project Acronym:	WASTE2H2
Full Title: Waste to Hydrogen	
Grant Agreement No.:	952593
Work package No.:	6
Work package Title: Scientific and Technological Strategies on Gasification and Hydrogen Technologies	
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Responsible Co-Authors:	
Date:	26/02/2021
Status:	Final
Dissemination level:	Public

Abstract

he purpose of this document is to present the evaluation of the publications of IPPortalegre in high impact journals in the relevant fields during the three years preceding the start date of the project.

Document History

Date	Version	Author(s)	Changes made
26/02/2021	1	Paulo Brito	Final version of the document

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WASTE2H2 has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952593.

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1. Introduction

A list of peer-reviewed publications of IPPortalegre in high-impact journals during the three years preceding the start date of the project (2018, 2019 and 2020) is provided in the present document. The list was divided into the main field of research that are relevant for the purposes of the WASTE2H2 project.

Field	Number of publications
Gasification	50
Torrefaction/Carbonization	7
Anaerobic Digestion	4
Biofuels	10
Fuel Cells	2
Energy Efficiency	5
Pyrolysis	5
Photocatalysis/Electrolysis	2

2. Gasification

"Modeling of fluidized bed gasification: Assessment of zero-dimensional and CFD approaches"

Couto, N., **Silva, V., Monteiro, E**., **Brito, P. S. D**., & Rouboa, A.

Q2

Journal of Thermal Science, 24(4), 378-385. (2015)

https://doi.org/10.1007/s11630-015-0798-7

Abstract: In modeling fluidized bed gasification experiments, equilibrium and CFD models are valuable options. The existence of multi-dimensional effects inside the reactor vessel due to the kinetics of the process and the fluid dynamics phenomena could result in deviation from the zero-dimensional assumption. Complex models integrating kinetics and hydrodynamics are being developed by using a computer fluid dynamics (CFD) approach. The objective of this investigation is to assess and compare the adequacy of zero-dimensional and CFD approaches in modeling fluidized bed gasification regarding a semi-industrial scale (numerical results are validated under experimental runs). Results show that the zero-dimensional model based on the approach of dual stage equilibrium performs reasonably well in adequately predicting the product gas composition at different operating conditions and for different feedstocks, although with quantitative discrepancy. Furthermore, the discrepancy depends on the oxygen content of the oxidation agent and on the steam-to biomass ratio decreasing when these parameters increased. CFD models provide deeper information being able to estimate the syngas composition or other operating parameter at any point of space and time. Despite of some quantitative discrepancy, the zero-dimensional modeling approach is deemed satisfactory from the viewpoint of the determining design conditions simulation.

"Numerical and experimental analysis of municipal solid wastes gasification process."

Couto, N., **Silva, V., Monteiro, E**., Teixeira, S., Chacartegui, R., Bouziane, K., **Brito, P. S. D.**, Rouboa, A.

Applied Thermal Engineering, 78, 185-195. (2015)

https://doi.org/10.1016/j.applthermaleng.2014.12.036

Q2

Abstract: As the quantity of municipal solid waste (MSW) increases with economic growth, problems arise in regard to sustainable management solutions. Thermal treatment presents a valid option for reducing the amounts of post-recycling waste to be landfilled. Incineration technology, besides reducing the total volume of waste and making use of the chemical energy in MSW for power generation, has negative environmental impact from high emission of pollutants. Recent policy to tackle climate change and resources conservation stimulated the development of renewable energy and landfill diversion technology, thereby giving gasification technology development renewed importance. In this work a two-dimensional CFD model for MSW gasification was developed and an Eulerian–Eulerian approach was used to describe the transport of mass, momentum and energy for the solid and gas phases. This model is validated using experimental data from the literature. The numerical results obtained are in good agreement with the reported experimental results.

"Assessment of municipal solid wastes gasification in a semi-industrial gasifier using syngas quality indices"

Couto, N. D., **Silva, V. B., Monteiro, E**., & Rouboa, A.

Q1

Energy, 93(PA1), 864-873. (2015)

https://doi.org/10.1016/j.tsf.2015.09.064

Abstract: In this work a comprehensive two-dimensional CFD model was used in order to assess the potential of syngas produced from gasification of Portuguese MSW (municipal solid waste) by using a semi-industrial gasification plant. An Eulerian–Eulerian approach within the computational fluid dynamics Fluent framework was used to describe the transport of mass, momentum and energy for both solid and gas phases. Pyrolysis was also modeled. Numerical results were validated against experimental ones. Results were in good agreement with each other. Influence of temperature, MSW admission and equivalent ratio on products of gasification and their concentrations were studied. Considering operating conditions influence on the combustible gases, it was concluded that gasification temperature had the greatest influence on syngas heating value. After analyzing syngas composition and other gasification products the best use for a particular produced syngas was investigated. For the MSW used in this work one of the most promising uses for the obtained syngas was for chemical fuel application.

"Hydrogen-rich gas from gasification of portuguese municipal solid wastes"

Couto, N., **Monteiro, E., Silva, V**., & Rouboa, A.

International Journal of Hydrogen Energy, 41(25), 10619-10630. (2016)

https://doi.org/10.1016/j.ijhydene.2016.04.091

Q1

Abstract: Gasification has been identified as a promising method of municipal solid waste (MSW) conversion to energy due to its pollution minimization effects and high overall efficiency. Recent studies have been carried out to produce hydrogen through MSW gasification with promising results. Despite this, it is still necessary to develop mathematical models able to assist the advance of this technology and to make way for large-scale commercialization.

A previously developed and validated numerical model was used to predict and analyze the viability of hydrogen-rich gas generation from MSW gasification in a semi-industrial fluidized bed gasifier. Influence of equivalence ratio, carbon-dioxide-to-MSW ratio, steam-to-MSW ratio, reactor temperature and catalyst used was investigated. The content of hydrogen in the generated gas increased up to 40% with the presence of NiO/MD catalysts, while reducing the tar content and increasing the gas yield. Finally, to assess the capabilities of the Portuguese wastes results were compared with previously studied Portuguese biomass substrates.

"Eulerian - eulerian CFD model on fluidized bed gasifier using coffee husks as fuel"

Ismail, T. M., Abd El-Salam, M., **Monteiro, E.**, & Rouboa, A.

Applied Thermal Engineering, 106, 1391-1402. (2016)

Q1

https://doi.org/10.1016/j.applthermaleng.2016.06.102

Abstract: A two-dimensional CFD computational model has been developed to describe the gasification process of coffee husks within a fluidized bed reactor. The Eulerian - Eulerian method is used for both gas and solid phases to provide an explanation for mass exchange, energy, and momentum. The results were obtained after comparing both the numerical model and the experimental data for validation. The current model also predicts the effects of equivalence ratio and moisture content on gasification temperature, and provides sensitive analysis of the model of the produced syngas composition in addition to the higher heating value and cold gas efficiency. The simulated syngas composition was found to be in good agreement with the experiment. The high moisture content of coffee husk has negative effects on cold gas efficiency and HHV, an effect that decreases as the equivalence ratio increases.

"Hydrodynamic modelling of municipal solid waste residues in a pilot scale fluidized bed"reactor.

Cardoso, J., Silva, V., Eusébio, D., & **Brito, P**.

Q1

Energies, 10(11), 1773. (2017)

https://doi.org/10.3390/en10111773

Abstract: The present study investigates the hydrodynamics and heat transfer behavior of municipal solid waste (MSW) gasification in a pilot scale bubbling fluidized bed reactor. A multiphase 2-D numerical model following an Eulerian-Eulerian approach within the FLUENT framework was implemented. User defined functions (UDFs) were coupled to improve hydrodynamics and heat transfer phenomena, and to minimize deviations between the experimental and numerical results. A grid independence study was accomplished through comparison of the bed volume fraction profiles and by reasoning the grid accuracy and computational cost. The standard deviation concept was used to determine the mixing quality indexes. Simulated results showed that UDFs improvements increased the accuracy of the mathematical model. Smaller size ratio of the MSW-dolomite mixture revealed a more uniform mixing, and larger ratios enhanced segregation. Also, increased superficial gas velocity promoted the solid particles mixing. Heat transfer within the fluidized bed showed strong dependence on the MSW solid particles sizes, with smaller particles revealing a more effective process.

"2nd law analysis of portuguese municipal solid waste gasification using CO2/air mixtures"

Couto, N., **Silva, V., Cardoso, J**., & Rouboa, A.

Q1

Journal of CO2 Utilization, 20, 347-356. (2017)

https://doi.org/10.1016/j.jcou.2017.06.001

Abstract: Urbanization, mainly caused by population growth and industrialization, is causing serious environmental problems. Municipal solid waste (MSW) is one of the major challenges facing the world today. In Portugal the growing volume of MSW has become a central problem for municipalities, due to lack of space and the high costs to solve it. Gasification is starting to be considered as a possible alternative when dealing with municipal wastes. However, first is necessary to overcome some concerns related to the process, such as tar mitigation and carbon dioxide emissions.

The presented study focuses on a second law analysis conducted on Portuguese MSW gasification using carbon dioxide and air mixtures. To do so, a previously developed numerical model, validated using data from a semi-industrial plant, was used to assess carbon dioxide injection. First, influence of operational conditions on syngas exergy values was studied. Exergy values increased close to 6% when equivalent rate was increased from 0.15 to 0.25, steadily dropping with further increase. On the other hand, exergy values appear to steadily increase with carbon dioxide addition (14% when increased from 0 to 1) and reactor temperature (40% when increased from 700 to 900 °C).
Then, the influence of temperature and CO2/MSW ratio on exergy efficiency, tar efficiency and carbon dioxide conversion was investigated. Results showed that both parameters have a positive effect on exergy efficiency. Conversely, CO2/MSW ratio and gasification temperature lead to decreases in both tar exergy efficiency and in carbon dioxide.

"Exergy analysis of Portuguese municipal solid waste treatment via steam gasification"

Couto, N., **Silva, V., Monteiro, E**., & Rouboa, A.

Q1

Energy Conversion and Management, 134, 235-246. (2017)

https://doi.org/10.1016/j.enconman.2016.12.040

Abstract: The presented study focuses on a thermodynamic analysis conducted on steam gasification of Portuguese municipal solid wastes (MSW). Current literature addressing this issue is extremely scarce due to the complexity in handling MSW's heterogeneity. To fill this significant gap, a mathematical model built upon a reliable set of experimental runs from a semi-industrial gasifier was used to evaluate the effects of reactor temperature and steam-to-biomass ratio (SBR) on produced gas and tar content. Results from a previously studied biomass substrate were used as benchmark. Numerical results were validated with both experimental results and existing literature. Increase in gasification temperature led to a clear increase in both exergy values and exergy efficiency. On the other hand, increase in SBR led to a sharp increase in the exergy values when steam was first introduced, leading to relatively constant values when SBR was further increased. Regarding exergy efficiency, SBR led to a clear maximum value, which in the case of forest residues was found at SBR = 1, while for MSW at 1.5. In order to promote a more hydrogen-rich gas, data obtained from the numerical model was used to design an exergy efficiency optimization model based on the response surface method. Maximum hydrogen efficiency was found at 900 °C with a SBR of 1.5 for MSW and 1 for forest residues. Surprisingly, forest residues and MSW presented virtually the same maximum hydrogen efficiency.

"An experimental and numerical study on the miscanthus gasification by using a pilot scale gasifier"

Couto, N. D., **Silva, V. B., Monteiro, E**., Rouboa, A., & **Brito, P**.

Q1

Renewable Energy, 109, 248-261. (2017)

https://doi.org/10.1016/j.renene.2017.03.028

Abstract: This work comprises the study of several mixtures of air with O2, CO2 and steam in a pilot scale gasification plant. Out of eight substrates characteristic of south-central and southern Portugal, *Miscanthus* was chosen for revealing the highest potential for energy generation and for its friendliness from an ecological standpoint. Experiments with *Miscanthus* were performed in a pilot scale reactor and generated results were compared with ones from a numerical model, which consists of a Eulerian-Eulerian approach within the Fluent framework that is able to describe the transport of mass, momentum and energy for both solid and gas phases.

The numerical model was used to compare several gasifying agent mixtures and their impact on syngas composition and respective quality indices under similar operating conditions. The influence of equivalent, steam/biomass and CO2/biomass ratios on syngas produced as well as temperature and cold gas efficiency were studied, and the most suitable application for each mixture was appraised based on the results.

"Hydrogen production using plasma gasification with steam injection"

Favas, J., **Monteiro, E.,** & Rouboa, A.

International Journal of Hydrogen Energy, 42(16), 10997-11005. (2017)

https://doi.org/10.1016/j.ijhydene.2017.03.109

Q1

Abstract: Plasma gasification is a promising gasification technology intended at providing sustainable disposal for various wastes. In this work, a process model was developed to simulate the biomass plasma gasification using Aspen Plus simulator. Effects of critical parameters, including gasification temperature, Equivalence Ratio (ER) and Steam-to-Biomass Ratio (SBR) on the composition of fuel gas were discussed. The model is validated against experimental data and found to be in good agreement. The results indicate that low temperatures are more favourable for the production of hydrogen, while high ER has a negative effect on the hydrogen production. The simulation results also demonstrate that steam injection is a key factor to produce more hydrogen rich gas in the SBR range studied, but had a major effect on CO2 formation. The temperature and the SBR show opposite behavior on the syngas LHV, which is attributed to the CO content in the syngas that increases with temperature and decreases with SBR. Results of plasma gasification show similar syngas LHV trends for the three biomasses cases being the higher syngas LHV obtained for vines pruning. These data are crucial to describe scenarios concerning the potential use of biomass as energy source.

"Assessment of the miscanthus gasification in a semi-industrial gasifier using a CFD model"

Monteiro, E., Ismail, T. M., Ramos, A., Abd El-Salam, M., **Brito, P. S. D**., & Rouboa, A.

Applied Thermal Engineering, 123, 448-457. (2017)

https://doi.org/10.1016/j.applthermaleng.2017.05.128

Q1

Abstract: In this work, a comprehensive two-dimensional computational fluid dynamics model was used in order to assess the potential of syngas produced from gasification of Portuguese miscanthus by using a semi-industrial gasification plant. An Eulerian-Eulerian approach is used in the fluent environment to describe the transport of mass exchange, momentum and energy for both solid and gas phases. The results were obtained after comparing both the numerical model and the experimental data for validation. The simulated syngas composition was found to be in good agreement with the experiment. The effect of equivalent ratio (ER), temperature and steam-to-biomass ratio (SBR) on products of gasification and their concentrations were assessed. The ER has some negative effects on syngas quality (decrease of fuel gases and lower heating value (LHV)) and some positive effect on the carbon conversion efficiency (CCE) and on the reduction of tar content. The reactor temperature has a positive effect on syngas quality (increase of fuel gases, lower heating value and decrease of tars). High temperatures also favor the gasification efficiency. The SBR has some positive effects on syngas quality (increase of H2 content and reduction of tars) and some negative effect on syngas LHV and there are some particular SBR that maximizes the CCE and CGE.

"Multi-stage optimization in a pilot scale gasification plant"

Silva, V., Couto, N., Eusébio, D., Rouboa, A., **Brito, P., Cardoso, J**., & Trninic, M.

