Bastiaans R, J Environ Sci Curr Res 2023, 6: 040
DOI: 10.24966/ESCR-5020/100040

HSOA Journal of
Environmental Science Current Research

Short Communicaton

Biomass to Hydrogen: A Short Biomass Potential Availability and Conversion Survey for Dutch Municipalities

Rob Bastiaans[1,2*]

[1]*Eindhoven University of Technology, PO box 513, 5600 MB Eindhoven, Netherlands*

[2]*Eindhoven Institute for Renewable Energy Systems (EIRES), Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, Netherlands*

Abstract

The local availability of lignocellulosic biomass was estimated for an arbitrary but representative Dutch municipality to facilitate the conversion and use of hydrogen on a decentralized scale. This study reveals that there is a large potential for this biomass at many locations to play important roles in the energy-transition. It is meant as a call to the scientific community to activate individuals and get some inspiration.

Keywords: Availability; Biomass; Conversion, Decentralized; Hydrogen; Local

Introduction

Many Dutch municipalities have the ambition to become a front-runner in the energy transition. They are mostly countryside municipalities that have some regional prominent economic characteristics which are threefold 1) a large amount of agriculture, 2) quite some companies rooted in the agricultural sector and 3) a good infrastructure. The first two points are condensed into a single term being 'the agro food sector'.

Additionally, for many Dutch municipalities the challenge is to increase their innovativeness, sustainability and knowledge and so to enforce their economic potential.

***Corresponding author:** Rob Bastiaans, Eindhoven University of Technology, PO box 513, 5600 MB Eindhoven, Eindhoven Institute for Renewable Energy Systems (EIRES), Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, Netherlands, E-mail: r.j.m.bastiaans@tue.nl

Citation: Bastiaans R (2023) Biomass to Hydrogen: A Short Biomass Potential Availability and Conversion Survey for Dutch Municipalities. J Environ Sci Curr Res 6: 040.

Received: February 3, 2023; **Accepted:** February 9, 2023; **Published:** February 16, 2023

Therefore, I asked myself the question of what the potential availability of biomass in such communities actually is and how it can be used in the energy sector. In the process from energy source to usage, some conversions are required. As an intermediate energy carrier, I immediately identified hydrogen, H2, as a means. But of course, direct combustion is possible. I used hydrogen as an intermediate because of its overall recognized abilities which lead to a standard and the associated technology found a breakthrough a couple of years ago by many stakeholders which leads to increasing price reductions of its required infrastructure. The process keeps on going and this momentum should be used although it is of course not the best choice for any application.

Additionally, the study emphasizes that it is important to take action in a right direction, the best direction is just an unimportant luxury.

Of course, such a study can provide valuable insights and information for a variety of stakeholders, including government officials, entrepreneurs, and members of the general public. It can serve as a starting point for further research and can help inform policy and decision-making related to the use of lignocellulosic biomass for hydrogen production on a decentralized scale. The study will likely include several conclusions, strategy suggestions, and recommendations that can guide future efforts in this area. Additionally, it will identify areas where more research is needed to fully understand the potential of this technology and how it can be best utilized to support a sustainable energy transition.

Small-scale integrated (synthesis and application) systems are important if not crucial because of their advantages being fourfold

1. Independency,
2. Available technology at sufficiently high TRL,
3. Affordable systems by local entrepreneurs at a limited scale and
4. Facilitating demo applications is therefore relatively easily accessible as well, important for proof of concepts.

To my opinion, it is both required and challenging to initiate a movement towards a more sustainable energy transition fast, for people feeling a sort of responsibility and don't want to leave it to (rather slow) governments. Individuals, small groups and entrepreneurs can play an important role in getting the process started. By building their own decentralized hydrogen production and usage systems and joining efforts, they can serve as "opinion leaders" and pave the way for wider adoption. The key is to find a few people who are passionate about the cause and are willing to take the first steps, which can be difficult. But once the movement starts to grow, it will become easier to attract more people and resources to the cause and to facilitate the transition to a more sustainable energy future.

