enginite

ENGineering and INdustry Innovative Training for Engineers (ENGINITE)

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2017-1-CY01-KA202-026728

B4 course

Product development. From concept to market

Prepared by CUT

Erasmus+

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1. Overview

In this module the participating engineers will be introduced to the driving forces of our era: innovation coupled with creative business development. Participants shall be requested to foster their interpersonal skills with a creative utilization of their background. Communication, presentation and negotiation skills development is a core element and success facilitator within this module. A challenging and fascinating environment will be established by using a motivating problem, team exercises, to turn the module into a lifetime experience. The learning outcomes will boost engineers in their future career. Engineers may employ the gained knowledge within a startup or a multinational company; in a cutting-edge project or in some traditional sector challenged by present market conditions; during routine or crisis situations. Whatever the scenario, the engineers will be well equipped and ready to handle the situation with creativity and professionalism.

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2. Key learning outcomes

Upon completion of the module, participants should be able to:

- Demonstrate the fundamental principles and methods of innovation, entrepreneurship and intrapreneurship.
- Develop and apply business models.
- Utilize tools to explore and create innovative business ideas.
- Develop and introduce of innovation and entrepreneurship/intrapreneurship culture in an organization.
- Communicate, finance, or market a new idea, product, or initiative.

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3. Problem-based learning scenario

Your company is responsible for collecting spent coffee waste (SCW) from cafeterias and coffee shops in your town/city.

The company spent a high amount of money for the treatment and the disposal of this waste so the survival of the company is in the edge.

The company hires several teams so each team to propose its own solution for the valorization of this waste (e.g. to generation of high value added products from SCW and/or energy etc.).

The company will select and will invest to the solution that will have the potential to be profitable, it will be specific, sufficiently explain, realistic and novel.

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4. Background information

Scientific papers:

1. Kourmentza, C., Economou, C.N., Tsafrakidou, P. and Kornaros, M., 2018. Spent coffee grounds make much more than waste: Exploring recent advances and future exploitation strategies for the valorization of an emerging food waste stream. *Journal of Cleaner Production*, *172*, pp.980-992.

https://www.sciencedirect.com/science/article/pii/S0959652617323788#fig2

Abstract: Coffee is one of the most popular beverages, directly linked with tradition, highlighting its cultural and social effect worldwide. Coffee consumption has been continuously increasing, generating huge amounts of solid residues in return in the form of Spent Coffee Grounds (SCG). In recent years, global environmental awareness and strict legislation have driven research towards the implementation of sustainable processes. Innovative and environmentally sound methodologies for the exploitation of waste-streams have gained interest among the scientific community. In the frame of circular economy, wastes are perceived as sources for the recovery of high value-added compounds. In this review, several scenarios, regarding the exploitation of this low-cost feedstock with huge valorization potential, are being presented via either physicochemical or biotechnological routes.

2. Karmee, S.K., 2017. A spent coffee grounds based biorefinery for the production of biofuels, biopolymers, antioxidants and biocomposites. *Waste Management*.

https://www.sciencedirect.com/science/article/pii/S0959652617323788#fig2

Abstract: Coffee is one of the most popular beverages, directly linked with tradition, highlighting its cultural and social effect worldwide. Coffee consumption has been continuously increasing, generating huge amounts of solid residues in return in the form of Spent Coffee Grounds (SCG). In recent years, global environmental awareness and strict legislation have driven research towards the implementation of sustainable processes. Innovative and environmentally sound methodologies for the exploitation of waste-streams have gained interest among the scientific community. In the frame of circular economy, wastes are perceived as sources for the recovery of high value-added compounds. In this review, several

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scenarios, regarding the exploitation of this low-cost feedstock with huge valorization potential, are being presented via either physicochemical or biotechnological routes.

3. Janissen, B. and Huynh, T., 2018. Chemical composition and value-adding applications of coffee industry by-products: A review. *Resources, Conservation and Recycling*, *128*, pp.110-117.
   https://www.sciencedirect.com/science/article/pii/S0921344917303154

Abstract: Processing urban waste is becoming a major challenge, with the current state and forecasted increase in urbanisation. Finding novel approaches to reduce and recycle this waste, using value-adding applications, is paramount if we are to meet the needs of a growing population. Organic waste is of particular concern, as much of this can be treated and recycled for horticulture practices, but most find their final sink in landfill. With coffee now the second largest commodity worldwide, recycling these nutrient-rich by-products could reduce the amount of organic waste sent to landfill, whilst producing value adding products. Some chemical compounds present in these by-products, such as caffeine, tannins and chlorogenic acid are of ecotoxicological concern and can limit their value-adding applications. The aim of this literature review was to 1) characterise the waste obtained from the coffee industry; 2) outline the current value adding applications; 3) highlight limitations that prevent full utilization of coffee by-products and 4) discuss possible solutions that could maximize by-product utilization and ameliorating their negative environmental impacts. It was concluded that full utilization of these by-products is not always achieved, even though there is evidence to support their potential. This was mainly due to a lack of infrastructure and cross-chain networks between applications