International Journal of Hydrogen Energy, 42(37), 23878-23890. (2017)

Q1

https://doi.org/10.1016/j.ijhydene.2017.04.261

Abstract: A 2-D multiphase CFD model was coupled with advanced statistical methods to find the best operating conditions to maximize a set of selected responses that characterize the normal operation of a pilot scale fluidized bed gasifier running Municipal Solid Waste. After using CFD simulations to compute 7 responses at 27 different operating conditions, a single response optimization based on the response surface method was carried out to identify the best operating conditions. Then, the desirability concept was advantageously used to proceed with a multiple optimization where all the responses were targeted under normal industrial conditions. The operating conditions that set the optimized responses not always coincide with the most stable process. To target both optimized and robust conditions a multiple optimization combining the response surface and the propagation of error methods were employed. Finally, the tolerance intervals were reduced to increase the process Cpk and six sigma standards about 20%. New measures to further increase the process performance were identified and the transmitted variation to the response from input factors was computed.

"Modelling higher heating value of different separated fractions from municipal and construction and demolition wastes"

Alves, O., Gonçalves, M., **Brito, P., & Monteiro, E.**

http://algoritmi.uminho.pt/ecos-2018-31st-international-conference-on-efficiency-cost-optimization-simulation-and-environmental-impact-of-energy-systems/

Abstract: Higher heating value (HHV) is an important property of biomass and wastes used to evaluate their potential conversion to useful thermal or electric energy. Because the measurement of this property requires expensive resources and is somewhat time-consuming, many works focused their attention on the determination of mathematic models relating the HHV with the composition of lignocellulosic biomass or other fuel materials, such as their ultimate and proximate analysis. These models can supply appropriate estimates of HHV but only for analogous materials, so they should not be used to compare samples with marked differences in composition or physical and chemical properties. In this work, 9 different separated fractions of municipal and construction and demolition wastes (wood, paper/card, plastics, sewage sludge and mixtures among them) were used to deduce a mathematical expression relating HHV with their contents of carbon, hydrogen, oxygen, nitrogen, sulphur and ash. For this purpose, HHV's, proximate and ultimate analysis were experimentally obtained and the results used to create three different expressions applying linear regression methods. The best expression was selected and validated by comparing deviations among the calculated results and those retrieved from the literature and from experimental measurements regarding different wastes. It was concluded that the best expression was HHV (MJ/kg db) = 0.3845×C+0.8831×H29.1217×S-0.0630×O-1.0063×N+0.3888×ASH-0.2546 (with C, H, S, O, N and ASH in wt% db, considering atomic ratios O/C and H/C within $0.0 \leq O/C \leq 1.2$ and $0.1 \leq H/C \leq 0.2$), giving an average absolute error of 8.5 % and an average bias error of -1.6 %. However, appreciable deviations may be found when estimating the HHV of polyurethane, paper/card, mixtures of paper/plastic and sewage sludge and thus the application of the expression for these materials is questionable.

"A review on occupational risk in gasification plants processing residues of sewage sludge and refuse-derived fuel"

Impact 0,53

Alves, O., Gonçalves, M., **Brito, P., Monteiro,** E., & Jacinto, C.

Paper presented at the Occupational Safety and Hygiene VI - Selected Contributions from the International Symposium Occupational Safety and Hygiene, SHO 2018, 29-34.

https://doi.org/10.1201/9781351008884-6

Abstract: This paper presents a review on Occupational Safety and Health (OSH) issues of gasification plants using residues of sewage sludge and refuse-derived fuel. The survey (2006–2016) consisted of a systematic review of literature retrieved from scientific databases. Despite abundant literature on environmental impacts of gasification plants, few publications focus on OSH aspects. Of these, 16 were considered relevant for the purpose. The results are summarized in a Table that provides a short description and the main findings of each study. It can be concluded that explosion and inhalation of toxic gases are the most common OSH risks reported in gasification processes; apparently, both are considered negligible if safety measures are adopted. Other risks identified comprise the release (and potential inhalation) of heavy metals and harmful tar production, but the main concern is on the environmental impact. Prevention measures mostly include adjusting granulometry to the type of biomass, workers' training, good ventilation and reliable equipment.

"Comparative scaling analysis of two different sized pilot-scale fluidized bed reactors operating with biomass substrates"

Cardoso, **J., Silva**, V., Eusébio, D., **Brito, P**., Hall, M. J., & Tarelho, L.

Q1

Energy, 151, 520-535. (2018)

https://doi.org/10.1016/j.energy.2018.03.090

Abstract: This paper presents a comparative scaling analysis of two different sized pilot-scale fluidized bed reactors operating with biomass substrates. A multiphase Eulerian-Eulerian 2-D mathematical model was implemented, coupled with in-house user-defined functions (UDF) built to enhance hydrodynamics and heat transfer phenomena. The model validation was attained by comparison to experimental data gathered from both reactors. A grid refinement study was carried out for both geometries to achieve an appropriate computational domain. Hydrodynamics was deeply studied for both reactors concerning the scale-up effect. Mixing and segregation phenomena, solid particle distribution and biomass velocity were matters of great concern. Results showed that UDF implementation successfully minimized deviations and increased the model's predictability. The largest deviations measured between experimental and numerical results for syngas composition were of about 20%. Solids mixing and segregation was found to be directly affected by the particles size, density, and superficial gas velocity, with the larger reactor revealing improved mixing ability. Improved mixing occurred for smaller particles size ratio (dbiomass = 3 mm), smaller particles density ratio (ρbiomass = 950 kg/m3), and higher dimensionless superficial gas velocities (U0/Umf=3.5). The larger unit showed an increase in near-wall velocity, lateral dispersion, and bubble size. As for the smaller reactor, higher velocities were obtained at the center region due to a more pronounced wall boundary layer. Similarities were found between the two reactors regarding the bubble distribution, dimensionless average bed pressure drop and biomass velocity vector profiles when dimensionless parameters were employed.

"Improved numerical approaches to predict hydrodynamics in a pilot-scale bubbling fluidized bed biomass reactor: A numerical study with experimental validation"

Cardoso, J., Silva, V., Eusébio, D., **Brito, P**., & Tarelho, L.

Q1

Energy Conversion and Management, 156, 53-67. (2018)

https://doi.org/10.1016/j.enconman.2017.11.005

Abstract: A computational 2-D Eulerian-Eulerian approach was developed to simulate the hydrodynamics and heat transfer of a biomass gasification process in a pilot-scale bubbling fluidized bed reactor. The mathematical model was validated under experimental results collected from fluidization curves gathered at different temperatures in a pilot-scale reactor (75 kWth). Own user defined functions (UDFs) were developed in C programming and included to improve drag and heat transfer phenomena, as well to minimize deviations between experimental and numerical data found in previous works. Mesh selection was achieved by comparing solid fraction and pressure drop contours with grids comprised of different number of cells. A comparative study for particle diameter and inlet gas velocity was conducted for three different biomass feedstocks' and their impact in the mixing and segregation index was studied. Mixing and segregation index were measured by implementing the standard deviation concept. Results indicated that UDFs significantly improved the mathematical model predictions on the reactor's fluidization curves. Biomass and sand particles size and density showed direct influence on the solids distribution along the bed height. Smaller biomass particles revealed faster heat conduction and improved mixing properties.

"Fluid dynamics model on fluidized bed gasifier using agro-industrial biomass as fuel"

Ismail, T. M., Abd El-Salam, M., **Monteiro, E**., & Rouboa, A.

Q1

Waste Management, 73, 476-486. (2018)

https://doi.org/10.1016/j.wasman.2017.06.018

Abstract: The present study shows the experimental and numerical results of thermal gasification of biomass, on the energy potential of agro-industrial waste from the Portalegre region. Gasification tests were performed in a pilot-scale fluidized bed gasifier, in order to study the behavior of peach stones and miscanthus to investigate the effect of gasification temperatures at 750 °C, 800 °C and 850 °C at a constant biomass flow rate of 45 kg/h. In order to optimize the operating conditions of the biomass gasification process, a numerical model is developed namely COMMENT code. This model is a computer model of two dimensions describing the biomass gasification processes in a fluidized bed gasifier using peach stone and miscanthus as fuel. Both phases, solid and gaseous, were described using an Eulerian-Eulerian approach exchanging mass, energy, and momentum. The numerical model results are then compared with experimental results. The produced results show the impact of the increased temperature in the calorific value of the syngas. The tests carried out at 750 °C shown an increase in CO2 and N2 and a decrease of CO in the range of 5% comparing to the tests carried out at 850 °C. In addition, increased temperature favors a decrease in tar production in thermal gasification process. Numerical results shows to be in good agreement with the experimental data.

"Experimental and modeling studies of portuguese peach stone gasification on an autothermal bubbling fluidized bed pilot plant"

Monteiro, E., Ismail, T. M., Ramos, A., Abd El-Salam, M., Brito, P., & Rouboa, A.

Energy, 142, 862-877. (2018)

https://doi.org/10.1016/j.energy.2017.10.100

Q1

Abstract: Among the renewable energies available, biomass constitutes an auspicious option, due to its environmental-friendly character allied to its significant energy supply. As a path to maximize biomass energy efficiency, gasification has been reported as an adequate technology. Numerical models that can predict and optimize the experimental conditions as well as the equipment design for biomass gasification are imperative, towards a cost-saving and sustainable performance. This work shows the experimental and numerical results of thermal gasification of Portuguese peach stone. Assays were performed using a thermal gasification pilot plant with a bubbling fluidized bed at temperatures ranging from 750° C to 850° C with mass flow rates of 30 kg/h to 60 kg/h. A homemade comprehensive two-dimensional CFD model is proposed to optimize the operating conditions of the biomass gasification process. The numerical model results were compared with experimental data and good agreement was found. A parametric study was performed in order to understand the influence of moisture content, steam to biomass ratio and equivalence ratio in the composition of the producer gas. The results of the study showed a negative impact of moisture and equivalence ratio over conversion efficiency and producer gas quality, and a positive impact for steam to biomass ratio which promotes higher calorific values and overall efficiency for the process.

"Co-gasification and recent developments on waste-to-energy conversion: A review"

Ramos, A., **Monteiro, E**., **Silva, V**., & Rouboa, A.

Q1

Renewable and Sustainable Energy Reviews, 81, 380-398. (2018)

https://doi.org/10.1016/j.rser.2017.07.025

Abstract: Biomass is currently seen as a promising renewable energy source, which can be sustainably utilized in the production of fuels and electric energy adding no carbon dioxide to the environment. Co-gasification has unveiled its potential amongst thermal techniques, as a result of the valuable products obtained, strengthening a solid position in the conversion of residues. Thus, the prevention of a complete depletion of non-renewable sources is supported and the effects of their utilization alleviated. Extensive literature review was conducted and, few reports on co-gasification of biomass and wastes were found. In this context, this review addresses their thermal conversion, highlighting issues related to the equipment, operating conditions and physicochemical phenomena involved in such a complex process. Among other conclusions, the most important finding of this work was the synergy often encountered between the two feedstocks, proving co-gasification can overcome several of the individual gasification issues enhancing products quality and yields over biomass or wastes alone, and attesting its environmental-friendly character, with lower greenhouse gas emissions. It was also possible to depict some trends on the effect of biomass and waste blending ratios, as well as elucidating some of the mechanisms involved in their interaction. These are majorly explained by the response of molecules during pyrolysis and by hydrogen transfer from waste polymers to biomass derivatives. Experimental conditions were also assessed, fluidized beds being reported as the most suitable reactors for biomass and wastes, under several different possible combinations of operational parameters. A critical discussion is presented, aiming to contribute to a more profound understanding of this matter, its key points and noteworthy potential.

"Thermochemical Conversion of Waste Tires for Energy Recovery"

Calado, L., Garcia, B., **Brito, P**., Panizio, R., & Lourinho, G.

Innovation, Engineering and Entrepreneurship pp 697-704

https://link.springer.com/chapter/10.1007/978-3-319-91334-6_95

Abstract: The present work studies the possibility of energy recovery by thermal conversion of waste tires, a potential feedstock for combustion and gasification processes. Considering the difficulties of using these residues in isolation, cocombustion and co-gasification tests with acacia and miscanthus biomass were carried out in order to assess the characteristics of these residues as a fuel for thermochemical processes. Co-gasification tests were run in a fixed bed reactor at temperatures of about 800 °C. The results obtained demonstrate the viability of the technology, with the ideal conditions for the production of syngas with higher LHV (3.64 MJ/Nm3) occurring in mixtures with 20% of waste tires. As for co-combustion, tests were performed in a pyro-tubular multi-fuel boiler with temperatures ranging from 400 °C to 500 °C. With respect to gaseous emissions (NOx, NO, and SO2), it was verified that increasing the percentage of tires in the mixture resulted in increased emissions of pollutant gases. These results present a problem since the obtained values are higher than those allowed by the Portuguese law. It was also concluded that gasification is a perfectly adjusted technology for the valorization of waste tires, being able to transform them into a fuel for energy recovery derived from residues with no other use.

"Characterization of Municipal, Construction and Demolition Wastes for Energy Production Through Gasification - A Case Study for a Portuguese Waste Management Company"

Octávio Alves, Jeysa Passos, Paulo Brito, Margarida Gonçalves, Eliseu Monteiro.

Innovation, Engineering and Entrepreneurship pp 619-625

https://doi.org/10.1007/978-3-319-91334-6_84

Abstract: Gasification of wastes is considered a promising alternative for energy generation due to its lower environmental impacts when compared with conventional landfilling and incineration. Valorisation of such wastes improves sustainability of resource management and of energy production. However, an appropriate characterisation of wastes in terms of physical and chemical properties is essential for the prediction of their behaviour during gasification, allowing to identify possible problems for the environment and installed equipment and also to define which materials present a greater energy potential. This study aimed to characterise 10 different fractions from municipal, construction and demolition wastes received in different fluxes by a Portuguese waste management company. These fractions included wood (44.83 wt%), plastic (22.15 wt%), paper/card (0.04 wt%), mixtures of paper and plastic (14.67 wt%) and sewage sludge (18.31 wt%). For this purpose, determination of density, proximate and ultimate analysis, higher heating value (HHV), thermogravimetric profiles and inorganic composition of ashes were performed for each fraction. Analysis revealed that plastics and their mixtures with paper/card possess the highest HHV's (25–45 MJ/kg db), thus exhibiting a greater capacity for energy production. High levels of ashes found in dried sewage sludge (50 wt% db) indicate that a lot of by-product will be generated after gasification, possibly increasing the treatment costs. A gasification unit operating at 50 kg/h and admitting a mixture of all these wastes would generate 109.7 kW of total power, having capacity to receive more waste fluxes along the year.

"Management of municipal and construction and demolition wastes in Portugal: future perspectives through gasification for energetic valorisation"

Q2

Passos, J.,; Alves, O.; **Brito, P.**

International Journal of Environmental Science and Technology volume 17, pages2907–2926(2020)

https://doi.org/10.1007/s13762-020-02656-6

Abstract: The generation and management of wastes constitute today one of the major challenges of societies due not only to the huge amounts that are produced, but also to the need of implementing new treatments that can be more sustainable at an environmental level. The present work explored the production, management and policies adopted in the treatment of relevant typologies of solid wastes in Portugal, in particular, municipal solid wastes and construction and demolition wastes and sewage sludge, and tried to quantify the energetic potential that can be achieved through gasification processes. In addition, a techno-economic study to evaluate the feasibility of the construction and operation of a small-scale gasification plant was also developed. Results indicated that there are various methods which are considered more sustainable for the treatment of such wastes like bio-digestion, pyrolysis and gasification, and which may replace the current techniques of incineration or landfilling that are largely adopted but have caused a number of problems to communities and also to the environment. It was identified a huge potential to valorise these wastes to obtain electricity through gasification, since a significant portion of them are currently disposed of or eliminated in inadequate ways. The economic analysis revealed that it is possible to implement a small-scale gasification plant with financial viability and possible attractive economic results for investors. Construction of these units located in strategic points over the country may contribute for a more sustainable treatment and valorisation of solid wastes.

