HEMP BY-PRODUCT VALORIZATION

Simone Pedrazzi[1], Nicolò Morselli[1], Marco Puglia[1], Giulia Santunione[1], Massimiliano Parenti[1], Filippo Ottani[1]
[1] BEELab (Bio energy efficiency laboratory), Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Via Vivarelli 10/1 – 41125 Modena, Italy.

ABSTRACT: This paper investigates possible circular economy pathways which can be applied in different hemp agriculture regimes using hemp by-products. Not only open field hemp cultivation but also the case of hemp growing in indoor greenhouses is presented. Several valorization technologies has been applied to achieve economic and environmental advantages for the farmer: composting of green and wet residues, combustion and gasification of hemp stalks and hurds, co-composting of hemp green residues (leafs and branches) and biochar obtained from hemp ligneous residues (stalk and hurd). Every pathways is discussed from the practical point of view and also considering the entire framework including all the stakeholder involved in the process.
Keywords: circular economy, hemp, market, residues, strategies.

1 INTRODUCTION

The hemp industry had a big increase in recent years [1,2]. Multiple reasons and interests created this boom: agricultural diversification; new flourishing markets like food, drinks, oils containing CBD extract [3-5]; new insulation material for building derived from biomass feedstock with low environmental impact [6], the extraction of THC and other cannabinoids for pharmaceutical purposes [7].

The cultivation of hemp in Italy is having a second golden age, the first started in the late Middle Ages and it ended between WWI and WWII and it was mainly focused on hemp fiber production. Hemp fiber produced in the Emilia Romagna Region, Northern Italy, had an incredible quality recognized all over the world [8].

Today, agriculture techniques are completely changed from the last century. Also hemp industry followed the recent mechanization in agriculture, but further improvements should be applied to have a sustainable growing from economical and environmental point of views [1,2,6]. First of all, depending of the final purposes of the hemp cultivation, several hemp by-products are not well recycled in the farm in a proper way. For example, considering hemp for seeds or CBD extraction, the 90-95% of the plants is not used and left in the field or burned in wildfires. The productivity of the plant is awesome, literature reports an annual productivity in cold climate conditions of about 10 ton per hectare of dry matter and only 5-10% is used for the final products [9]. In many cases this biomass residues can be reused to produce heat follow the circular economy in the farm [10,11].

Different is the situation of indoor plant growth in greenhouses. Compared to open field growth, under controlled environment facilities allows to avoid conditions, negative effects of biotic and abiotic stresses can be avoided to assuring higher biomass production and higher stability of CBD and THC compounds. On the other hand, indoor growing systems are affected by high specific energy consumptions leading to high OPEX and low overall sustainability of the facility. Mills in 2012 suggested a total value of 6074 kWh/kg [12]. High costs are justified by the large margins guaranteed by the hemp market. Growers are likely to invest money in new technologies that assure even marginal increase in the amount of yielded material.

2 MATERIAL AND METHODS

2.1. Italian hemp market

Italian hemp market is characterized by several sub-markets related to different hemp products. Table I resumes these markets and the use of hemp by-products for each of them.

The most diffuse is the hemp fiber market addressed for the textile industries. In this market, the main by-product is hemp hurd (Figure 2 left) that is commonly used as filler for construction material like tiles of bricks and it has a marker value of about 200 €/ton [6]. Hemp seed market has small dimension and large quantities of residues are left in the field (stalks in Figure 1 left and center) or (flowers and leaves in Figure 1 right).

Table I: Italian hemp market

Market	Customers sector	Market dimensions	Growing mode	By-product types	By-products use
Hemp fiber	Textile	Big	Outdoor	Hurd, flowers, leaves	Hurd for construction materials, the others are left in the field
Hemp seeds	Food	Small	Outdoor	Stalks, flowers, leaves	Stalks are left in the field, leaves and flowers are disposed as green waste
Hemp flowers for CBD or THC extraction	Pharmaceutical	Medium	Indoor	Stalks, leaves	Disposal as green waste

Figure 1 – Hemp cultivation for seed production (left); hemp stalks derived from hemp plants cutting (center); hemp flowers and leaves derived from flower-seed separation (right)