4. MATA, Teresa M.; MARTINS, António A.; CAETANO, Nídia S. Bio-refinery approach for spent coffee grounds valorization. *Bioresource technology*, 2017.
   https://www.sciencedirect.com/science/article/pii/S0960852417316711

Abstract: Although normally seen as a problem, current policies and strategic plans concur that if adequately managed, waste can be a source of the most interesting and valuable products, among which metals, oils and fats, lignin, cellulose and hemicelluloses, tannins, antioxidants, caffeine, polyphenols, pigments, flavonoids, through recycling, compound recovery or energy valorization, following the waste hierarchy. Besides contributing to more sustainable and circular economies, those products also have high commercial value when compared to the ones obtained by currently used waste treatment methods. In this paper, it is shown how the bio-refinery framework can be used to obtain high value products from organic waste. With spent coffee grounds as a case study, a sequential process

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is used to obtain first the most valuable, and then other products, allowing proper valorization of residues and increased sustainability of the whole process. Challenges facing full development and implementation of waste based bio-refineries are highlighted.

5. Peshev, D., Mitev, D., Peeva, L., & Peev, G. (2018). Valorization of spent coffee grounds–A new approach. *Separation and Purification Technology*, *192*, 271-277. https://www.sciencedirect.com/science/article/pii/S1383586617327326

Abstract: It is established that from well selected spent coffee grounds by water extraction and subsequent extract nanofiltration one can obtain valuable products as permeate and retentate fractions. The obtained permeate is of high caffeine concentration and is potentially applicable in soft and energy drinks production. The retentate has main characteristics (antioxidants concentration, caffeine content and browning index) suitable for its application as coffee drink or ingredient in food technologies.The conditions of the two processes allowing such separation are described and discussed: water/spent coffee grounds ratio, temperature and duration of extraction; membrane, pressure, modes of filtration and degree of feed volume reduction. The results obtained outline the elements of a new approach for valorization of spent coffee grounds avoiding the permeate treatment to powdered caffeine and extending the area of retentate applicability.

6. Murthy, P. S., & Naidu, M. M. (2012). Sustainable management of coffee industry by-products and value addition—A review. *Resources, Conservation and recycling*, *66*, 45-58.

https://www.sciencedirect.com/science/article/pii/S0921344912000894

Abstract: Coffee is one of the popular beverages of the world and second largest traded commodity after petroleum. Coffee is cultivated in about 80 countries across the globe and entangles huge business worldwide. Coffee dispensation requires an elevated degree of processing know how and produces large amounts of processing by-products such as coffee pulp and husk, which have limited applications such as fertilizer, livestock feed, compost and such others. Biotechnological applications in the field of industrial residues management promote sustainable development of country's economy. The objectives pertaining to food processing by-products, waste and effluents include the recovery of fine chemicals and production of precious metabolites via chemical and biotechnological processes. Pre-treatments, followed by recovery procedures endow value-added products (natural antioxidants,

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vitamins, enzymes, cellulose, starch, lipids, proteins, pigments) of high significance to the pharmaceutical, cosmetic and food industries. With the background of high crop production in the upcoming years, there is an imperative need to counterpart this production with some utilization and industrial application of coffee by-products since coffee industry emerges enormous amounts of coffee by-products which are thriving nutrient resources. The present review highlights explorations of value addition to coffee by-products which can be achieved with valorization strategy, integration of techniques and applications of bioengineering principles in food processing and waste management and secondly conserve environment with disposal problem accelerating both ecological and economical resources

International companies that use spent coffee waste.

1. http://www.bio-bean.com/

Bio-bean® is an award-winning clean technology company that has industrialised the process of recycling spent coffee grounds into advanced biofuels and biochemicals.

Founded in 2013 by Arthur Kay, bio-bean manufactures a range of products from waste coffee grounds, saving businesses money, reducing greenhouse gas emissions, and displacing conventional fossil fuels

2. https://bizfluent.com/how-5754350-start-coffee-gound-recycling-business.html

3. https://www.theguardian.com/sustainable-business/2015/may/05/the-uk-company-turning-coffee-waste-into-furniture
4. http://www.asiaone.com/world/why-company-recycling-old-coffee-grounds-make-bed-sheets
5. https://www.coffeeculture.ie/coffee-grounds-not-waste-eco-marketing-opportunity/

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5. Case studies

Spent coffee waste for biodiesel:

1. Kookos, I. K. (2018). Technoeconomic and environmental assessment of a process for biodiesel production from spent coffee grounds (SCGs). *Resources, Conservation and Recycling*, *134*, 156-164.