"A Holistic Review on Biomass Gasification Modified Equilibrium Models"

Ferreira, S., Monteiro, E., Brito, P., & Vilarinho, C.

Energies 2019, 12(1), 160

https://doi.org/10.3390/en12010160

Q1

Abstract: Biomass gasification is realized as a settled process to produce energy in a sustainable form, between all the biomass-based energy generation routes. Consequently, there are a renewed interest in biomass gasification promoting the research of different mathematical models to enlighten and comprehend gasification process complexities. This review is focused on the thermodynamic equilibrium models, which is the class of models that seems to be more developed. It is verified that the review articles available in the literature do not address non-stoichiometric methods, as well as an ambiguous categorization of stoichiometric and non-stoichiometric methods. Therefore, the main purpose of this article is to review the non-stoichiometric equilibrium models and categorize them, and review the different stoichiometric equilibrium model's categorization available in the literature. The modeling procedures adopted for the different modeling categories are compared. Conclusion can be drawn that almost all equilibrium models are modified by the inclusion of empirical correction factors that improves the model prediction capabilities but with loss of generality.

"Comparative 2D and 3D analysis on the hydrodynamics behaviour during biomass gasification in a pilot-scale fluidized bed reactor"

Cardoso, J., Silva, V., Eusébio, D., **Brito, P.,** Boloy, R. M., Tarelho, L., & Silveira, J. L.

Renewable Energy - Volume 131, February 2019, Pages 713-729

Q1

https://doi.org/10.1016/j.renene.2018.07.080

Abstract: 2D and 3D simulations were carried out to predict the whole gasification process behaviour in a pilot-scale bubbling fluidized bed reactor. Special concern for the complex hydrodynamics phenomena within the fluidized bed was undertaken. The implemented multiphase Eulerian-Eulerian mathematical model was validated by comparison to experimental gasification runs and fluidization curves gathered from the pilot-scale fluidized bed. Appropriate 2D and 3D computational domains were achieved by applying a mesh sensitivity study. Solids distribution within the fluidized bed, mixing and segregation phenomena and binary mixture heat transfer were comparatively studied for both configurations. 3D simulations showed improved predicting performance with the experimental results. Also, 3D simulations presented improved segregation degree, while 2D simulations showed improved mixing index, alongside with a tendency to underestimate the reactor heat transfer behaviour. Main findings point to a general good agreement with some close resemblances in the solids distribution between the 2D and 3D simulations whenever quantitative values were considered, while in absolute terms larger discrepancies were seen. The bed expansion was misrepresented at higher superficial gas velocities to a great extent by the 2D configuration. Moreover, it was found that higher superficial gas velocity will induce higher differences between both configurations. Lastly, both configurations successfully described the general tendencies, however, 2D simulations are appropriate every time accuracy is not demanding, whereas 3D simulations should be considered for accurate predictions.

"Techno-economic analysis of olive pomace gasification for cogeneration applications in small facilities"

Cardoso, J., **Silva, V**., Eusebio, D., Trninić, M. R., Carvalho, T., **Brito, P.**

Thermal Science 2019 Volume 23, Issue Suppl. 5, Pages: 1487-1498

Q3

https://doi.org/10.2298/TSCI180726410C

Abstract: A mathematical model approach was employed to simulate olive pomace gasification in a bubbling fluidized bed reactor. To validate the model a set of gasification experiments were performed in a 250 kW quasi-industrial gasifier. The cold gas efficiency of the th gasifier and tar production were evaluated to assess the energy potential of olive pomace while determining its most suitable end-use applications. A techno-economic analysis addressing the comparison of two different commercially manufactured gasifying unit sizes (100 kW and 1000 kW) and a Monte-Carlo sensitivity analysis were employed to assess both the feasibility of each application size and also foresee the main investment risks in conducting olive pomace gasification in small rural facilities. Olive pomace gasification showed to be more suitable for personal household purposes. The low cold gas efficiency (around 20%) makes this producer gas more appropriate for small cogeneration facilities applications. The use of olive pomace residues in gasification showed viable economic performance in small cogeneration solutions at a scale of 1000 kW for agriculture waste-to-energy recovery in olive oil agriculture cooperatives, while 100 kW showed to be unable to reach an economically sustainable scenario. Final remarks point out that despite the feasibility of the venture at a scale of 1000 kW special concerns must be considered regarding the study attractiveness to potential investors.

"Modelling and experimental analysis of a small-scale olive pomace gasifier for cogeneration applications: A techno-economic assessment"

Q3

Cardoso, J., **Silva, V**., Eusébio, D., Carvalho, T., & **Brito, P**.

Renewable EnergyChemical Industry and Chemical Engineering Quarterly 2019 Volume 25, Issue 4, Pages: 329-339

https://doi.org/10.2298/CICEQ190109010C

Abstract: A 2-D numerical simulation approach was implemented to describe the gasification process of olive pomace in a bubbling fluidized bed reactor. The numerical model was validated under experimental gasification runs performed in a 250 kWth quasi-industrial biomass gasifier. The producer gas composition, H2/CO ratio, CH4/H2 ratio, cold gas efficiency and tar content were evaluated. The most suitable applications for the potential use of olive pomace as an energy source in Portugal were assessed based on the results. A techno-economic study and a Monte Carlo sensitivity analysis were performed to assess the feasibility and foresee the main investment risks in conducting olive pomace gasification in small facilities. Results indicated that olive pomace gasification is more suitable for domestic purposes. The low cold gas efficiency of the process (around 20%) turns the process more appropriate for producer gas production in small cogeneration facilities. Olive pomace gasification solutions showed viable economic performance in small cogeneration solutions for agriculture waste-to-energy recovery in olive oil agriculture cooperatives. However, the slender profitability may turn the project unattractive for most investors from a financial standpoint.

"Techno-economic analysis of forest biomass blends gasification for small-scale power production facilities in the Azores"

Cardoso, J., **Silva, V**., Eusébio, D., Azevedo, I. L., Tarelho, L., **Brito, P.**

Q1

Fuel Volume 279, 1 November 2020, 118552

https://doi.org/10.1016/j.fuel.2020.118552

Abstract: The present work assesses the energetic valorisation of forest biomass blends in the archipelago of the Azores, to do so, a multiphase 2-D Eulerian-Eulerian model was employed to simulate forest biomass gasification in a pilot-scale fluidized bed reactor. The numerical model was validated under experimental gasification runs performed in a 250 kWth quasi-industrial biomass gasifier. The potential use of the produced syngas as a complementary energy source for small-scale power production in the Azores was assessed based on the results. The exergy efficiency and tar production of the process were determined. A techno-economic study combining the net present value (NPV), internal rate of return (IRR), and payback period (PBP) followed by a Monte Carlo sensitivity analysis was comparatively performed for two distinct application sizes (100 and 1000 kW) so to gauge which unit size carries enhanced operative feasibility and foresee the main investment risks in conducting forest biomass blends gasification for power production in small facilities. Results revealed that the 100 kW unit was economically impracticable under current market conditions, while the 1000 kW unit showed to be economically feasible with an NPV of 486 k€, IRR of 17.44% and PBP of 7.4 years. The sensitivity analysis predicted a higher risk of failure in the NPV, being highly sensitive to the electricity sales tariff and electricity production. Indeed, forest biomass gasification projects carry great potential when applied to small facilities with economic viability in some economies of scales, withal, special concerns must always be considered regarding the project attractiveness to potential investors.

"An Eulerian model for forest residues gasification in a plasma gasifier"

Ismail, T. M., **Monteiro, E**., Ramos, A., El-Salam, M. A., & Rouboa, A.

Q1

Energy Volume 182, 1 September 2019, Pages 1069-1083

https://doi.org/10.1016/j.energy.2019.06.070

Abstract: A new mathematical model for plasma gasification was adopted and added to the COMMENT homemade code. The COMMENT code is dedicated to coupled transfer applications in the fields of thermal, fluid mechanics and chemical engineering, both solid and gaseous states being assessed. Phenomena like continuity, species transport, heat transfer, turbulence and chemical reactions were taken into account. Plasma gasification of forest residues was simulated within defined conditions and assumptions, the producer gas being monitored and characterized. The presented model was validated against literature data. A high level of agreement between the numerical and the experimental values was achieved, proving that the model is robust and suitable for the proposed goal. This new model requires low computational capacity and allows a wide range of reactor types to be used in the gasification process. A parametric study was also conducted in order to understand the influence of some variables on gasification products and their concentrations along the runs. It was possible to conclude that lower equivalence ratios (ER) favored H2 and CO production as well as lower heating value (LHV), while higher ER values enhanced N2 contents, carbon conversion efficiency (CCE) and minor alterations were observed for CH4 and CO2. H2, N2 and CO2 as well as CCE and cold-gas efficiency (CGE) were also enhanced by higher steam-to-biomass ratios (SBR), while CO content and LHV dropped, CH4 remaining almost unaltered. For higher temperatures H2, CO and N2 levels were improved as well as LHV, whereas CO2 and CGE were reduced and CH4 remained unchanged. The results showed that the model proposed in this study is a promising tool for simulating the plasma gasification process of biomass within a gasifier.

"Parametric studies in the gasification agent and fluidization velocity during oxygen-enriched gasification of biomass in a pilot-scale fluidized bed: Experimental and numerical assessment"

Ismail, T. M., **Monteiro, E.**, Ramos, A., El-Salam, M. A., & Rouboa, A.

Q1

Renewable Energy Volume 147, Part 1, March 2020, Pages 2429-2439

https://doi.org/10.1016/j.renene.2019.10.029

Abstract: The need to achieve renewable alternatives for energy production is pressing and new technologies have been developed. Biomass is a feasible feedstock for thermal conversion techniques like gasification. This technique converts carbonaceous fuels into energy, producing a synthetic gas (syngas) with further commercial uses such as electricity generation, fuels or the chemical industry among others. In this work, a numerical model was developed in order to optimize the experimental parameters in the gasification of agricultural residues. Hence, oxygen content (OC) in the gasifying agent, equivalence ratio (ER) and fluidization velocity were varied so as to assess the effect of each parameter in syngas quality. Lower ER favored higher CO and H2 yields, enhancing also the lower heating value (LHV). Higher fluidization velocity also promoted these features, as well as gasification conversion efficiency (GCE) and carbon conversion efficiency (CCE). Higher OC in the gasifying agent improve syngas quality. The optimal gasification performance was achieved for OC = 40%. The results obtained in this work are essential to describe scenarios relating to the potential use of agricultural residues as a source of energy via gasification.

"Plasma fixed bed gasification using an Eulerian model"

Q1

Ismail, T. M., Ramos, A., Abd El-Salam, M., **Monteiro, E**., & Rouboa, A.

International Journal of Hydrogen Energy Volume 44, Issue 54, 5 November 2019, Pages 28668-28684

https://doi.org/10.1016/j.ijhydene.2019.08.035

Abstract: Gasification of solid waste is considered as a green and sustainable solution to perform energy recovery from several waste streams. This work aims to adapt an Euler-Euler multiphase mathematical model to understand the effects of physical and chemical factors, i.e. equivalence ratio (ER), steam to fuel ratio (SFR), and input plasma power of municipal solid waste (MSW) fixed bed gasification. The model is capable of simulating temperature and velocity fields, as well as gas and solid composition variations inside the reactor. A two-step pyrolysis model is used considering the pyrolysis mechanism of cellulose and plastic components. Drying, pyrolysis, homogeneous gas reactions, and heterogeneous combustion/gasification reactions were also included in the model. It was shown that the proposed model could provide accurate predictions against experimental data with a deviation generally lesser than 10%. Conclusion could be drawn that an ER of 0.3 and an SRF of 0.5 seems to be the most favourable conditions in order to obtain a high-quality syngas. Higher plasma power is favourable to obtain a high-quality syngas. However, the high electric power required penalizes the process efficiency and may compromise the economic viability of a plasma gasification project.

“Assessment of Municipal Solid Wastes Gasification Through CFD Simulation”

Monteiro, E., Couto, N., **Silva, V**., & Rouboa, A.

Innovation, Engineering and Entrepreneurship, Page 662

https://doi.org/10.1007/978-3-319-91334-6_90

Abstract: A two dimensional CFD model for MSW gasification has been used to predict and analyze the viability of the hydrogen generation from MSW gasification. The model is based in an Eulerian-Eulerian approach to describe the transport of mass, momentum and energy for the solid and gas phases. The model is applied to a fluidized bed gasifier to full predict and analyze the viability of the hydrogen generation from MSW gasification taking into account the equivalence ratio and steam-to-waste ratio. Conclusion could be drawn that the increase of equivalence ratio has a negative effect on hydrogen production because the oxidation reactions are favored. The introduction of steam to MSW gasification is favorable for improving hydrogen yield, because it increases the partial pressure of steam inside the reactor which favors the gas-phase reactions.

“Influence of the Biomass Gasification Processes on the Final Composition of Syngas”

Nuno Couto, N.; Rouboa, A.; **Silva, V. ; Monteiro, E**.; Bouziane K.

Energy Procedia Volume 36, 2013, Pages 596-606

https://doi.org/10.1016/j.egypro.2013.07.068

SJR 2019
0.55

Abstract: Interest in the technology of gasification has shown a number of ups and downs since its first appearance. It appears that interest in gasification research correlates closely with the relative cost and availability of liquid and gaseous fossil fuels. Gasification is a versatile thermo-chemical conversion process which produces a gas mixture of H2, CO and CH4 the proportions being determined by the use of air, oxygen or steam as oxidizer, with a concomitant range of heat values, low (4–6 MJ/Nm3), medium (12–18 MJ/Nm3) and high (40 MJ/Nm3). A variety of biomass gasifiers have been developed. Differentiation is based on the means of supporting the biomass in the reactor vessel, the direction of flow of both the biomass and oxidant, and the way heat is supplied to the reactor. Gases formed by gasification are contaminated by some constituents such as particles, alkali metals, nitrogen components, tars, sulfurs and chlorides. The level of contamination varies, depending on the gasification process and the feedstock. Gas cleaning must be applied to prevent erosion, corrosion and environmental problems in downstream equipment. In this work, a global perspective about the producer gas final composition dependence, the so-called syngas, from the biomass, oxidizer, reactor type, temperature and pressure is given based on a literature benchmarking. This study shows that there are some discrepancies in the values given by various authors. This highlights the strong dependence of the syngas final composition from the biomass conditions, type of gasifier and pressure and temperature of the process. Thus, in order to make precise studies on the use of syngas it will be necessary to consider that its composition will be rather constant. The development of mathematical models for numerical simulation fully validated experimentally are strongly desirable and may be a very useful tool to determine the final composition of syngas by changes in initial conditions without laborious and expensive experimental tests.

"Co-gasification of refused derived fuel and biomass in a pilot-scale bubbling fluidized bed reactor"

Pio, D.T.; Tarelho, L.A.C.; Tavares, A.M.A; Matos, M.A.A.; **Silva, V.**

Q1

Energy Conversion and Management Volume 206, 15 February 2020, 112476

https://doi.org/10.1016/j.enconman.2020.112476

Abstract: In this work, direct (air) co-gasification of refused derived fuel with biomass was demonstrated in an 80kWth pilot-scale bubbling fluidized bed reactor. The influence of the process operating parameters, namely average bed temperature between 785 and 829 °C, equivalence ratio between 0.21 and 0.36 and refused derived fuel weight percentage in the fuel mixture (0, 10, 20, 50 and 100 wt%) was analyzed. For the operating conditions used, the process was demonstrated as autothermal and operating under steady-state conditions, with no defluidization phenomena observed. The increase of the refused derived fuel weight percentage in the fuel mixture led to an increase of the methane and ethylene concentration in the producer gas and, consequently, an increase of the producer gas lower heating value, reaching a maximum value of 6.4 MJ/Nm3. In terms of efficiency parameters, cold gas efficiency was found between 32.6 and 53.5% and carbon conversion efficiency between 56.0 and 84.1%. A slight increase of the cold gas efficiency was observed with the increase of the refused derived fuel weight percentage in the fuel mixture. Thus, refused derived fuel co-gasification with biomass was shown as a highly promising process for the valorization of wastes as an energetic resource.