Figure 2: Hemp hurd from fiber (left); hemp indoor facility for CBD rich flower (right)

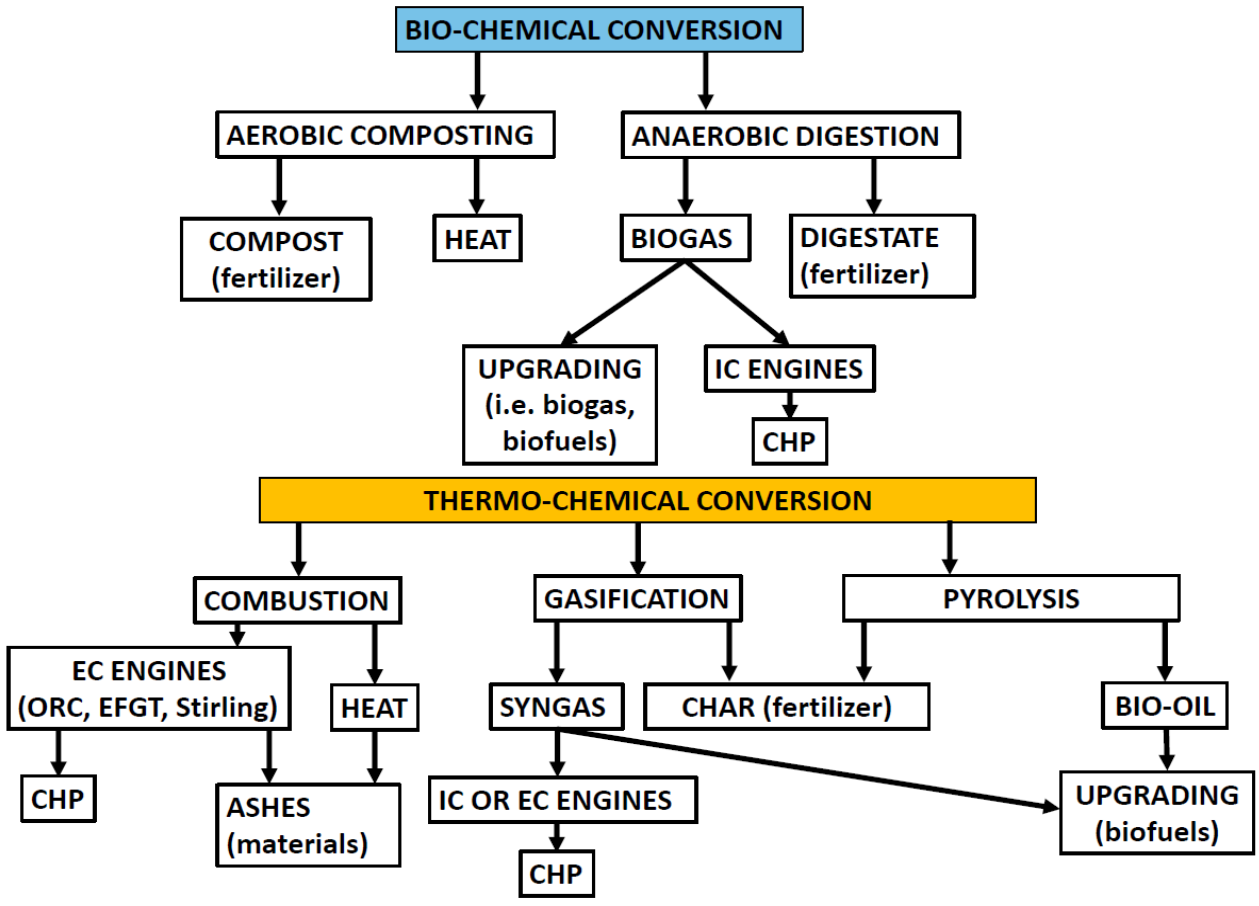

Figure 3: Biomass residues valorization technologies

Carbon: $n_{CO} + n_{CO_2} + n_{CH_4} + (1 - \alpha_c) + n_{tar} - 1 = 0$ (9)