Abstract: The valorization of the spent coffee grounds (SCGs) has attracted a lot of attention recently from both the academia and industry. The development of an economically attractive and environmentally sustainable process based on available experimental data on the SCGs valorization has not been investigated in the open literature. This is clearly a very important issue and is the subject of the present work. Evidence is presented to support the conclusion that the economic performance of the process can be acceptable only at large production capacities realized at centralized facilities. In addition, it is shown, using a "gate-to-gate" Life Cycle Assessment (LCI), that the environmental performance of the process is acceptable and the process can be considered sustainable. Further research is necessary in the area of efficient recovery of the bioactive compounds available in SCGs. These compounds have a significant added value that can render the process economically attractive at capacities that are low enough to be practically realizable

https://www.sciencedirect.com/science/article/pii/S0921344918300405

2. Caetano, N.S., Silva, V.F., Melo, A.C., Martins, A.A. and Mata, T.M., 2014. Spent coffee grounds for biodiesel production and other applications. *Clean Technologies and Environmental Policy*, *16*(7), pp.1423-1430.

https://link.springer.com/article/10.1007/s10098-014-0773-0

Abstract: This work evaluates the possibility of using spent coffee grounds (SCG) for biodiesel production and other applications. An experimental study was conducted with different solvents showing that lipid content up to 6 wt% can be obtained from SCG. Results also show that besides biodiesel production, SCG can be used as fertilizer as it is rich in nitrogen, and as solid fuel with higher heating value (HHV) equivalent to some agriculture and wood residues. The extracted lipids were characterized for their properties of acid value, density at 15 °C, viscosity at 40 °C, iodine number, and HHV, which are negatively influenced by water content and solvents used in lipid extraction. Results suggest that for lipids with high free fatty acids (FFA), the best procedure for conversion to biodiesel would be a two-step process of acid esterification followed by alkaline transesterification, instead of a sole step of direct transesterification with acid catalyst. Biodiesel was characterized for its properties of iodine number, acid value, and ester content. Although these quality parameters were not within the limits of NP EN 14214:2009 standard, SCG lipids can be used for biodiesel, blended with higher-quality vegetable oils before transesterification, or the biodiesel produced from SCG can be blended with higher-quality biodiesel or even with fossil diesel, in order to meet the standard requirements.

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Spent coffee waste for biodiesel and bioethanol:

3. Kwon, E.E., Yi, H. and Jeon, Y.J., 2013. Sequential co-production of biodiesel and bioethanol with spent coffee grounds. *Bioresource technology*, *136*, pp.475-480.

   https://www.sciencedirect.com/science/article/pii/S0960852413004203
   The sequential co-production of bioethanol and biodiesel from spent coffee grounds was investigated. The direct conversion of bioethanol from spent coffee grounds was not found to be a desirable option because of the relatively slow enzymatic saccharification behavior in the presence of triglycerides and the free fatty acids (FFAs) found to exist in the raw materials. Similarly, the direct transformation of the spent coffee grounds into ethanol without first extracting lipids was not found to be a feasible alternative. However, the crude lipids extracted from the spent coffee grounds were themselves converted into fatty acid methyl ester (FAME) and fatty acid ethyl ester (FAEE) via the non-catalytic biodiesel transesterification reaction. The yields of bioethanol and biodiesel were 0.46 g g^{-1} and 97.5 ± 0.5%, which were calculated based on consumed sugar and lipids extracted from spent coffee grounds respectively. Thus, this study clearly validated our theory that spent coffee grounds could be a strong candidate for the production of bioethanol and biodiesel.

   Spent coffee waste -Bioethanol

4. Choi, I.S., Wi, S.G., Kim, S.B. and Bae, H.J., 2012. Conversion of coffee residue waste into bioethanol with using popping pretreatment. *Bioresource technology*, *125*, pp.132-137.

https://www.sciencedirect.com/science/article/pii/S0960852412012709

Abstract: Coffee residue waste (CRW), which is produced after coffee extraction for coffee powder and instant coffee preparation, is a primary industrial waste. In this study, the use of CRW for bioethanol production was evaluated. The carbohydrate content of CRW was analyzed for fermentable sugars such as glucose, galactose, and mannose, which can be fermented by *Saccharomyces cerevisiae*. Pretreatment at a pressure of 1.47 MPa for 10 min with popping pretreatment was required to increase enzymatic hydrolysis. CRW was well hydrolyzed following popping pretreatment at 1.47 MPa. The enzymatic conversion rate of CRW to fermentable sugars was 85.6%. Ethanol concentration and yield (based on sugar content) following enzymatic hydrolysis after simultaneous saccharification and fermentation were 15.3 g/L and 87.2%, respectively.