"Composition of producer gas obtained by gasification of pellet mixtures produced with residual lignocellulosic biomass, cork wastes, polymers and polymer derived chars"

Longo, A., Gonçalves, M., Nobre, C., Alves, O., **Calado, L., & Brito, P**.

Innovation, Engineering and Entrepreneurship pp 648-654

https://doi.org/10.1007/978-3-319-91334-6_88

Abstract: In this work, the gasification of pellets produced from residual pine biomass and their mixtures with cork wastes, polymeric wastes and polymer derived char pellets was studied. The gasification tests were performed in a fixed bed downdraft gasifier at the temperatures of 700 °C and 800 °C. The influence of pellet combinations and gasification temperature in the composition and high heating value of the product gas was evaluated. The results were compared with commercially available pine pellets. At 800 °C, all the tested pellet mixtures exhibited higher CO and H 2 concentrations than the commercial pellets, with 9.3% mol CO and 6.2% mol H 2 for the mixture with cork wastes pellets, for example. The high heating value of the product gas for the different pellet mixtures presented values between 1.04 and 3.84 MJ/m 3 , for different gasification conditions. Residual lignocellulosic biomass and mixed wastes have the potential to be used as sustainable raw materials for energy production by gasification. Gasification operational parameters, such as temperature and equivalence ratio are decisive factors in product gas output, that need to be optimized in order to efficiently take advantage of the energy potential from these raw materials. Furthermore, this approach can contribute to the coupling of waste management and energy production through endogenous resources, reducing the deposition of these waste materials in landfills.

“Energy Conversion of Polymeric Residues in Co-Gasification with Pine Biomass in a Downdraft Reactor”

Panizio, R.M., **Duque de Brito, P.S., do Carmo Calado, L.F**.

27th European Biomass Conference and Exhibition – Session 2CV.8.42 – Pages 994 – 998

http://www.etaflorence.it/proceedings/?detail=16449

Abstract: Energy recovery from polymeric waste is mainly carried out in waste incineration plants and cement kilns. The present work studies the possibility of energy recovery by thermal conversion of electrical cable insulation, a raw material that has the potential for gasification processes. Considering the difficulties of using these residues alone and the environmental problems with this gasification, co-gasification tests were performed with pine chips, to evaluate the characteristics of these residues as fuel for thermochemical processes. The co-gasification tests were carried out in a downdraft reactor of fixed bed, at temperatures between 750 and 950 ° C and an installed power of 3 kW. Mixtures of 10 and 20% of electrical cable insulation were used. The results obtained, demonstrate the feasibility of using this technology for the thermochemical energy recovery, with the ideal conditions to produce syngas with higher LHV (more than 5 MJ / Nm^3) occurring in mixtures with 10% mixture of electrically conductive insulation. It was concluded that co-gasification is a perfectly adjusted technology for the recovery of these wastes, being able to transform them into fuel for recovery energy from wastes without other use.

"Techno-Economic Assessment of the Use of Syngas Generated from Biomass to Feed an Internal Combustion Engine"

Copa, J.R.; Tuna, C.E.; Silveira, J.L.; Boloy, R.A.M.; Brito, P.; Silva, V.; Cardoso, J.; Eusébio, D..

Energies 2020, 13(12), 3097

Q2

https://doi.org/10.3390/en13123097

Abstract: The focus of this study is to provide a comparative techno-economic analysis concerning the deployment of small-scale gasification systems in dealing with various fuels from two countries, Portugal and Brazil, for electricity generation in a 15 kWe downdraft gasifier. To quantify this, a mathematical model was implemented and validated against experimental runs gathered from the downdraft reactor. Further, a spreadsheet economic model was developed combining the net present value (NPV), internal rate of return (IRR) and the payback period (PBP) over the project's lifetime set to 25 years. Cost factors included expenses related to electricity generation, initial investment, operation and maintenance and fuel costs. Revenues were estimated from the electricity sales to the grid. A Monte Carlo sensitivity analysis was used to measure the performance of the economic model and determine the investment risk. The analysis showed an electricity production between 11.6 to 15 kW, with a general system efficiency of approximately 13.5%. The viability of the projects was predicted for an NPV set between 18.99 to 31.65 k€, an IRR between 16.88 to 20.09% and a PBP between 8.67 to 12.61 years. The risk assessment yielded favorable investment projections with greater risk of investment loss in the NPV and the lowest for IRR. Despite the feasibility of the project, the economic performance proved to be highly reliant on the electricity sales prices subdue of energy market uncertainties. Also, regardless of the broad benefits delivered by these systems, their viability is still strikingly influenced by governmental decisions, subsidiary support and favorable electricity sales prices. Overall, this study highlights the empowering effect of small-scale gasification systems settled in decentralized communities for electric power generation.

"Thermochemical and Economic Analysis for Energy Recovery by the Gasification of WEEE Plastic Waste from the Disassembly of Large-Scale Outdoor Obsolete Luminaires by LEDs in the Alto Alentejo Region (Portugal)"

Q1

Hermoso-Orzáez, M.J.; Mota-Panizio, R.; **Carmo-Calado, L.; Brito, P.**

Appl. Sci. 2020, 10(13), 4601

https://doi.org/10.3390/app10134601

Abstract: The recovery of urban waste is a social demand and a measure of the energy-environmental sustainability of cities and regions. In particular, waste of electrical origin, waste of electrical and electronic materials (WEEE) can be recovered with great success. The plastic fraction of these wastes allows their gasification mixed with biomass, and the results allow for producing syngas with a higher energy potential. This work allows for obtaining energy from the recovery of obsolete materials through thermochemical conversion processes of the plastic waste from the disassembly of the luminaires by mixing the said plastic waste in different proportions with the biomass of crop residues (olive). The gasification tests of these mixtures were carried out in a downstream fixed-bed drown daft reactor, at temperatures of approximately 800 °C. The results demonstrate the applied technical and economic feasibility of the technology by thermal gasification, for the production of LHV (Low Heating Value) syngas with highest power energy (more than 5 MJ/m3) produced in mixtures of up to 20% of plastic waste. This study was complemented with the economic-financial analysis. This research can be used as a case study for the energy recovery through gasification processes of plastic waste from luminaires (WEEE), mixed with agricultural biomass that is planned to be carried out on a large scale in the Alentejo (Portugal), as a solution applied in circular economy strategies.

"A critical analysis on the gasification of lignocellulosic and polymeric wastes"

Panizio, R.M.; Alves, O.; Gonçalves, M.; **Calado, L.; Brito, P.**

Wastes: Solutions, Treatments and Opportunities III (pp.555-560)

https://www.taylorfrancis.com/chapters/critical-analysis-gasification-lignocellulosic-polymeric-wastes-panizio-alves-gon%C3%A7alves-calado-brito/e/10.1201/9780429289798-88

Abstract: The present study compares the energetic potential of the gasification gas produced from the gasification of lignocellulosic wastes (Eucalyptus) and its co-gasification with polymeric wastes (Refuse-Derivate-Fuel pellets) at an incorporation rate of 30 wt%. The gasification tests were performed using a downdraft reactor, at 800° C, and the gasification gas was collected at equilibrium conditions. The gasification by-products (biochars and tars) were also collected at the end of each test. The results demonstrated that these two types of fuels, may be successfully converted producing a syngas with a heating value exceeding 5 MJ/Nm^3. The results also demonstrate the advantage of adding polymeric waste to the lignocellulosic biomass, since feeding operations are facilitated by mixing those fuels and the calorific value of the gasification gas increased by 6% to a final value of 5.4 MJ/Nm^3.

"A holistic review on biomass gasification modified equilibrium models"

Ferreira, S. **Monteiro, E. Brito**, P. Vilarinho, C.

Q2

Energies 2019, 12(1), 160

https://doi.org/10.3390/en12010160

Abstract: Biomass gasification is realized as a settled process to produce energy in a sustainable form, between all the biomass-based energy generation routes. Consequently, there are a renewed interest in biomass gasification promoting the research of different mathematical models to enlighten and comprehend gasification process complexities. This review is focused on the thermodynamic equilibrium models, which is the class of models that seems to be more developed. It is verified that the review articles available in the literature do not address non-stoichiometric methods, as well as an ambiguous categorization of stoichiometric and non-stoichiometric methods. Therefore, the main purpose of this article is to review the non-stoichiometric equilibrium models and categorize them, and review the different stoichiometric equilibrium model's categorization available in the literature. The modeling procedures adopted for the different modeling categories are compared. Conclusion can be drawn that almost all equilibrium models are modified by the inclusion of empirical correction factors that improves the model prediction capabilities but with loss of generality.

"Experimental analysis of brewers' spent grains steam gasification in an allothermal batch reactor"

Ferreira, S., **Monteiro, E., Brito, P., (...), Calado, L.**, Vilarinho, C.

Q2

Energies 12(5),912

https://doi.org/10.3390/en12050912

Abstract: In this work, brewers' spent grains (BSG) were evaluated and studied in order to obtain a combustible gas by means of allothermal steam gasification. BSG were preprocessed in a rotary dryer and a pelletizer prior to gasification in an indirectly heated batch reactor. BSG characterization was conducted by means of proximate, ultimate, and thermogravimetric analysis, allowing us to conclude that BSG have characteristics comparable to those of regular lignocellulosic biomasses. Gasification tests were performed in an allothermal bench-scale batch reactor in order to determine the effect of temperature and steam-to-biomass ratio (S/B) in the produced gas. The produced gas was mainly composed of 22.8–30.2% H2, 15.1–22.3% CO, and 7.2–11.1% CH4, contributing to a heating value of 8.11–9.0 MJ/Nm3 with the higher values found for a low S/B ratio and for high temperatures. The performance of the process was assessed by evaluating the cold gas and carbon conversion efficiencies. These indicators were found to be in the ranges 47.0%–52.1% and 57.0%–62.7%, respectively. The main conclusion of this work is that the produced gas obtained from BSG steam gasification has sufficient quality to open other options to beer producers to use their own brewing wastes to satisfy their energy needs, allowing them to progress toward the circular economy concept.

“Numerical approaches and comprehensive models for gasification process: A review”

Ramos, A. **Monteiro, E.** Rouboa, A.

Q1

Renewable and Sustainable Energy Reviews, Volume 110, August 2019, Pages 188-206

https://doi.org/10.1016/j.rser.2019.04.048

Abstract: Nowadays, gasification is seen as a worldwide settled technique for sustainably generating energy from residues. Its final product is a synthetic gas which may be used for several purposes such as fueling engines, industry and the transport sector. This technique involves several complex reactions, different thermodynamic regimes and environments, and may be held under a myriad of operational conditions. Thus, simulation tools have become very useful to predict the optimal parameters to be applied and the heating content of the final product, therefore producing the most suitable syngas for the desired utilizations. Computational fluid dynamics (CFD) reduces the time needed to design and implement each gasification experiment, using mathematical approaches and developing specific codes regarding the type of feedstock, reactor utilized and expected atmosphere.

This paper reviewed the major works on numerical methods for gasification and co-gasification of feedstocks, such as biomass, waste and fossil fuels, published in the last two decades. A thorough explanation of the solid and gaseous phases, their interconnections and behavior was presented, while relating the characteristics of the main methods to the final product obtained. Major trends were identified as well as some suggestions regarding future perspectives were done. Kinetic, thermodynamic and computational fluid dynamic models were seen to be preferred concerning the study of syngas production from distinct types of feedstocks. Also, biomass and coal were the most frequently used feedstocks, with 37% and 24% of the total share, respectively. Relative to the gasifier type, fluidized beds were used in almost 50% of the assessments, followed by entrained beds, mostly used for coal gasification. Only major trends could be identified for some of the experimental conditions applied, due to the high variances seen for different feedstocks or reactor features. This review supports the need to continue developing new models and adapting the existing ones in order to reach broader conclusions, since distinct parameters afford completely different outcomes.

"Techno-economic analysis of a biomass gasification power plant dealing with forestry residues blends for electricity production in Portugal"

Cardoso, J. **Silva, V**. Eusébio, D.

Q1

Journal of Cleaner Production, Volume 212, 1 March 2019, Pages 741-753

https://doi.org/10.1016/j.jclepro.2018.12.054

Abstract: In 2017, deadly wildfires flared across central and north of Portugal. Following these events, the Government released a set of forestry policies promoting the increase of the currently installed forest biomass combustion thermal power plant capacity. In this study, we conduct a techno-economic analysis of an 11 MW gasification power plant, as a cleaner alternative to traditional combustion plants, dealing with forest biomass blends in Portugal central region. The analysis is built based on existing literature review and evaluation reports concerning investment projects in biomass-to-energy power plants. A spreadsheet economic model combining net present value (NPV), internal rate of return (IRR) and payback period (PBP) is developed over the plant's lifetime period of 25 years. Cost factors incurred in initial investment, amortizations, fixed assets and working capital investments, financial income, operation and maintenance costs, employees and structure costs. Revenues are generated from selling electricity to the grid. A Monte Carlo sensitivity analysis is employed to gauge the economic model performance and investment risk. Lastly, an assessment of the environmental impact, noxious emissions and future prospects to this biomass-based energy conversion process are addressed. Results predict the feasibility of the project, with an NPV of 2.367 M€, an IRR of 8.66% and PBP of 23.1 years. Sensitivity analysis foresees affordable risks for investors, and that the project's NPV is highly sensitive to the electricity sales price and electricity production. Despite the viability of the project delivered by the economic model, the economic performance is strongly reliant on revenues from electricity sales regulated by uncertain tariffs and reimbursements. Thus, special concerns must be considered regarding the project attractiveness to potential investors.

"An Eulerian model for forest residues gasification in a plasma gasifier"

Ismail, T.M., **Monteiro, E**., Ramos, A., El-Salam, M.A., Rouboa, A.

Q1

Energy. 182, pp. 1069-1083

https://doi.org/10.1016/j.energy.2019.06.070

Abstract: A new mathematical model for plasma gasification was adopted and added to the COMMENT homemade code. The COMMENT code is dedicated to coupled transfer applications in the fields of thermal, fluid mechanics and chemical engineering, both solid and gaseous states being assessed. Phenomena like continuity, species transport, heat transfer, turbulence and chemical reactions were taken into account. Plasma gasification of forest residues was simulated within defined conditions and assumptions, the producer gas being monitored and characterized. The presented model was validated against literature data. A high level of agreement between the numerical and the experimental values was achieved, proving that the model is robust and suitable for the proposed goal. This new model requires low computational capacity and allows a wide range of reactor types to be used in the gasification process. A parametric study was also conducted in order to understand the influence of some variables on gasification products and their concentrations along the runs. It was possible to conclude that lower equivalence ratios (ER) favored H2 and CO production as well as lower heating value (LHV), while higher ER values enhanced N2 contents, carbon conversion efficiency (CCE) and minor alterations were observed for CH4 and CO2. H2, N2 and CO2 as well as CCE and cold-gas efficiency (CGE) were also enhanced by higher steam-to-biomass ratios (SBR), while CO content and LHV dropped, CH4 remaining almost unaltered. For higher temperatures H2, CO and N2 levels were improved as well as LHV, whereas CO2 and CGE were reduced and CH4 remained unchanged. The results showed that the model proposed in this study is a promising tool for simulating the plasma gasification process of biomass within a gasifier. A new mathematical model for plasma gasification was adopted and added to the COMMENT homemade code. The COMMENT code is dedicated to coupled transfer applications in the fields of thermal, fluid mechanics and chemical engineering, both solid and gaseous states being assessed. Phenomena like continuity, species transport, heat transfer, turbulence and chemical reactions were taken into account. Plasma gasification of forest residues was simulated within defined conditions and assumptions, the producer gas being monitored and characterized. The presented model was validated against literature data. A high level of agreement between the numerical and the experimental values was achieved, proving that the model is robust and suitable for the proposed goal. This new model requires low computational capacity and allows a wide range of reactor types to be used in the gasification process. A parametric study was also conducted in order to understand the influence of some variables on gasification products and their concentrations along the runs. It was possible to conclude that lower equivalence ratios (ER) favored H2 and CO production as well as lower heating value (LHV), while higher ER values enhanced N2 contents, carbon conversion efficiency (CCE) and minor alterations were observed for CH4 and CO2. H2, N2 and CO2 as well as CCE and cold-gas efficiency (CGE) were also enhanced by higher steam-to-biomass ratios (SBR), while CO content and LHV dropped, CH4 remaining almost unaltered. For higher temperatures H2, CO and N2 levels were improved as well as LHV, whereas CO2 and CGE were reduced and CH4 remained unchanged. The results showed that the model proposed in this study is a promising tool for simulating the plasma gasification process of biomass within a gasifier.