This document is meant to serve as a kind of convincing manual to provide several important and facilitating partners, like municipalities for a streamlined or efficient process for obtaining government

Citation: Bastiaans R (2023) Biomass to Hydrogen: A Short Biomass Potential Availability and Conversion Survey for Dutch Municipalities. J Environ Sci Curr Res 6: 040.

permits or licenses for a specific project or activity. This can include streamlined or simplified paperwork, reduced wait times for approvals, and reduced regulatory burdens. Governments may implement quick licensing procedures to encourage investment, stimulate economic growth, and make it easier for businesses and individuals to undertake projects that align with public policy goals, such as clean energy development. Of course, a similar survey may be conducted to adjust it to specific situations.

Method

It is very difficult to investigate the availability potential of an area covered by multiple applications of it. Common land applications include residential, commercial, industrial, agricultural, and natural/ conservation areas. The latter two are the main inputs for biomass whereas the first two might add in waste streams. Each type of land use may have different regulations, zoning requirements, and potential impacts on the environment and local communities. Understanding the division of land applications can help plan for sustainable land use and development, and balance competing land use demands. However, it is quite impracticable to investigate potential biomass sources by their very local use and integrate it. This could be executed by detailed interviewing of notably agricultural businesses. A gross estimation would be more helpful.

Therefore, a literature search was performed to find a reference case. This case was then mapped, to obtain an order-of-magnitude estimation, for the case considered. The study will also examine the potential applications of this technology, such as its use in residential, commercial, or industrial settings.

Biomass availability

The investigation started by taking a representative arbitrary (but very useful, though as it is the place of my residence) Dutch countryside municipality, which was Land van Cuijk, further abbreviated as LvC. LvC is inhabited by about 90.000 individuals and has a surface of 351 km^2. I found a trustworthy 2011 study of Oak Ridge National Laboratories (USA), invoking 50 scientific experts and 11 scientific reviewers, commissioned by the USA Department of Energy (DOE) [1]. Although from a totally different region I found it adequate for use as a reference. In [1] we observe that a local yearly amount of biomass production can amount up to 5500 dry tons per annum and per square mile in the United States, see figure 1. It was based on a conservational estimation of available resources of cellulosic feedstocks including forest and agricultural biomass, as well as specific energy crops. The limit of $ 60 per dry ton is a realistic market price limit and can compete with other energy carriers and other assumptions are realistic, include sustainability and do not have any severe impact. To my opinion LvC can compete with this amount as agricultural intensity, soil fertility and efficiency can be assumed at least as large. Therefore, I would estimate LvC annual biomass production at 2000 dry tons per annum per square km. A regional surface of 351 km^1 means a yearly availability of 700000 tons. For confirmation, I contacted the current principal investigator, of this project [2]. He referred me to the updated report [3] in which it was confirmed that nothing changed severely. Because this is just an order-of-magnitude survey I kept the 2011 numbers.

Conversion to hydrogen

In a recent review on biomass conversion to hydrogen, [4], it is concluded that the best H_2 yield from biomass is through

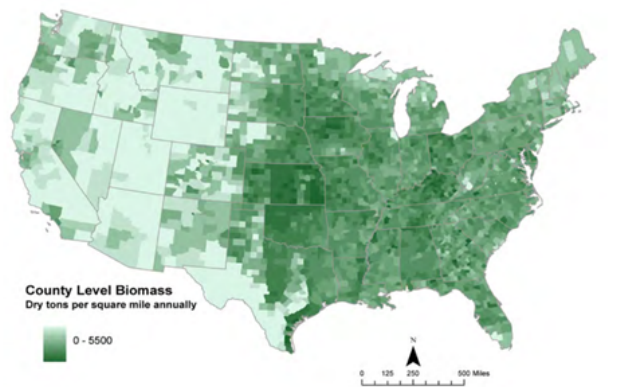

Figure 1: Potential county-level resources at $602 per dry ton or less in 2030 All costs to farmgate or roadside (excludes handling and loading, transportation, and storage).