Spent coffee waste – polyhydroxyalkanoates

5. Cruz, M. V., Paiva, A., Lisboa, P., Freitas, F., Alves, V. D., Simões, P., ... & Reis, M. A. (2014). Production of polyhydroxyalkanoates from spent coffee grounds oil obtained by supercritical fluid extraction technology. *Bioresource technology*, *157*, 360-363.

https://www.sciencedirect.com/science/article/pii/S0960852414001849

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Abstract: Spent coffee grounds (SCG) oil was obtained by supercritical carbon dioxide ($scCO_2$) extraction in a pilot plant apparatus, with an oil extraction yield of 90% at a 35 kg $kg^{-1}CO_2$/SCG ratio. *Cupriavidus necator* DSM 428 was cultivated in 2 L bioreactor using extracted SCG oil as sole carbon source for production of polyhydroxyalkanoates. The culture reached a cell dry weight of 16.7 g L^{-1} with a polymer content of 78.4% (w/w). The volumetric polymer productivity and oil yield were 4.7 g L^{-1} day^{-1} and 0.77 g g^{-1}, respectively. The polymer produced was a homopolymer of 3-hydroxybutyrate with an average molecular weight of 2.34×10^5 and a polydispersity index of 1.2. The polymer exhibited brittle behaviour, with very low elongation at break (1.3%), tensile strength at break of 16 MPa and Young's Modulus of 1.0 GPa. Results show that SCG can be a bioresource for polyhydroxyalkanoates production with interesting properties.

Spent coffee waste phenolic compounds and bioenergy

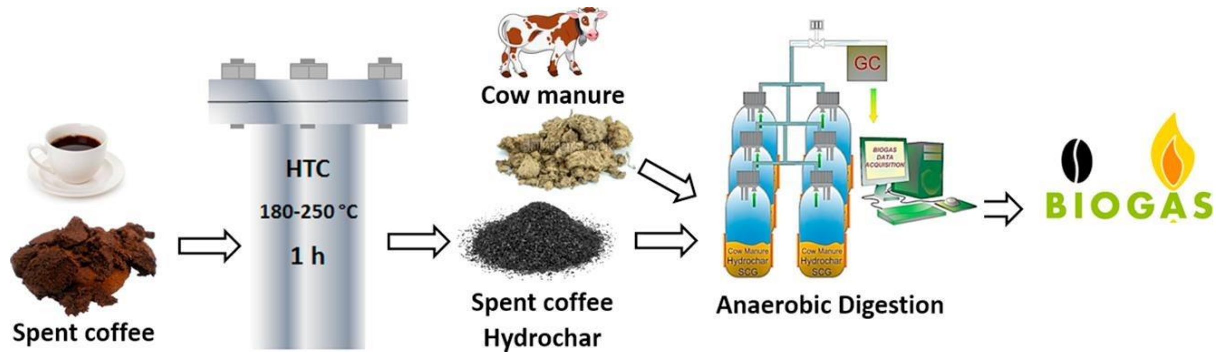
6. Spent coffee grounds as a valuable source of phenolic compounds and bioenergy

https://www.sciencedirect.com/science/article/pii/S0959652611005117

Abstract: Spent coffee grounds collected from coffee bars (SCG-1) or recovered from coffee capsules (SCG-2) were investigated as a potential source of phenolic compounds and energy. Preliminary characterization of these materials provided a total phenolic content of 17.75 mg GAE/g for SCG-1 and 21.56 mg GAE/g for SCG-2. A solvent-extraction procedure using aqueous ethanol as the solvent and operating under mild temperature conditions was developed and tested. A two-level factorial design was used to study the effects of temperature (T = 30–50 °C), extraction time (E = 60–120 min), liquid-to-solid ratio (R = 20–40 mL/g) and ethanol concentration in the aqueous mixture (C = 30–70 vol%) on the recovery of phenolic compounds. Under the best conditions, over 90% of the phenolic compounds contained in the starting waste materials were recovered. T, R and C were the most influential factors and all of them had a positive effect on the extraction efficiency.The calorific values of the two coffee wastes were 23.72 MJ/kg (SCG-1) and 24.07 MJ/kg (SCG-2). They were only marginally affected by the extraction procedure, which supports the possibility of integrating the recovery of phenolic compounds with the use of the resulting solid residue to produce pellets or other agglomerates for heating purposes. A case study application aimed at evaluating the potential valorization of the spent coffee produced in the Province of Rome is also presented.