"Process optimization and robustness analysis of municipal solid waste gasification using air-carbon dioxide mixtures as gasifying agent"

Cardoso, J., **Silva, V.,** Eusébio, D.

Q1

International Journal of Energy Research, 43(9), pp. 4715-4728

https://doi.org/10.1002/er.4611

Abstract: In this work, a computational fluid dynamics (CFD) model was coupled with an advanced statistical strategy combining design of experiments (DoE) and the Monte Carlo method to comparatively optimize and test the robustness of two municipal solid waste (MSW) gasification processes one using air-carbon dioxide (CO2) mixtures as a gasifying agent and the other using air alone. A 3k full factorial design of 18 computer simulations was performed using as input factors for air-CO2 mixtures the equivalence ratio and CO2-to-MSW ratio, while MSW feeding rate and air flow rate were used for air gasification. The selected responses were CO2, H2, CO, and CnHm generation, CH4/H2 and H2/CO ratios, carbon conversion, and cold gas efficiency (CGE). Findings were that DoE allowed determining the best-operating conditions to achieve optimal syngas quality. Monte Carlo identified the best-operating conditions reaching a more stable high-quality syngas. Air-CO2 mixture gasification showed enhanced responses with major improvements in CO2 conversion and CGE, both up to a 13% increase. The optimal operating conditions that set the optimized responses showed to not always imply the most stable set of values to operate the system. Finally, this combined optimization process performance revealed to grant professionals the ability to make smarter decisions in an industrial environment.

"Numerical investigation of optimum operating conditions for syngas and hydrogen production from biomass gasification using Aspen Plus"

Tavares, R., **Monteiro, E.**, Tabet, F., Rouboa, A.

Q1

Renewable Energy, 146, pp. 1309-1314

https://doi.org/10.1016/j.renene.2019.07.051

Abstract: This study is dedicated to present a reliable numerical methodology using Aspen Plus process simulator capable of performing a sensibility analysis of the downdraft gasification of Portuguese forest residues. Effects of critical parameters, including gasification temperature and steam-to-biomass ratio (SBR) on composition of the produced gas are discussed. The sensibility analysis is conducted using Aspen Plus simulator incorporating Fortran subroutines. The model is validated by experimental data and found to be in good agreement. The results of the sensibility analysis performed using air as gasification agent indicate that higher temperatures are favourable for a produced gas with higher hydrogen content and heating value. The simulation results also demonstrate that the use of steam as gasification agent allows increasing the hydrogen content and heating value of the produced gas in comparison to the use of air as gasifying agent. The knowledge of this data is decisive to the development of projects concerning the use of Portuguese forest residues as energy source.

“Co-Gasification of Sewage Sludge Mixed with Waste Wood in Different Proportions”

Octávio Alves, **Luís Calado**, Roberta M. Panizio, Santa M. Santos, Maria M. Gonçalves, **Eliseu Monteiro and Paulo Brito**

Journal Proceedings, 2019, v.38 – 1, pág 9

https://doi:10.3390/proceedings2019038009

Abstract: Co-gasification experiments with mixtures in various proportions of waste wood (WW) and sewage sludge (SS) were performed in a downdraft gasifier, in order to evaluate process performance and properties of gas and chars. Addition of SS improved the energy conversion efficiency and product gas yield, and minimised the formation of tars. Char production was greater, with formation of agglomerations inside the reactor. The optimal waste mixture contained 87.5 wt.% WW and 12.5 wt.% SS, generating a product gas yield of 2.9 m^3/kg waste with a calorific value of 4.8 MJ/m^3, and a tar production of 4.7 g/kg waste.

"Co-Combustion of Waste Tires and Plastic-Rubber Wastes with Biomass Technical and Environmental Analysis"

Carmo-Calado, L.; Hermoso-Orzáez, M.J.; Mota-Panizio, R.; Guilherme-Garcia, B.; **Brito, P**.

Sustainability. 2020; 12(3):1036.

Q2

https://doi.org/10.3390/su12031036

Abstract: The present work studies the possibility of energy recovery by thermal conversion of combustible residual materials, namely tires and rubber-plastic, plastic waste from outdoor luminaires. The waste has great potential for energy recovery (HHV: 38.6 MJ/kg for tires and 31.6 MJ/kg for plastic). Considering the thermal conversion difficulties of these residues, four co-combustion tests with mixtures of tires/plastics + pelletized Miscanthus, and an additional test with 100% Miscanthus were performed. The temperature was increased to the maximum allowed by the equipment, about 500 °C. The water temperature at the boiler outlet and the water flow were controlled (60 °C and 11 L/min). Different mixtures of residues (0–60% tires/plastics) were tested and compared in terms of power and gaseous emissions. Results indicate that energy production increased with the increase of tire residue in the mixture, reaching a maximum of 157 kW for 40% of miscanthus and 60% of tires. However, the automatic feeding difficulties of the boiler also increased, requiring constant operator intervention. As for plastic and rubber waste, fuel consumption generally decreased with increasing percentages of these materials in the blend, with temperatures ranging from 383 °C to 411 °C. Power also decreased by including such wastes (66–100 kW) due to feeding difficulties and cinder-fusing problems related to ash melting. From the study, it can be concluded that co-combustion is a suitable technology for the recovery of waste tires, but operational problems arise with high levels of residues in the mixture. Increasing pollutant emissions and the need for pre-treatments are other limiting factors. In this sense, the thermal gasification process was tested with the same residues and the same percentages of mixtures used in the co-combustion tests. The gasification tests were performed in a downdraft reactor at temperatures above 800 °C. Each test started with 100% acacia chip for reference (like the previous miscanthus), and then with mixtures of 0–60% of tires and blends of plastics and rubbers. Results obtained for the two residues demonstrated the viability of the technology, however, with mixtures higher than 40% it was very difficult to develop a process under stable conditions. The optimum condition for producing a synthesis gas with a substantial heating value occurred with mixtures of 20% of polymeric wastes, which resulted in gases with a calorific value of 3.64 MJ/Nm3 for tires and 3.09 MJ/Nm3 for plastics and rubbers.

"Thermochemical and Economic Analysis for Energy Recovery by the Gasification of WEEE Plastic Waste from the Disassembly of Large-Scale Outdoor Obsolete Luminaires by LEDs in the Alto Alentejo Region (Portugal)"

Manuel Jesús Hermoso-Orzáez; Roberta Mota-Panizio; **Luis Carmo-Calado; Paulo Brito**.

28th European Biomass Conference and Exhibition, 2CV.3.16, 422 – 433

http://www.etaflorence.it/proceedings/?detail=17584

(10.5071/28thEUBCE2020-2CV.3.23)

Abstract: In the last few years, a lot of wildfires flared across central and north of Portugal, namely in 2017 which caused many victims. Following these events, the Government released a set of forestry policies promoting the increase of the currently installed forest biomass combustion thermal power plant capacity. The present study conducted a comparison between two gasifiers, as a cleaner alternative and CO2 zero emissions to traditional combustion plants, dealing with forest biomass blends in Portugal's central region. Gasification is currently a promising technology that enables the conversion of biomass into valuable syngas for energy production, achieving better efficiencies and lower environmental impacts when compared with traditional treatments like combustion or incineration. The experiments were carried out to evaluating the process performance and to analyse the properties of product gas at the end, between the two downdraft gasifiers. Results predict that syngas produced in the PP20 gasifier presents values of calorific power in the order of 5 MJ/Nm^3, instead, the Prototype presents 3.7 MJ/Nm3. On the other hand, the PP20 gasifier obtainable an E / R (equivalence ratio) close to 0.32 and for the Prototype gasifier, the E/R was close to 0.40. From the above, the difference between both processes regarding the equivalence ratio and the amount of air entering the reactor is not similar, still, the higher concentrations of carbon dioxide and nitrogen presents in the synthesis gas, demonstrates that the Prototype needs more energy (combustion reactions) to maintain the gasification temperature.

“Biomass Gasification - A Comparison of Syngas Yield Between Two Downdraft Gasifiers”

Carmo-Calado, L., Mota-Panizio, R., Hermoso-Orzáez, M.J., **Brito, P.**

28th European Biomass Conference and Exhibition, 2CV.3.16, 422 - 433

http://www.etaflorence.it/proceedings/?detail=17741&mode=topic&categories=0&items=%2D%2D&searchstring=Hermoso-Orz%E1ez&limit=0

(10.5071/28thEUBCE2020-2CV.3.16)

Abstract: Urban waste management and recovery are a social demand and, in some way, a measure of the energy and environmental sustainability of cities and regions. To a large extent it is the responsibility of all and in particular of the City Councils as managers of urban waste generated by citizens. In particular, waste of electrical origin, luminaires, cables, bulbs are in the hands of specialized managers who seek to use them by valuing them or recovering them energetically. The plastic fraction of these wastes is really significant and allows their gasification mixed with biomass residues, for the production of synthesis gas. This paper studies the possibilities of energy recovery by thermal conversion of plastic waste from the disassembly of street lighting luminaires by mixing said plastic waste in different proportions with Biomass from crop residues (Olive), as raw material to apply energy recovery processes by gasification. Taking into account the difficulties of using these wastes in isolation, gasification tests were carried out with pine and olive biomass chips, to evaluate the characteristics of these wastes as a fuel for thermochemical processes. Co-gasification tests were performed in a downstream fixed bed reactor, at temperatures of approximately 700 ° C. The results obtained demonstrate the applied viability of the technology, with the ideal conditions for the production of LHV synthesis gas plus high (more than 5 MJ / Nm3) that are produced in mixtures with 10% and 20% of plastic waste of electrical and electronic equipment (WEEE). It was concluded that gasification is a perfectly adjusted technology for the recovery of plastic waste from dismantled obsolete luminaires, with a high index of plastic material, being able to transform them into a fuel for the recovery of energy derived from waste without other use. This study was complemented with the financial and environmental economic analysis. Using it as a case study for the potential of luminaire residues from the technological reconversion to LED that is planned to be carried out on a large scale in the Alentejo Region (Portugal), as a circular economy solution, through the recovery and valorization of biomass and industrial waste.

"Gasification of Biomass and Plastic Waste from the Disassembly of Public Lighting Luminaires for Energy Valorization. Case Study of Circular Economy Applied to the Alentejo Region in Portugal"

Hermoso-Orzáez, M.J., Mota-Panizio, R., **Carmo-Calado, L., Brito, P.**

28th European Biomass Conference and Exhibition, 2CV.3.16, 422 - 433

http://www.etaflorence.it/proceedings/?detail=17584

(10.5071/28thEUBCE2020-2CV.3.16)

Abstract: Urban waste management and recovery are a social demand and, in some way, a measure of the energy and environmental sustainability of cities and regions. To a large extent it is the responsibility of all and in particular of the City Councils as managers of urban waste generated by citizens. In particular, waste of electrical origin, luminaires, cables, bulbs are in the hands of specialized managers who seek to use them by valuing them or recovering them energetically. The plastic fraction of these wastes is really significant and allows their gasification mixed with biomass residues, for the production of synthesis gas. This paper studies the possibilities of energy recovery by thermal conversion of plastic waste from the disassembly of street lighting luminaires by mixing said plastic waste in different proportions with Biomass from crop residues (Olive), as raw material to apply energy recovery processes by gasification. Taking into account the difficulties of using these wastes in isolation, gasification tests were carried out with pine and olive biomass chips, to evaluate the characteristics of these wastes as a fuel for thermochemical processes. Co-gasification tests were performed in a downstream fixed bed reactor, at temperatures of approximately 700 ° C. The results obtained demonstrate the applied viability of the technology, with the ideal conditions for the production of LHV synthesis gas plus high (more than 5 MJ / Nm3) that are produced in mixtures with 10% and 20% of plastic waste of electrical and electronic equipment (WEEE). It was concluded that gasification is a perfectly adjusted technology for the recovery of plastic waste from dismantled obsolete luminaires, with a high index of plastic material, being able to transform them into a fuel for the recovery of energy derived from waste without other use. This study was complemented with the financial and environmental economic analysis. Using it as a case study for the potential of luminaire residues from the technological reconversion to LED that is planned to be carried out on a large scale in the Alentejo Region (Portugal), as a circular economy solution, through the recovery and valorization of biomass and industrial waste.

"Energy Recovery via Thermal Gasification from Waste Insulation Electrical Cables (WIEC)"

Mota-Panizio, R.; Hermoso-Orzáez, M.J.; **Carmo-Calado, L.;** Campos, V.A.F.d.; Silveira, J.L.; Gonçalves, M.M.; **Brito, P.**

Applied Sciences. 2020; 10(22):8253

https://doi.org/10.3390/app10228253

Q1

Abstract: The recovery of noble metals from electrical wires and cables results in waste materials such as polyvinyl chloride (PVC) and polyethylene (PE), that is, waste insulation electrical cables (WIEC), which have been processed by gasification for energy recovery. This study focused on the effect of blending the ratio of WIEC on the gasification feedstock composition and the lower heating value (LHV) of produced syngas, through controlled tests and tests under different loads on the generator. The controlled gasification experiments were carried out at blending ratios between pine biomass and WIEC of 90:10, 80:20, and 70:30 and with pine biomass only (100%). For the loads gasification, the experiments were carried out at a blending ratio of 80:20. The controlled experimental results presented that the highest hydrogen content, approximated 17.7 vol.%, was observed at a blending ratio of 70:30 between pine biomass and WIEC and the highest LHV of syngas was observed at a blending ratio of 90:10, with 5.7 MJ/Nm3. For the load gasification experiments, the results showed that the highest hydrogen content was obtained with a load of 15 kW in the generator, approximately 18.48 vol.% of hydrogen content, and the highest LHV of synthesis gas was observed during the 5 kW test, with 5.22 MJ/Nm3. Overall, the new processing of waste insulation electrical cables using a downdraft gasification reactor demonstrates great promise for high quality syngas production.

3. Torrefaction/Carbonization

"A brief assessment on the application of torrefaction and carbonization for refuse derived fuel Upgrading"

Nobre, C., Gonçalves, M., Vilarinho, C.