Hydrogen: $2n_{H_2} + 2n_{H_2O} + 4n_{CH_4} + n_{tar}p - x = 0$ (10)

Oxygen: $n_{CO} + 2n_{CO_2} + n_{CH_4} + n_{tar}q - y = 0$ (11)

One sector that had a fast growing during the last decade is the hemp flower market addressed for CBD and/or THC extraction. In this sector the plants are grown indoor (Figure 2 right) to have a better control to the flower quality. However, all the by-products (stalks and leaves) are disposed as green waste. The high energy consumption of the greenhouses [12] suggests to valorize these by-products to produce energy for the process.

2.2. Biomass residues valorisation technologies

Figure 3 shows several pathways to valorise biomass residues. The main distinction is between biological processes (on the top of the figure) and thermo-chemical processes (on the bottom of the figure). Looking the final products obtainable, 3 main categories should be identified:

- Energy: heat and/or electricity that can be sell or used in the hemp industry.
- Fuels: gaseous or liquid fuels that can be sell or used in the hemp industry.
- Higher value materials: digestate, biochar and ashes that can be used as fertilizers or for construction material.

3 RESULTS AND DISCUSSION

Table II reports the results of the study related to the hemp fiber market. The most promising way to valorise residues is to use hemp hurd in a gasification stage in order to produce electricy and heat (CHP). The by-products of gasification is biochar, a good fertilizer [13-15] and also a material that can be efficiently used as filler in construction bricks and tiles [16]. Biochar can be used also to increment the velocity of the flowers and seeds composting process, the final fertilizer obtainable using biochar is called Combi [17] and it has great fertilization properties, higher than the standard compost [17].

Combi can substitute Materials such as coco coir, bat guano and worm castings commonly used in indoor and field application. Table III reports the results of the study related to the hemp seeds market. The most promising way to valorise residues is to use stalks in combustion facility to produce heat or electricity and heat using ORC cycles [18] and to use flowers and leaves in anaerobic processes for electricity production. Table IV reports the results of the study related to the hemp flowers market. The same conclusions reached for the hemp seeds market are obtained in this case.

Table II: Valorization study for by-products from hemp fiber industry

HEMP FIBER MARKET			
By products type		**Hurd**	
		Prons	**Cons**
By-product use	Construction materials	• Existing market	• Low earnings • big volumes required
Alternative by-product use	Combustion	• No fuel pre-processing • Mature technology • Low emissions	• Carbon neutral process • Ashes difficult to dispose or re-use
Alternative by-product use	Gasification	• Negative carbon process • High quality char • Ultra low emissions • Syngas upgrading simple and economics	• Fuel pre-processing (i.e. pellettization) • Maintenance cost • Technology not at commercial stage
Alternative by-product use	Pyrolysis	• No fuel pre-processing • High emissions	• Carbon positive process • Low quality char • Bio-oil processing complex and expensive
By products type		**Flowers, leaves, seeds**	
		Prons	**Cons**
By-product use	Left in the field	• Nutrients to the ground • Easy and economic	• Fermentantion with CH_4 emissions • No revenue
Alternative by-product use	Anaerobic digestion	• Mature technology • Economical efficient • Low maintenance	• High cost of investment • Big volumes required • Need of other biomasses to balance the digestor recipe • Digestate difficult to re-use in the field
Alternative by-product use	Aerobic composting	• Easy process • Mix with other residual biomasses accepted	• Low revenues • Big area required • Slow process, however char from gasification and pyrolysis can be used to faster the reaction (COMBI)