Spent coffee enhanced biomethane potential via an integrated hydrothermal carbonization-anaerobic digestion process

https://www.sciencedirect.com/science/article/pii/S0960852418301950#f0025



Abstract: This study reports the implications of using spent coffee hydrochar as substrate for anaerobic digestion (AD) processes. Three different spent coffee hydrochars produced at 180, 220 and 250 °C, 1 h residence time, were investigated for their biomethane potential in AD process inoculated with cow manure. Spent coffee hydrochars were characterized in terms of ultimate, proximate and higher heating value (HHV), and their theoretical bio-methane yield evaluated using Boyle-Buswell equation and compared to the experimental values. The results were then analyzed using the modified Gompertz equation to determine the main AD evolution parameters. Different hydrochar properties were related to AD process performances. AD of spent coffee hydrochars produced at 180 °C showed the highest biomethane production rate (46 mL CH_4/gVS·d), a biomethane potential of 491 mL/gVS (AD lasting 25 days), and a biomethane gas daily composition of about 70%

7. **Valorization of spent coffee grounds recycling as a potential alternative fuel resource in Turkey: An experimental study**

https://www.tandfonline.com/doi/abs/10.1080/10962247.2017.136773

In this study, recycling of spent coffee grounds (SCG) as a potential feedstock for alternative fuel production and compounds of added value in Turkey was assessed. The average oil content was found (≈ 13% *w/w*). All samples (before and after extraction) were tested for scanning electron microscopy (SEM), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), X-ray diffraction (XRD), calorific value, surface analysis and porosity, Fourier transform infrared (FT-IR), and elemental analysis to assess their potential towards fuel properties. Elemental analysis indicated that carbon represents the highest percentages (49.59% and 46.42%, respectively), followed by nitrogen (16.7% and 15.5%), hydrogen (6.74% and 6.04%), and sulfur (0.851% and 0.561%). These results indicate that SCG can be utilized as compost, as it is rich in nitrogen. Properties of the extracted oil were examined, followed by biodiesel production. The quality of biodiesel was compared with American Society for Testing and Materials (ASTM) D6751 standards, and all the properties complied with standard specifications. The fatty acid compositions were analyzed by gas chromatography. It was observed that coffee waste methyl ester (CWME) is mainly composed of palmitic (35.8%) and arachidic (44.6%) acids, which are saturated fatty acids. The low degree of unsaturation provides an excellent oxidation stability (10.4 hr). CWME has also excellent cetane number, higher heating value, and iodine value with poor cold flow properties. The studies

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also investigated blending of biodiesel with Euro diesel and butanol. Following this, a remarkable improvement in cloud and pour points of biodiesel was obtained. Spent coffee grounds after oil extraction is an ideal material for garden fertilizer, feedstock for ethanol, biogas production, and as fuel pellets. The outcome of such research work produces valuable insights on the recycling importance of SCG in Turkey.

Implications: Coffee is a huge industry, and coffee has been widely used due to its refreshing properties. This industry generates large quantities of waste. Therefore, recycling of spent coffee grounds for producing alternative fuels and compounds of added value is crucial. Elemental analysis indicated that coffee waste can be utilized as compost, as it is rich in nitrogen. Coffee waste after oil extraction is an ideal feedstock for ethanol and biogas production, garden fertilizer, and as fuel pellets. The low degree of unsaturation provides excellent oxidation stability. Its biodiesel has also excellent cetane number, higher heating value, and lower iodine value.

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6. Discussion Questions

1. Define the specific problem that your team has at hand.
2. In what way(s) can the problem be solved? Elaborate each one.
3. What further information would your team need in order to accomplish the job well?
4. Where can this information to be found?
5. What do you think is expected in the budget proposal?
6. How would your team prepare to present to the company's Top Management?
7. What will be your team's action plan?

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7. Reflective Questions

1. What were you required to do to complete the project?
2. How did you prepare for the project?
3. What did you learn by completing this project?
4. What challenges did you face to complete the project?
5. Did anything unexpected happen? How did you overcome the challenges? Provide details.

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6. Assessment Document

The participants in groups of 4-5 people will have to prepare a small presentation regarding their problem solution in order to present the solution they have chosen explaining the concept and all the factors involved in their solution.

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