Lecture Notes in Electrical Engineering, 505, pp. 633-640.

https://doi.org/10.1007/978-3-319-91334-6_86

Q3

Abstract: Refuse derived fuel (RDF) represents a very robust and endogenous resource that has the potential to minimize landfilling of solid waste, reduce greenhouse gas emissions through its biogenic component and contribute to national energy provision whilst diversifying solid fuel supplies. This waste derived fuel can be produced from different waste streams after significant mechanical and biological processing. In spite of their processing, these waste derived fuels still have a high degree of heterogeneity, presenting variable fuel properties and some negative characteristics such as high moisture, ash and chlorine contents. Although RDF is used for energy generation in some high energy demanding industrial applications or dedicated energy recovery facilities, its physical-chemical characteristics can result in significant technical and environmental problems that may benefit from an upgrading treatment. Torrefaction and carbonization are thermal treatments that have the potential to upgrade RDF, producing a waste derived char with reduced moisture and chlorine contents, more homogeneous and friable, which are characteristics of great importance for feeding systems in gasification and combustion facilities. Using waste derived chars could result in major environmental and waste management advantages, with potential to help with the waste management crisis, reducing waste volume and corresponding to the present European guidelines for energy recovery from wastes, fitting perfectly in the concept of circular economy.

“Hydrothermal Carbonization of Refuse Derived Fuel”

Nobre, C., Alves, O., **Durão, L.,** Vilarinho, C., & Gonçalves, M.

Conference: 27th European Biomass Conference & Exhibition, EUBCE 2019At: Lisbon, Portugal

https://doi.org/10.5071/27THEUBCE2019-3CO.15.1

Abstract: Hydrothermal carbonization (HTC) was employed as an upgrading thermochemical conversion process for Refuse Derived Fuel (RDF). The effect of process temperature and residence time on the main characteristics of the produced hydrochars was studied. Results illustrated that the HTC process yielded hydrochars with upgraded characteristics such as reduced ash content (between 3.3 and 4.8 wt.%, db) and increased high heating value (between 25.2 and 28.1 MJ/kg, db) when compared with the original feedstock. Hydrochars also presented reduced chlorine contents, with the process reaching a chlorine reduction of 56 % at 300 ºC for 120 minutes. The produced hydrochars presented enhanced fuel properties when compared with the original RDF sample, as such, HTC could be applied as an upgrading tool for a very heterogenous and abundant fuel resource, that in most cases does not present adequate fuel characteristics.

“Carbonisation as a pre-treatment for RDF wastes prior to gasification”

O. Alves, R. Panizio, M. Gonçalves, J. Passos, L. Calado, E. Monteiro, P. Brito

Wastes: Solutions, Treatments and Opportunities III - 1st Edition

https://www.taylorfrancis.com/chapters/carbonisation-pre-treatment-rdf-wastes-prior-gasification-alves-panizio-gon%C3%A7alves-passos-calado-monteiro-brito/e/10.1201/9780429289798-86

Abstract: The present work is intended to evaluate carbonisation as a pre-treatment for heterogeneous wastes containing polymeric fractions, before their gasification for energy production. Carbonisation had an upgrading effect in the raw wastes by yielding chars with higher apparent density and an improved behaviour during feeding operations. The performance of the gasification process was compared for the raw wastes and the corresponding biochars. The results obtained indicate that carbonisation helped to improve this performance by increasing the calorific value of syngas, and the process efficiency. Gasification of the chars produced less tars and gaseous HCl which is a positive effect concerning maintenance operations and overall costs. Therefore, the carbonisation pre-treatment can be seen as a valid option to be integrated in a gasification process to convert wastes into energy especially for low density wastes with high chlorine contents.

“Hydrothermal torrefaction of mixtures of biomass and hydrocarbon-rich sludge in the presence of fossil fuels”

Oliveira, A.P., Gonçalves, M., **Durão, L.**, Vilarinho, C.

Lecture Notes in Electrical Engineering, 505, pp. 705-711

https://doi.org/10.1007/978-3-319-91334-6_96

Q3

Abstract: A new process for the torrefaction of mixtures of biomass and oily sludges is proposed. A fossil fuel (gasoline or diesel) was added to mixtures of biomass and hydrocarbon-rich sludge (10:1), and this mixture was subject to distillation until all liquids are recovered. The fossil fuel partially dissolved the sludge components and promoted their evenly distribution over the biomass particles. During distillation, the fossil fuel and all the distillable components present in the biomass and sludge were collected and the mixture was subject to temperatures at which a considerable transformation of the non-distillable fraction occurred. The biomass lost water and suffered partial decomposition and rearrangement to yield biochars with HHV of 23.6 and 33.2 MJ/kg. The original biomass had a HHV of 17.9 MJ/kg, but the hydrothermal torrefaction process as well as the fortification with heavy hydrocarbons from the oily sludge significantly increased its calorific value. The distillable liquids were recovered in the form of two immiscible liquid phases: (a) an organic phase mainly composed by the added fossil fuel but also containing the nonpolar volatile components present in the sludge and the biomass, and (b) an aqueous phase that contained the free and emulsified water present in the biomass and in the sludge, but also the water and polar organic components released from the mixture during this thermal treatment. This process takes place at atmospheric pressure and temperatures lower than 300 °C and can be applied to different sludges with high carbon content to promote their energetic valorization.

“Torrefaction and carbonization of refuse derived fuel: Char characterization and evaluation of gaseous and liquid emissions”

Nobre, C. Alves, O. Longo, A. Vilarinho, C. Gonçalves, M.

Q1

Bioresource Technology August 2019, Article number 121325

https://doi.org/10.1007/978-3-319-91334-6_96

Abstract: Refuse derived fuel containing non-hazardous industrial wastes was subjected to torrefaction and carbonization in an industrial furnace. The RDF samples were heated at 300 °C and 400 °C, for 30 min, yielding solid products (chars) as well as gases and liquids. Proximate and ultimate composition, mineral composition, chlorine content and high heating value were determined for the original sample and the produced chars. Thermal treatment produced RDF chars with carbon contents of 61.6 and 80.2 wt%, and high heating values of 19.9 and 23.5 MJ/kg, that could be further upgraded by washing with water to reduce ash and chlorine concentrations and improve calorific value. Gas products were composed of carbon dioxide and carbon monoxide with minor amounts of hydrogen. Methane was only detected in the gas produced at 400 °C. The process generated liquid products rich in organic compounds that represent potential in further energy or material recovery.

"Upgrading of refuse derived fuel through torrefaction and carbonization: Evaluation of RDF char fuel properties"

Nobre, C., Vilarinho, C., Alves, O., Mendes, B., Gonçalves, M.

Q1

Energy, 181, pp. 66-76

https://doi.org/10.1016/j.energy.2019.05.105

Abstract: Refuse derived fuel (RDF) is produced in large amounts but its heterogeneous nature and low calorific value reduce the potential for energetic valorization of this material.

In this work, the torrefaction and carbonization of RDF was studied in a temperature range of 200–400 °C and residence times from 15 to 60 min, yielding chars with increased density, high heating value (HHV), carbon content, ash content and fixed carbon. Leaching experiments showed that some inorganic components like calcium or chlorine could be removed from the RDF char, upgrading its fuel quality. For temperatures in the torrefaction range (200 °C and 250 °C), energy yields were higher than 96.3% and process energy efficiencies were higher than 85%, but the HHV of the RDF chars were lower than 19.4 MJ kg−1. In the carbonization range (300 °C to 400 °C) it was possible to obtain RDF chars with HHV in the range of 20.1–26.2 MJ kg−1, with energy yields from 84.5 to 91.7% and process energy efficiencies from 70.8 to 79.2%. The obtained results showed that thermochemical processing can be used to upgrade RDF thus promoting sustainable solutions for its management and valorization.

“Characterization of hydrochar and process water from the hydrothermal carbonization of Refuse Derived Fuel”

Nobre, C.; Alves, O.; Durão, L.; Şen, A.; Vilarinho, C.; Gonçalves, M.

Q1

Waste Management Volume 120, 1 February 2021, Pages 303-313

https://doi.org/10.1016/j.wasman.2020.11.040

Abstract: In this study, hydrothermal carbonization (HTC) was used as a thermochemical conversion process to upgrade Refuse Derived Fuel (RDF). The effect of process temperature (250 °C, 275 °C and 300 °C), residence time (30 min and 120 min), and RDF-to-water ratio (1:15 and 1:5) on the main characteristics of the produced hydrochars and process waters was assessed. The HTC process yielded hydrochars with enhanced fuel properties when compared to the original feedstock, namely higher carbon content and heating value. The hydrochars also presented reduced oxygen and ash contents. The hydrochar produced at 300 °C for 120 min presented the lowest ash content (3.3 wt%, db) whereas the highest heating value was found for the hydrochar obtained at 275 °C for 120 min (28.1 MJ/kg, db). The HTC process was also responsible for a significant reduction in chlorine concentration, showing dechlorination efficiencies between 69.2 and 77.9%. However, the HTC process generated acidic process waters with high COD values (maximum 27.2 gO2/L), which need to be further managed or valorized. Energy calculations were also performed, revealing that lower water amounts, lower temperatures, and longer residence times, represent optimal conditions for higher hydrochar yields and consequently good process efficiencies.

4. Anaerobic digestion

"Experimental biogas production and biomethane potential of swine wastewater among different production stages"

Lourinho, G., **Brito, P.S.D., Rodrigues, L.F.T.G.**

Q3

Lecture Notes in Electrical Engineering, 505, pp. 633-640.

https://doi.org/10.1007/978-3-319-91334-6_92

Abstract: Effluent streams originating from swine production can be a major cause of point-source pollution and very dangerous for the surrounding environment. In this work, biogas and biomethane potential of swine-derived effluents were assessed under mesophilic conditions (37 °C) among different production stages (Farrowing, Gestation, Weaners, and Fattening) in order to investigate the suitability of anaerobic digestion as a treatment technology and energy recovery tool. Anaerobic biodegradability of the different wastewaters were also evaluated in order to better understand the degradation patterns of each waste stream. The specific methane yields for each substrate wastewater were successfully determined gravimetrically and ranged from 293.9 ± 31.6 mL CH4.gVS added^{-1} for Gestation, 248.0 ± 246.6 mLCH4.gVS added^{-1} for Fattening, and 172.4 ± 1.62 mLCH4.gVS added^{-1} for Weaners. Farrowing wastewater presented no detectable biomethane production in the studied conditions probably due to very low organics content. Anaerobic biodegradability results showed that wastewaters from Gestation (60.28%) had a higher biodegradability index when compared with Fattening (37.96%) and Weaners (45.97%) stages. The results obtained in this work should be encouraging for on-farm energy recovery and anaerobic digestion technology viewed as an important contributor to alleviate the increasing energy demand within the swine industry. However, as indicated by biodegradability data, biological treatment does not comprise a complete solution and should be complemented with other treatment methods.

"Spatial multicriteria gis-based analysis to anaerobic biogas plant location for dairy waste and wastewater treatment and energy recovery (Barcelos, NW Portugal)"

Rodrigues, C., Rodrigues, A.C., Vilarinho, C., Alves, M., Alonso, J.M.

Q3

Lecture Notes in Electrical Engineering 505, pp. 626-632

https://link.springer.com/chapter/10.1007%2F978-3-319-91334-6_85

Abstract: Intensification, concentration and specialization of dairy cow farms originate many activity by-products, such as wastewater and slurry which implies treatment costs, reduce environmental quality and promote social conflicts between the urban and rural population. These (by)products present a high potential for energy recovery from biogas produced in anaerobic digestion processes, thus contributing to sustainable development. This study is focused on the development of a GIS-based spatial support decision system that supports Multicriteria Analysis and Weighted Hierarchical Analysis (AHP) models aiming to identify site locations with appropriate conditions for the implementation of biogas production units, using waste and wastewater produced by the dairy cow farms in Barcelos municipality (NW Portugal). This spatially explicit model considers environmental, social and economic factors, as well as, legal location constraints tested with a consistent sensitivity analysis of the modelling processes and results. The results indicate sites with appropriate conditions for the location of biogas production units, considering the minimal distance to the dairy cow farms, electric and road networks, in higher areas with forest land cover and maximizing the distance from the urban spaces, as well as, from the river/ground water surfaces and agricultural/ecological reserves. In the next studies it´s relevant to explore biogas units dimensioning concerns, explore other complementary biomass sources in anaerobic (co)digestion solutions and expand collected spatial data to spatial decision support system during future biogas units operation phase.

“Economic Evaluation of the Feasibility When Installing a Biogas Plant for Treatment of Slaughterhouse Wastewater”

I.C. Gato, R.M. Panizio, L**.F.C. Calado and P.S.D. Brito**

Journal Proceedings, 2019, v. 38 – 1, pág 5

https://doi:10.3390/proceedings2019038005

Abstract: The process of anaerobic digestion generates biogas filled with CH4, this gas may be harnessed to produce electricity, heating and even used to produce biofuel. An evaluation of the economic viability of the implementation of a digestion unit was done, by applying this principle at a slaughterhouse in Alto Alentejo. The project was scaled to process about 151.000 m3/year, it has an estimated cost of over 337.000 euros. The evaluation was made with an investment from the company itself, investment programs and with recycling of the heat, obtaining a return on investment period of 10, 6 and 2 years respectively.

"Potential of Biogas Production in Anaerobic Co-digestion of Opuntia ficus-indica and Slaughterhouse Wastes"

Roberta Mota Panizio, **Luís Filipe do Carmo Calado**, Gonçalo Lourinho, **Paulo Sérgio Duque de Brito**, Juliana Bortoli Mees

Waste and Biomass Valorization volume 11, pages 4639–4647(2020)

Q2

https://doi.org/10.1007/s12649-019-00835-2

Abstract: This study assessed the co-digestion of slaughterhouse wastewater (SWW) with Opuntia fícus-indica (OFI) under semi-continuous conditions. Four different mixing ratios were studied at mesophilic temperature (38 ± 1°C): 100% SWW, 75% SWW/25% OFI, 25% SWW/75% OFI and 100% OFI. Process parameters such as biogas production, methane content, redox potential, pH, alkalinity, NH4-N, and VFA were used to infer differences in the bioreactors. Biodigester 2 (75% SWW and 25% OFI) presented the best cumulative biogas yield and methane content with 86 L and 57% (v/v), respectively. Inhibition of the biogas production process was observed in the remaining reactors. The results showed that the co-digestion of SWW with OFI residues improved process performance in terms of biogas production. This improvement demonstrated that OFI could be applied as a novel co-substrate in systems digesting wastewaters that contain high levels of nitrogen compounds.

5. Biofuels

"Advanced biodiesel production technologies: Novel developments"

Q1

Lourinho, G., & **Brito, P.**

Reviews in Environmental Science and Biotechnology, 14(2), 287-316. (2015)

https://doi.org/10.1007/s11157-014-9359-x

Abstract: Biodiesel, i.e. a mixture of monoalkyl esters of long chain fatty acids derived from renewable biological sources such as vegetable oils has in recent years emerged as an alternative fuel for transportation sector. The conventional method of producing biodiesel is through homogeneous catalytic transesterification; however, increased production costs associated with downstream purification steps have led to the development of more cost-effective and environmental friendly technologies. These advanced production technologies involve heterogeneous or enzymatic catalysts to produce biodiesel, as well as no catalysts in supercritical conditions. Heterogeneous catalytic systems can ease the separation of biodiesel from the reaction mixture along with the possibility of catalyst recovery, potentially leading to lower production costs; enzymatic catalysts give the same advantages, but transesterification can be carried out in milder conditions and with a wider range of feedstocks. Biodiesel synthesis in supercritical conditions composes another alternative to conventional methods due to higher reaction rates, shorter reaction times, and simpler biodiesel separation steps. Nevertheless, mass transfer limitations caused by diffusion problems between phases represent an hindrance for future establishment of these technologies, calling for the development of novel methods to intensify the process. These process intensification technologies include ultrasound irradiation, microwave heating, use of co-solvents, and membrane reactors. The main focus of this review is to discuss recent advances as regards to biodiesel production technologies, devoting a special attention to the use of novel catalysts, diversified feedstocks, besides an analysis of main operational parameters of transesterification processes.