Table III: Valorization study for by-products from hemp seeds industry

HEMP SEEDS MARKET			
By products type		**Stalks**	
		Prons	**Cons**
By-product use	Left in the field	• Nutrients to the ground • Easy and economic	• Fermantantion with CH_4 emissions • No revenue
Alternative by-product use	Combustion	• Easy fuel pre-processing • Mature technology • Low emissions	• Carbon neutral process • Ashes difficult to dispose or re-use
Alternative by-product use	Gasification	• Negative carbon process • High quality char • Ultra low emissions • Syngas upgrading simple and economics	• Hard fuel pre-processing (i.e. pellettization) • Maintenance cost • Technology not at commercial stage
Alternative by-product use	Pyrolysis	• Easy fuel pre-processing • High emissions	• Carbon positive process • Low quality char • Bio-oil processing complex and expensive
By products type		**Flowers, leaves**	
		Prons	**Cons**
By-product use	Green waste disposal	• Easy process	• Cost of disposal
Alternative by-product use	Anaerobic digestion	• Mature technology • Economical efficient • Low maintenance	• High cost of investment • Big volumes required • Need of other biomasses to balance the digestor recipe • Digestate difficult to re-use in the field
Alternative by-product use	Aerobic composting	• Easy process • Mix with other residual biomasses accepted	• Low revenues • Big area required • Slow process, however char from gasification and pyrolysis can be used to faster the reaction (COMBI)

Table IV: Valorization study for by-products from hemp industry for flower for CBD and THC

HEMP FLOWERS MARKET			
By products type		**Stalks**	
		Prons	**Cons**
By-product use	Green waste disposal	• Easy process	• Cost of disposal (special waste)
Alternative by-product use	Combustion	• Easy fuel pre-processing • Mature technology • Low emissions	• Carbon neutral process • Ashes difficult to dispose or re-use
Alternative by-product use	Gasification	• Negative carbon process • High quality char • Ultra low emissions • Syngas upgrading simple and economics	• Hard fuel pre-processing (i.e. pellettization) • Maintenance cost • Technology not at commercial stage
Alternative by-product use	Pyrolysis	• Easy fuel pre-processing • High emissions	• Carbon positive process • Low quality char • Bio-oil processing complex and expensive
By products type		**Leaves**	
		Prons	**Cons**
By-product use	Green waste disposal	• Easy process	• Cost of disposal (special waste)
Alternative by-product use	Anaerobic digestion	• Mature technology • Economical efficient • Low maintenance	• High cost of investment • Big volumes required • Need of other biomasses to balance the digestor recipe • Digestate difficult to re-use in the field
Alternative by-product use	Aerobic composting	• Easy process • Mix with other residual biomasses accepted	• Low revenues • Big area required • Slow process, however char from gasification and pyrolysis can be used to faster the reaction (COMBI)

4 CONCLUSIONS

A wide range discussion about hemp markets residues valorization is here presented. The main valorization technologies are reported and discusses from a critical point of view. For hemp hurd residues the most promising technology is gasification, instead for hemp leaves, seeds and flowers residues anaerobic digestion is the most suitable way except in the case where biochar is available: in this scenario Combi production should be more interesting. Combi can be used as soil fertilizer in open field cultivation or can substitute pots substrate in indoor cultivation representing a smart circular economy pathways.

5 ACKNOWLEDGEMENTS

This work was supported by the UNIHEMP research project "Use of iNdustrIal Hemp biomass for Energy and new biocheMicals Production" (ARS01_00668) funded by PON "Ricerca innovazione" 2014 – 2020 – Azione II – OS L.B). Grant decree UNIHEMP prot. n. 2016 of 27/07/2018, CUP B76C18000520005 – COR 571294.

6 REFERENCES

[1 Schluttenhofer, Craig and Ling Yuan. 2017. "Challenges towards Revitalizing Hemp: A Multifaceted Crop." Trends in Plant Science 22(11):917–29.

[2] Das, L., Liu, E., Saeed, A., Williams, D.W., Hu, H., Li, C., Ray, A.E., Shi, J. 2017. "Industrial hemp as a potential bioenergy crop in comparison with kenaf, switchgrass and biomass sorghum" Bioresource Technology, 244:641-649

[3] Gupta, A., Abraham, R.E., Barrow, C.J, Puri, M. 2015. "Omega-3 fatty acid production from enzyme saccharified hemp hydrolysate using a novel marine thraustochytrid strain." Bioresource Technology 184:373-378.