(thermochemical) gasification. The general air gasification reaction of biomass is presented in Equation (1),

$$\text{Biomass} + \text{Air} \rightarrow N_2 + CO + H_2 + CO_2 + CH_4 + H_2O + \text{LHC} + \text{Tar} + \text{Char}, \quad (1)$$

In which LHC denotes light hydrocarbons. We can easily convert many species on the right hand side by thermochemical means, separate or safely emit, filter them out or use them. It can be taken care of by internally integrated means or by after-treatment.

From local estimated yearly feedstock [5] (H_2 Yield of ~ 100 (g/kg feedstock)) we can conclude on the potential possibility to produce 70 $\cdot 10^6$ kg of H_2 each year. With a hydrogen energy density of 120 MJ/kg we obtain 8.4 PJ/yr at a conversion efficiency of 100%. A value of 30 % would be a quite conventional lower estimate. With this we come up to 2.5 PJ/yr and we can provide feedstock for the electricity consumption of 250000 households[2].

This would be equivalent to about 700 GWh altogether usable potential even in the case of partial use/ decentralizing feedstock harvest, conversion and application efficiency. For the total household energy supply (including gas) the ratio is about 3 to 1, for gas use and electricity respectively. So, for the total energy use we would need 4 times as much as the amount above, reducing the number of households to 62000, still more than we probably host in our region! Indeed, with about 100000 people let us assume a clustering of 3 people per household the region's household energy need can be covered almost two times. If local industry needs are equivalent to total household needs we can possibly cover the entire region in total energy demand [6].

In the following points we concentrate on this best H_2 yield from biomass through (thermochemical) gasification. Thermochemical conversion has the advantage of being available at a large production scale because the technologies used are based on current well-established methods for converting fossil fuels. Therefore, the industrial application has already been established. Gasification and pyrolysis implementation methods are already designed for a wide variety of dried feedstocks, while steam gasification and steam reforming are the best compromises for wet biomass treatment which is somewhat more complex.

Other interesting research found may be covered in recent scientific archival publications [7-39], including many reviews, but currently merely out of the scope of the goal of this study. However probably very valuable for continuing investigations on a multitude of aspects including economic and social implications.

Conclusion

Although this report is based on a limited amount of data, the data is quite trustworthy and therefore able to serve as a good reference, we can already conclude on important points. There is a huge potential in the amount of biomass in LvC available. Furthermore, existing efficient technologies to convert this energy source to the desired form are available, either.

According to CBS the mean Dutch domestic annual electricity consumption in 2021 was 2810 kWh = 10 GJ. Power (electricity) or heat. As LvC is estimated as having the capacity of supplying more than sufficient total energy for households it can serve industrial activities as well, probably covering everything. Bottomline is that LvC has the potential to play as a frontrunner in the energy transition. LvC, and thus many Dutch municipalities, can be a self-sufficient energy region based on its agri food sector. The message holds for any community over the world if a prefactor is applied. Added literature might be used to lift implementations a step higher. The author saw it as his task to uncover this potential, not unimportant, but now the vast majority of work starts by actually liberating this potential by using it and make your municipality the winning team! For local applications starting the process with even a fraction of the estimated amounts is always possible and contributes to the mitigation of the climate problem.

Ethical Compliance

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Funding statement

The author was supported by the Eindhoven Institute for Renewable Energy Systems (EIRES), Eindhoven University of Technology.

Conflict of Interest declaration

The author declares that he has conflicts of interest.

Acknowledgment

I thank Alessio Fancello, Niels Deen and Matthew Langholtz for helpful comments and discussions. Furthermore, I appreciate the motivating roles of Wiljan Laarakkers and Roger Engelberts.