“Assessment of biomass energy potential in a region of portugal (Alto Alentejo)”

Lourinho, G., & Brito, P.

Q1

Energy, 81, 189-201. (2015)

https://doi.org/10.1016/j.energy.2014.12.021

Abstract: This work focuses on assessing the potential for generation of biomass residues from agroforestry sources in a region of Portugal (Alto Alentejo), within the scope of energy valorization of the biomass by means of combustion technologies. The model uses a GIS-based method to estimate the technical potential of biomass based on current cartographic and statistical data. The analyzed components related to the biomass potential are: effective biomass area (in ha), biomass availability (in dry t/year) and energy potential (in GJ/year). The potential of agricultural and forest residues in Alto Alentejo is estimated to be 4000 dry t/year and 40,000 dry t/year, respectively. This amount of biomass corresponds to an energy potential of 158,000 GJ/year, which is equivalent to 100% of the combined consumption of electricity in three out of the nine municipalities covered in this study. A preliminary analysis on the suitability of the location and characteristics of a 9 MW biomass power plant in the region is made; alternative solutions and most representative species are also discussed. It was concluded that not enough biomass is available to supply the energy facility and that the most promising option for the region is the combustion of residues in small scale units.

"Biomass resources in Portugal: Current status and prospects"

Ferreira, S., **Monteiro, E., Brito, P**., & Vilarinho, C.

Renewable and Sustainable Energy Reviews, 78, 1221-1235. (2017)

https://doi.org/10.1016/j.rser.2017.03.140

Q1

Abstract: Portugal relies to a very large extent on imports to meet its energy needs. The predominant energy source is oil, which comes in its entirety from other countries. Renewables now are the second most important energy source being hydropower the most important domestic source of energy. Since more than one third of the territory is forests, biomass is one of the most potential renewable energy sources. This paper presents the scope, potential and technologies related to the use of biomass resources. The study also discusses the biomass projects undertaken by the government and non-government organizations, plans and strategies to promote the biomass. The current status of biomass resources shows that the total potential estimated for various sectors of the country is of 42,489.7 GW h/year. The study also reveals one overexploited biomass resource such as forest biomass (if all the predicted biomass power plants enter into the running phase) and underexploited biomass resources such as municipal solid wastes, waste waters and animal manures. The future prospects for biomass are the embodied in the EU and national strategies for the RES sector, which estimates an average annual growth of 5% for installed capacity and 1% for the power production.

"Assessment of the Use of Forest Biomass Residues for Bioenergy in Alto Alentejo, Portugal: Logistics, Economic and Financial Perspectives"

Guilhermino, A., Lourinho, G., **Brito, P**., & Almeida, N.

Q2

Waste Biomass Valorization 9, 739–753 (2018).

https://doi.org/10.1007/s12649-017-9830-3

Abstract: Purpose

This paper presents a GIS-based assessment of the logistics aspects of forestry biomass residues utilization with the prospect of implementing a biomass plant in Alto Alentejo, a region of Portugal.

Methods

The method follows a cost minimization approach and focuses on the cost calculation of each energy unit generated (in €/MWh), as well as the demonstration of the main economic and financial statements within the project framework. Three municipalities are selected as candidate sites for the biomass plant: Avis, Crato and Portalegre; and the conversion technologies considered are fixed bed combustion (GC/ST), fluidized bed combustion (FBC/ST), and integrated biomass gasification (BIG/CC).

Results

Results show that the most suitable municipality for the implementation of a biomass plant is Portalegre, with average electricity production costs of 95, 98 and 133 €/MWh for each considered technology. The assessment also reveals that the power plant configurations studied are financially unattractive due to negative profitabilities. However, sensitivity analysis indicates that good economic performances can be achieved by considering larger biomass plants.

Conclusions

Biomass power generation in dedicated plants can be economically sustainable in Alto Alentejo, but may not be the most suitable option for the region taking into account the available biomass potential.

"Biomass production of poplar short rotation coppice over five and six rotations and its aptitude as a fuel"

Štochlová, P., Novotná, K., Costa, M., Rodrigues, A.

Biomass and Bioenergy, pp. 183-192

https://doi.org/10.1016/j.biombioe.2019.01.011

Q1

Abstract: Cultivations of poplar short rotation coppices (SRC) over five/six 3-year rotation cycles of three clones of Populus nigra and one interspecific commercial hybrid clone were studied in the Czech Republic at three sites with different environmental conditions. Two sites were planted in 1998 and the other was planted in 2002. This study focused on the evaluation of the growth and biomass yields, and on the biomass aptitude to be used as a fuel. Plant mortality, ranging between 10% and 100%, was found as a determinant variable for SRC management. Biomass yield decreased comparatively with earlier harvests, with only the commercial clone delivering productivity levels higher than 11 Mg ha−1.yr−1. The sixth harvest was applied to a single mid-level site quality profile, marginal to food cultivations. This site was subjected to an intensive management during the first four rotations with fertilization, herbicide application and soil discing. These treatments were central to assure the high plant survival rate after the sixth rotation with adequate biomass productivity. The number of shoots per plant was higher in the site chosen for extension of lifecyle, supporting the hypothesis that this variable, by facilitating resprouting, allows a cultivation to withhold further rotations. The harvested biomass was found appropriate to be used as a fuel. The results suggest that the sustainability of SRC poplar cultivations can be achieved under lifecycles longer than 20 years, under 3-year rotation cycles, with proper clones, site and management practices.

"Fast determination of lignocellulosic composition of poplar biomass by thermogravimetry"

Rego, F., Soares Dias, A.P., Casquilho, M., Rosa, F.C., Rodrigues, A.

Q1

Biomass and Bioenergy, pp. 375-380

https://doi.org/10.1016/j.biombioe.2019.01.037

Abstract: The evaluation of the amount of lignocellulosic polymeric components of woody biomass is fundamental to assess its adequacy to produce energy or chemicals. Classic techniques for quantification of these components are slow and laborious, and modern expeditious techniques such as thermogravimetry (TG) have allowed for new and accurate measurement methodologies. TG was used to analyze woody biomass and lignocellulosic composition was assessed through deconvolution of rate of mass loss curves with a pseudo-component model. The quantification of hemicelluloses, cellulose and lignin was performed for nine different poplar genotypes grown as a short rotation coppice (SRC) in Portugal and Belgium. The average composition was (% mass, dry basis) 23% hemicelluloses, 49% cellulose and 27% lignin, with the remaining 1% ash. The classic determination of lignin (Klason) allowed to comparable content (29%). Moreover, TG results agree with published data obtained by conventional wet techniques for poplar wood. The usefulness of the application of TG for lignocellulosic content determination was verified, allowing useful and simple characterization of biomass for thermochemical conversion processes. SRCs are envisaged as an auspicious renewable source of woody biomass, and TG can be a valuable tool to improve the knowledge of factors related to the influence of genetic and environmental conditions on biomass quality.

"Strategies for the design of domestic pellet boilers"

Ribeiro, P., Vilarinho, C., Ferreira, M., (...), Fraga, L., Teixeira, J.

Lecture Notes in Electrical Engineering 505, pp. 668-674

https://link.springer.com/chapter/10.1007/978-3-319-91334-6_91

Q3

Abstract: Domestic and industrial heating are amongst the most attractive applications for biomass as it combines high efficiency and ease-of-use. Boilers and furnaces in this range are usually of simple design and control algorithm while expected to operate over a wide range of thermal loads, typically from up 30% of the nominal load. Such constrainments often limit the overall efficiency of biomass use. In addition, from the manufacturing point of view, a product with flexibility of operation would provide a quasi-universal solution for a wide range of applications.

"Waste-to-energy technologies applied for refuse derived fuel (RDF) valorisation"

Ribeiro, A., Soares, M., Castro, C., (...), Vilarinho, C., Carvalho, J.

Lecture Notes in Electrical Engineering 505, pp. 641-647

https://link.springer.com/chapter/10.1007%2F978-3-319-91334-6_87

Q3

Abstract: Refuse Derived Fuel (RDF) is a solid fuel made after basic processing steps or techniques that increase the calorific value of municipal solid waste (MSW), commercial or industrial waste materials. Therefore, energy production from RDF can provide economic and environmental benefits as it reduces the amount of wastes sent to landfill and allows the energy recovery from a renewable source.

In this work, it was studied the application of waste-to-energy technologies to RDF valorisation, namely pyrolysis and gasification. This study intended to evaluate the effect of temperature and different technologies (gasification and pyrolysis) in gas production, gas composition and mass conversion of RDF. Experiments of RDF gasification and pyrolysis were performed in a laboratory scale fixed bed gasifier, under different conditions.

The effect of reaction temperature was studied at 450, 600 and 750 °C in pyrolysis experiments and at 750 °C and 850 °C in gasification. Results showed that, for the same operational conditions, pyrolysis was more efficient at 750 °C. At this temperature, it was obtained a syngas of 11.2 MJ/m3 and a specific gas production of 0.43 m3 syngas/kg RDF. Results also proved that, for the same operational conditions, the rise of temperature improved gas production ratio (Nm3/kg RDF), gas low heating value (LHV) and mass conversion. Regarding to gas production ratio the utilization of air at equivalence ratio (ER) of 0.6 induced the formation of 1.5 m3 gas/kg RDF. Differently, steam gasification only allowed the production of 0.5 m3 gas/kg RDF. Mass conversion and carbon conversion achieved almost 100% in air gasification at highest molar ratio.

"Insights for the Valorization of Biomass from Portuguese Invasive Acacia spp. in a Biorefinery Perspective"

Correia, R.; Quintela, J.; Duarte, M.P.; Gonçalves, M.

Q1

Forests 2020, 11(12), 1342

https://doi.org/10.3390/f11121342

Abstract: Acacia spp. are widespread all over the Portuguese territory, representing a threat to local biodiversity and to the productivity of the forest sector. The measures adopted in some countries for their eradication or to control their propagation are expensive, have been considered unfeasible from practical and economical perspectives, and have generated large amounts of residue that must be valorized in a sustainable way. This review brings together information on the valorization of bark, wood, leaves, flowers, pods, seeds, roots, and exudates from Acacia spp., through the production of high-value bioactive extracts (e.g., antioxidant, antimicrobial, anti-inflammatory, antidiabetic, antiviral, anthelmintic, or pesticidal agents, suitable to be explored by pharmaceutical, nutraceutical, cosmetics, and food and feed industries), its incorporation in innovative materials (e.g., polymers and composites, nanomaterials, low-cost adsorbents), as well as through the application of advanced thermochemical processes (e.g., flash pyrolysis) and pre-treatments to decompose biomass in its structural components, regarding the production of biofuels along with valuable chemicals derived from cellulose, hemicellulose, and lignin. The knowledge of this research is important to encourage an efficient and sustainable valorization of Acacia spp. within a biorefinery concept, which can bring a significant economic return from the valorization of these residues, simultaneously contributing to forest cleaning and management, to reduce the risk of fires, and to improve the social-economic development of rural areas.

"The relationship between oil prices and the Brazilian stock market"

Q2

Ferreira, P.; Pereira, É.; Silva, M.

Physica A: Statistical Mechanics and its Applications Volume 545, 1 May 2020, 123745

https://doi.org/10.1016/j.physa.2019.123745

Abstract: Crude oil remains a very important product not only because of its regular use, but also because it is a very important financial asset, influencing the economy as a whole. In this paper, we assess how WTI oil price shocks are related with the Brazilian economy as a whole, but also with each of the listed companies in Ibovespa, searching for the relationships with different economic activities. Based on the Detrended Cross-Correlation Analysis correlation coefficient, which allows us to analyse the impacts for different time scales, we conclude unsurprisingly that the most affected sectors are those most related with the use of oil. However, another important result is the significant correlation between oil price shocks and the returns of the financial sector, showing this particular sector's exposure to oil, i.e., this is one of the sectors most correlated with oil returns. This is relevant not only for investors but also for authorities, because possible future oil shocks could have a high impact on the Brazilian financial sector.

6. Fuel Cells

"Targeting optimized and robust operating conditions in a hydrogen-fed proton exchange membrane fuel cell"

Silva, V., Eusébio, D., Cardoso, J., Zhiani, M., & Majidi, S.

Q1

Energy Conversion and Management, 154, 149-156. (2017)

https://doi.org/10.1016/j.enconman.2017.10.053

Abstract: Response Surface Methodology (RSM) when combined with the Propagation of Error (PoE) approach offers an efficient robust design able to find the best operating conditions to simultaneously maximize power density and reduce normal operation variability in a hydrogen-fed Proton Exchange Membrane Fuel Cell (PEMFC). To proceed with the statistical analysis, a central composite design with 20 experimental runs (6 central points were used to assess the experimental error) was adopted to inspect which factors have significant effects and how they interact each other. This allowed generating a polynomial function to determine the maximum power density at 1415 mW/cm2. Taking advantage of the desirability concept and using the PoE measure as a response, a multiple optimization under different restrictions was carried out defining a new set of operating conditions able to target the maximum possible power density at the most robust conditions (1074 mW·cm−2 at 55 °C, 50% RHC and 25 Psi). Then, actions were carried out to narrow even more the tolerance intervals towards more ambitious standards. Reducing the standard deviation from input factors through the use of adequate controlling measures led to a decrease of almost 50% in the tolerance intervals. This is an useful methodology to help the PEMFC normal operation more repeatable and predictable under its lifetime by combing both optimization and robustness goals.

"Effect of MEA activation method on the long-term performance of PEM fuel cell"

Taghiabadi, M.M. Zhiani, M. **Silva, V.**

Applied Energy Volume 242, 15 May 2019, Pages 602-611

Q1

https://doi.org/10.1016/j.apenergy.2019.03.157

Abstract: In this paper, the influence of activation procedure on the long-term performance of membrane electrode assembly (MEA) is investigated. The MEAs are activated by most commonly used procedures; constant voltage and constant current. After activation, MEAs are implemented under 9000 aging cycles. During aging process, MEAs performance is evaluated using polarization curves, electrochemical impedance spectroscopy and cyclic voltammetry. The obtained results show that the activated MEA by constant current method shows an average voltage decay of 11.33 μV/cycle at 1 A/cm2, compared to 4.4 μV/cycle for the activated MEA by constant voltage procedure. This is due to the more reduction of electrochemical surface area for the activated MEA by constant current method (32% vs. 19%). Also, after 9000 degradation cycles, more severe platinum nanoparticles agglomeration is seen in the cathode catalyst layer of activated MEA by constant current procedure. This shows that MEA activation by constant current activation method not only need to the longer activation time, but also causes higher catalyst layer degradation.

7. Energy efficiency

"Study and optimization of the energy profile of the meat industry in the region of alentejo, Portugal"

Alves, O., **Brito, P., Lopes, P**., & Reis, P.

Progress in Clean Energy, Volume 1 pp 135-152

https://doi.org/10.1007/978-3-319-16709-1_9

Impact 0,45

Abstract: Today, the meat processing industry plays an important role in boosting the economy of the region of Alentejo, Portugal, which possesses a strong economic linkage to rural traditional activities. However, several problems have been detected relating to an efficient use of the energy in their productive processes, leading to excessive and unnecessary consumptions, increasing bills and therefore costs of final products, reducing company's competitiveness and causing increased emissions of greenhouse gases to the atmosphere.