[4] Ascrizzi, R., Ceccarini, L., Tavarini, S, Flamini, G., Angelini, L.G. 2019. "Valorisation of Hemp Inflorescence after Seed Harvest: Cultivation Site and Harvest Time Influence Agronomic Characteristics and Essential Oil Yield and Composition." Industrial Crops and Products 139(February).

[5] Bonaccorso, S., Ricciardi, A., Zangani, C., Chiappini, S., and Schifano, F. 2019. "Cannabidiol (CBD) Use in Psychiatric Disorders: A Systematic Review." NeuroToxicology 74(August):282–98

[6] Ingrao, C., Lo Giudice, A., Bacenetti, J., Tricase, C., Dotelli, G., Fiala, M., Siracusa, V., Mbohwa, C. 2015. "Energy and Environmental Assessment of Industrial Hemp for Building Applications: A Review." Renewable and Sustainable Energy Reviews 51:29–42.

[7] Citti, C., Braghiroli, D., Vandelli, M.A., Cannazza, G. 2018. "Pharmaceutical and Biomedical Analysis of Cannabinoids: A Critical Review." Journal of Pharmaceutical and Biomedical Analysis 147:565–79.

[8] U.S. Department of Agriculture (1914). Yearbook of the United States Department of Agriculture. p. 297.

[9] J Mankowski, J Kolodziej. Increasing heat of combustion of briquettes made of hemp shives. International conference on flax and other bast plants, 2008.

[10] Kolarikova, M. & Ivanova, Tatiana & Havrland, Bohumil. (2013). Energy balance of briquettes made of hemp (Cannabis sativa L.) cultivars (Ferimon, Bialobrzeskie) from autumn harvest to produce heat for household use. Engineering for Rural Development. 504-508.

[11] Daniel Nilsson, Sven Bernesson, Per-Anders Hansson, Pellet production from agricultural raw materials – A systems study, Biomass and Bioenergy, Volume 35, Issue 1, 2011, Pages 679-689, ISSN 0961-9534, https://doi.org/10.1016/j.biombioe.2010.10.016.

[12] Mills, E. 2012. "The Carbon Footprint of Indoor Cannabis Production." Energy Policy 46:58–67.

[13] Pedrazzi, S., Santunione, G., Minarelli, A., Allesina, G. Energy and biochar co-production from municipal green waste gasification: A model applied to a landfill in the north of Italy (2019) Energy Conversion and Management, 187, 274-282. DOI: 10.1016/j.enconman.2019.03.049 (Primo quartile Q1 secondo Scopus ASJC Code 2105)

[14] Allesina, G., Pedrazzi, S., Allegretti, F., Morselli, N., Puglia, M., Santunione, G., Tartarini, P. Gasification of cotton crop residues for combined power and biochar production in Mozambique (2018) Applied Thermal Engineering, 139, pp. 387-394. DOI: 10.1016/j.applthermaleng.2018.04.115

[15] Pedrazzi, S., Allesina, G., Morselli, N., Puglia, M., Barbieri, L., Lancellotti, L., Ceotto, E., Giorgini, L., Malcevschi, A., Pederzini, C., Tartarini, P. The energetic recover of biomass from river maintenance: the REBAF project (2017) European Biomass Conference and Exhibition Proceedings, 2017 (25thEUBCE), pp. 52-57. DOI: 10.5071/26thEUBCE2018-2CV.2.7

[16] Vezzali, V., Andreola, F., Barbieri, L., Lancellotti, I., Pozzi, P., Allesina, G., Pedrazzi, S., Tartarini, P. Gasification of biomass from river maintenance and char application in building materials production (2018) Environmental Engineering and Management Journal, 17 (10), 2485-2496.

[17] Getachew Agegnehu, Adrian M. Bass, Paul N. Nelson, Michael I. Bird, Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil, Science of The Total Environment, Volume 543, Part A, 2016, Pages 295-306, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2015.11.054.

[18] Muharrem Eyidogan, Fatma Canka Kilic, Durmus Kaya, Volkan Coban, Selman Cagman, Investigation of Organic Rankine Cycle (ORC) technologies in Turkey from the technical and economic point of view, Renewable and Sustainable Energy Reviews, Volume 58, 2016, Pages 885-895, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2015.12.158.