The aim of this study is to characterize energy consumption of the meat processing industry in Alentejo, to understand where excesses are being committed and at the same time to identify opportunities for improvement of energy performance in the productive process. For this purpose data were collected through a field survey within a sample of companies and the respective findings were statistically analysed. Subsequently a study of the technical–economic impact of a set of efficiency measures was evaluated to reduce energy consumption and cost.

Results obtained showed that it is in the refrigeration systems and heat boilers that it is possible to achieve the largest reductions in energy consumptions and energy over costs, which may go up to 7 % (savings on consumption) and 19 % (savings on cost) through the implementation of efficiency measures with a payback period of less than 11 years.

"Measurement and classification of energy efficiency in HVAC systems"

Alves, O., **Monteiro, E., Brito, P., & Romano, P.**

Q1

Energy and Buildings, 130, 408-419. (2016)

https://doi.org/10.1016/j.enbuild.2016.08.070

Abstract: Climate control systems typically account for a substantial part of energy consumption in commercial buildings. The obligations established in global agreements as well as regulations and legislation that limit the energy consumption and greenhouse gases emissions gave a novel importance to the HVAC systems rating. This paper describes various indicators for assessing the energy performance of HVAC systems by defining the concepts involved and presenting calculation procedures. Various methods are used, from the basic indicators (*EER*, *COP*) to the most sophisticated (*SEER*, *SCOP*), which are due to the need to include more parameters to determine the level of energy efficiency accurately and to adjust it to the actual operation of the equipment.

A case study is presented in order to calculate the indicators of actual systems in Europe and to assess developments by geographical location. A difference between the results of the various indicators when changing the geographical location and weather conditions that affect the systems was noticeable, which can lead to misconceptions regarding the energy efficiency. It is therefore important to correctly use the indicators that best fit the location, a task that is not usually performed by the manufacturers.

"Energy consumption as a condition for per capita carbon dioxide emission growth: The results of a qualitative comparative analysis in the European Union"

Q1

Loures, L. Ferreira, P.

Renewable and Sustainable Energy Reviews Volume 110, August 2019, Pages 220-225

https://doi.org/10.1016/j.rser.2019.05.008

Abstract: The problematic of climatic changes and the respective consequences raises the need to discuss the problem and define measures to control and/or reverse them. Because one of the causes of climatic changes is the emission of greenhouse gases, the European Union defined the reduction of emissions as a main concern as well as increasing efficiency in the energy sector. With the objective of analysing the main conditions affecting the growth of per capita emissions, this paper uses a fuzzy-set qualitative comparative analysis (fsQCA). Based on a sample of data from 2010 to 2014, the conditions evaluated were: i) GDP growth; ii) change in the share of GDP relating to private consumption; iii) change in the share of GDP relating to public consumption; iv) change in the share of GDP on investment; v) and energy consumption growth. The main drivers contributing to reduced emissions were the crisis and energy consumption. Evaluation of the main factors affecting emissions growth is the main contribution of this study. Considering that economic growth is an obvious goal, the European Union must design measures encouraging investment in more efficient and less pollutant technologies, which is also in accordance with OECD sustainability goals.

“Comparative Analysis between Hydrous Ethanol and Gasoline C Pricing in Brazilian Retail Market”

Murari, T. B., Filho, A. S. N., Pereira, E. J. A. L., **Ferreira, P**., Pitombo, S., Pereira, H. B. B., . . . Moret, M. A.

Q2

Sustainability 2019, 11(17), 4719

https://doi.org/10.3390/su11174719

Abstract: The global energy landscape is rapidly changing, including the transition to a low carbon economy and the use of liquid biofuel. The production of liquid biofuel has emerged as an alternative to the use of fossil fuels for purposes of energy conservation, carbon emission mitigation and agricultural development. In this article we study the co-movements between hydrous ethanol and gasoline C in the Brazilian retail market. A multi-scale cross correlation analysis was applied to the Average Retail Margin time series of hydrous ethanol for fifteen relevant retail markets in Brazil to analyze the competitiveness of hydrous ethanol towards gasoline C. The empirical results showed a remarkable different behavior between hydrous ethanol and gasoline C, for any time scale, regardless of geographical distance or regional differences.

"Effects of renewable energy on landscape in Europe: Comparison of hydro, wind, solar, bio-, geothermal and infrastructure energy landscapes"

Frolova, M., Centeri, C., A., Brito,P., . . . Roth, M.

Q2

Hungarian Geographical Bulletin, 68(4), 317-339.

https://doi.org/10.15201/hungeobull.68.4.1

Abstract: Landscape quality has become a fundamental issue in the development of renewable energy (henceforth abbreviated RE) projects. Rapid technological advances in RE production and distribution, coupled with changing policy frameworks, bring specific challenges during planning in order to avoid degradation of landscape quality. The current work provides a comprehensive review on RE landscapes and the impacts of RE systems on landscape for most European countries. It is based on a review by an interdisciplinary international team of experts of empirical research findings on landscape impacts of RE from thirty-seven countries that have participated in the COST Action TU1401 Renewable Energy and Landscape Quality (RELY).

8. Pyrolysis

"Pyrolysis of lipid wastes under different atmospheres: Vacuum, nitrogen and methane"

Durão, L., Gonçalves, M., Oliveira, A., Nobre, C., Mendes, B., Kolaitis, T., & Tsoutsos, T.

Paper presented at the WASTES - Solutions, Treatments and Opportunities II - Selected Papers from the 4th Edition of the International Conference Wastes: Solutions, Treatments and Opportunities, 2017, 425-430. (2018)

https://doi.org/10.1201/9781315206172-67

Abstract: Pyrolysis of high acidity olive oil, olive husk oil and animal fat was carried out under different atmospheres (vacuum, N2 and CH4), at constant temperature and different residence times. Bio-oils were the main pyrolysis products, with mass yields from 55.2% to 88.9%. The use of nitrogen or methane atmospheres led to an increase in the formation of gas products (14.1% to 26%), while increasing the residence time resulted in higher yields of gases and solids. The pyrolysis bio-oils contained 54.4% to 88.7% (w/w) of distillable liquids, collected as a light fraction and a heavy fraction. Both fractions were analysed by GC-MS to determine the hydrocarbon profiles and identification of functional groups. Vacuum pyrolysis promoted the formation of low molecular weight liquids while the use of a methane atmosphere increased the relative concentration of aliphatic components in the bio-oil.

"Catalyzed pyrolysis of SRC poplar biomass. Alkaline carbonates and zeolites catalysts"

Soares Dias, A.P., Rego, F., Fonseca, F., (...), Rosa, F., Rodrigues, A.

Energy 183, pp. 1114-1122

https://doi.org/10.1016/j.energy.2019.07.009

Q1

Abstract: Poplar biomass of nine different genotypes, from short rotation coppice, was pyrolyzed in a fixed bed reactor using several solid catalysts. Pine bark was used as reference for uncatalyzed pyrolysis. Pyrolysis tests were performed for temperatures in the range 425–500 °C, selected from the thermal degradation profiles obtained by thermogravimetry under N2 flow. All the analyzed poplar genotypes showed similar pyrolysis behavior, with the highest bio-oil yield (53% average value) being obtained for the highest tested temperature (500 °C). In analogous conditions, the pine bark resulted in higher bio-char yields than poplar biomass, due to its larger lignin content.

Catalyzed pyrolysis carried out at 500 °C using 10% of catalyst (Wcat/Wbiomass) for H-ZSM5 and FCC (spent catalyst from Fluid Catalytic Cracking unit) zeolites, and Mg and Na carbonates, showed improved gasification with slightly lower liquid production. The FCC catalyst promoted the lowest depreciation of bio-oil yield with the highest decrease of acid functional groups. All the used catalysts were effective to lessen the acidic components of the produced bio-oils thus having a beneficial effect on the pyrolysis liquid products.

“Low-temperature pyrolysis products of waste cork and lignocellulosic biomass: product characterization”

Nobre, C.; Şen, A.; **Durão, L**.; Miranda, I.; Pereira, H.; Gonçalves, M.; Gonçalves, M.

Biomass Conversion and Biorefinery 2021

Q3

https://www.x-mol.com/paperRedirect/1354163150522343424

Abstract: In recent years, there has been growing interest in the pyrolysis of biomass due to economic and environmental reasons. Low-temperature pyrolysis is one of the most straightforward and low-cost pyrolysis processes that may be used to produce added-value biochars as well as liquid and gas products from waste biomass.

Lignocellulosic biomass obtained from the fractionation of Quercus cerris bark including cork-rich and phloem-rich granules were subjected to low-temperature pyrolysis (250–325 °C) and the resulting pyrolysis products were examined. The results showed that 59–90% biochar, 8–24% bio-oil, and 2–16% gas products could be obtained from the waste cork, while phloem results in 53–89% biochar, 8–21% bio-oil, and 3–30% gas. The produced chars are rich sources of calcium, magnesium, and potassium and these elements are concentrated in the char as the pyrolysis temperature increases. The pyrolysis condensates contain high amounts of lignin-derived phenolic compounds with 2-methoxy phenol being the most abundant compound.

"Performance and Emissions of a Spark Ignition Engine Operated with Gasoline Supplemented with Pyrogasoline and Ethanol"

Durão, L.; Costa, J.; Arantes, T.; Brito, F.P.; Martins, J.; Gonçalves, M.

Q2

Energies 2020, 13(18), 4671

https://doi.org/10.3390/en13184671

Abstract: The partial replacement of fossil fuels by biofuels contributes to a reduction of CO2 emissions, alleviating the greenhouse effect and climate changes. Furthermore, fuels produced from waste biomass materials have no impact on agricultural land use and reduce deposition of such wastes in landfills. In this paper we evaluate the addition of pyrolysis biogasoline (pyrogasoline) as an additive for fossil gasoline. Pyrogasoline was produced from used cooking oils unfit to produce biodiesel. This study was based on a set of engine tests using binary and ternary mixtures of gasoline with 0, 2.5, and 5% pyrogasoline and ethanol. The use of ternary blends of gasoline and two different biofuels was tested with the purpose of achieving optimal combustion conditions and lower emissions, taking advantage of synergistic effects due to the different properties and chemical compositions of those biofuels. The tests were performed on a spark-ignition engine, operated at full load (100% throttle, or WOT—wide open throttle) between 2000 and 6000 rpm, while recording engine performance and exhaust gases pollutants data. Binary mixtures with pyrogasoline did not improve or worsen the engine's performance, but the ternary mixtures (gasoline + pyrogasoline + ethanol) positively improved the engine's performance with torque gains between 0.8 and 3.1% compared to gasoline. All fuels presented CO and unburned hydrocarbons emissions below those produced by this type of engine operated under normal (fossil) gasoline. On the other hand, NOx emissions from oxygenated fuels had contradictory behaviour compared to gasoline. If we consider the gains achieved by the torque with the ternary mixtures and reductions in polluting emissions obtained by mixtures with pyrogasoline, a future for this fuel can be foreseen as a partial replacement of fossil gasoline.

"Production of high calorific value biochars by low temperature pyrolysis of lipid wastes and lignocellulosic biomass"

Durão, L., Gonçalves, M., Nobre, C., Alves, O., **Brito, P.**, & Mendes, B.

Lecture Notes in Electrical Engineering Volume 505, 2019, Pages 655-661

Q3

https://doi.org/10.1007/978-3-319-91334-6_89

Abstract: Low quality waste oils and fats, with elevated levels of acidity, water and other contaminants are not appropriate for biodiesel production or other material recycling processes. Nevertheless, they can be converted to energy-dense bio-oils by pyrolysis, in an oxygen deficient atmosphere. These bio-oils may be used in combustion or upgraded to yield liquid biofuels for internal combustion engines although their chemical stability still creates some limitations during storage. This work aimed at the evaluation of biochar production by pyrolysis of mixtures of lipid wastes and pine sawdust. For this purpose, thermal conversion was performed with initial vacuum, at temperatures between 573.15 and 673.15 K and a reaction time of 60 min. Biomass incorporation varied between 0 and 38% (w/w). Biochar formation was favored by biomass incorporation and by the increase in temperature. The biochar yield varied from 1–28% and its high calorific value ranged between 24.3 to 36.6 MJ/kg. For incorporations of pine sawdust higher than 23% the carbon content and the calorific value of the biochar decreased due to a higher oxygen content in the raw materials. Highly calorific bio-oils were also produced in these conditions with yields from 24 to 83% (w/w), and high calorific values from 37.8 to 43.4 MJ/kg. These bio-oils have a carbon content higher than 75% and contain high molecular weight components. As such, they could be used in direct combustion in boilers, or as pellet additives. This approach contributes to the implementation of the renewed hierarchy for wastes as defined in the Directive 2008/98/EC namely by identifying alternatives to the deposition of the used cooking oils in landfills.

9. Photocatalysis/Electrolysis

"Solar CPC pilot plant photocatalytic degradation of indigo carmine dye in waters and wastewaters using supported-TiO2: Influence of photodegradation parameters"

Saggioro, E. M., Oliveira, A. S., Pavesi, T., Tototzintle, M. J., Maldonado, M. I., Correia, F. V., & Moreira, J. C.

International Journal of Photoenergy, 2015

https://doi.org/10.1155/2015/656153

Q1

Abstract: The photocatalytic degradation of indigo carmine (IC) dye in the presence of titanium dioxide under different conditions was reported. Several factors which interfere with the photodegradation efficiency as catalyst concentration, pH, initial concentration of dye, presence of inorganic anions, temperature, and the addition of hydrogen peroxide were studied under artificial irradiation with a 125 W mercury vapor lamp. Additionally, the catalyst supported on glass spheres was used for the photocatalytic degradation of the dye present in several types of waters in a CPC solar pilot plant. The photocatalytic products, carboxylic acids, and were followed during IC mineralization. Formate, acetate, and oxalate were detected in real MWWTP secondary effluent. The mineralization efficiency was of 42 and 21% using in suspension and supported TiO2, respectively. In order to evaluate biological effects, Eisenia andrei earthworms were used as a model organism. No significant difference () of weight was observed in the earthworm submitted to different concentrations of IC and its photoproducts. The photocatalytic degradation of IC on TiO2 supported on glass spheres suffered strong influence of the water matrix; nevertheless, the method has the enormous advantage that it eliminates the need for the final catalyst removal step, reducing therefore the cost of treatment.

"Hydrogen production via water electrolysis: Patent search and analysis"

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Q3

Recent Patents on Engineering, 10(3), 196-207. (2016)

https://doi.org/10.2174/1872212110666160728101353

Abstract: Background: A significant effort has been underway to put renewable energy sources at the heart of the current energy model. Hydrogen produced via water electrolysis has been identified as one of the most promising means to help achieve this goal, especially by enabling energy storage in a sustainable and non-polluting way. In recent years, this situation has triggered novel developments in water electrolysis technologies and patenting of new inventions.

Objective: The aim of this work is to review the state-of-the-art in hydrogen production from water electrolysis using a patent search and analysis. The paper also reviews, in brief, some relevant patents on water electrolysis technologies.

Method: The patent search was carried out on the European Espacenet database. The research method was based on the use of keywords and subsequent content analysis. Patent data was discussed and analyzed in terms of production technology, year of publication, geographical area of the holder and applicant type.

Results: A total of 103 patent documents were identified, most of them (75%) reporting developments on conventional water electrolysis technologies. Patents on emergent technologies were mostly granted after 2005. Global research effort was mainly supported by academia both in Europe and the US. Industry played an important role in Japan.

Conclusion: Patent data suggests that water electrolysis technologies are either in their early stages of growth (High Steam Temperature Electrolysis, High Pressure Electrolysis) or in a phase of growth/maturity (Alkaline Electrolysis, Solid Polymer Electrolysis) with novel developments still needed and more patents foreseen in the future.