References

1. U.S. Department of Energy (2011) *U.S. Billion-Ton Update*: *Biomass Supply for a Bioenergy and Bioproducts Industry*. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227.
2. https://www.kcl.ac.uk/study/postgraduate-taught/courses/mobile-and-personal-communications-msc
3. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf
4. Lepage T, Kammoun M, Schmetz Q, Richel A (2021) Biomass-to-hydrogen: A review of main routes production, processes evaluation and techno-economical assessment. Biomass and Bioenergy 144: 105920.
5. http://bioenergykdf.net.
6. https://www.cbs.nl/en-gb/figures/detail/81528ENG
7. Oyedeji O, Langholtz M, Hellwinckel C, Webb E (2021) Supply analysis of preferential market incentive for energy crops. Biofuels Bioproducts and Biorefining 15: 736-748.
8. LiC, Aston JE, Lacey JA, Thompson VS, Thompson DN (2016) Impact of feedstock quality and variation on biochemical and thermochemical conversion. Renewable and Sustainable Energy Reviews 65: 525-536.
9. Golecha R (2016) Minimizing the Cost of Agriculture Waste for Cellulosic Biofuels. Strategic Planning for Energy and the Environment 36: 14-21.
10. Golecha R, Gan J (2016) Optimal contracting structure between cellulosic biorefineries and farmers to reduce the impact of biomass supply variation: Game theoretic analysis. Biofuels Bioproducts and Biorefining 10: 129-138.
11. Golecha R (2016) Biomass Supply Strategy for Building a Sustainable Cellulosic Biofuel Business. Strategic Planning for Energy and the Environment 35: 22-33.
12. Martinez-Villarreal R, Kammoun M, Richel A (2023) The critical role of hydrogen in the development of new biofuels. Current Opinion in Green and Sustainable Chemistry 39: 100716.
13. Wu N, Lan K, YaoY (2023) An integrated techno-economic and environmental assessment for carbon capture in hydrogen production by biomass gasification. Resources Conservation and Recycling 188: 106693.
14. Mould K, Silva F, Knott SF, O'Regan B (2022) A comparative analysis of biogas and hydrogen, and the impact of the certificates and blockchain new paradigms. International Journal of Hydrogen Energy 47: 39303-39318.
15. Hafeez S, Harkou E, Spanou A, Manos G, Constantinou A (2022) Review on recent progress and reactor set-ups for hydrogen production from formic acid. Materials Today Chemistry 26: 101120.
16. Eloffy MG, Elgarahy AM, Saber AN, Mohsen A, Elwakeel KZ (2022) Biomass-to-sustainable biohydrogen: Insights into the production routes, and technical challenges. Chemical Engineering Journal Advances 12: 100410.
17. Flores CFG, Martinez MFJ (2022) Biorefineries: Achievements and challenges for a bio-based economy. Frontiers in Chemistry 10: 973417.
18. Castro J, Leaver J, Pang S (2022) Simulation and Techno-Economic Assessment of Hydrogen Production from Biomass Gasification-Based Processes: A Review Energies 15: 8455.
19. Vuppaladadiyam AK, Vuppaladadiyam SSV, Awasthi A, Bhattacharya S, Leu SY (2022) Biomass pyrolysis: A review on recent advancements and green hydrogen production. Bioresource Technology 364: 128087.
20. Lee D, Nam H, Won SM, Wang S, Park YK (2022) Recent progress in the catalytic thermochemical conversion process of biomass for biofuels. Chemical Engineering Journal 447: 137501.
21. Wijayasekera SC, Hewage K, Hettiaratchi P, Pokhrel D, Sadiq R (2022) Sustainability of waste-to-hydrogen conversion pathways: A life cycle thinking-based assessment. Energy Conversion and Management 270: 116218.
22. Buffi M, Prussi M, Scarlat N (2022) Energy and environmental assessment of hydrogen from biomass sources: Challenges and perspectives. Biomass and Bioenergy 165: 106556.
23. Taipabu MI, Viswanathan K, Wu W, Hattu N, Atabani AE (2022) A critical review of the hydrogen production from biomass-based feedstocks: Challenge, solution, and future prospect. Process Safety and Environmental Protection 164: 384-407.
24. Sridhar A, Ponnuchamy M, Kumar PS, Kapoor A, Xiao L (2022) Progress in the production of hydrogen energy from food waste: A bibliometric analysis. International Journal of Hydrogen Energy 47: 26326-26354.

25. Karras T, Brosowski A, Thrän D (2022) A Review on Supply Costs and Prices of Residual Biomass in Techno-Economic Models for Europe. Sustainability (Switzerland) 14: 7473.

26. Tezer O, Karabağ N, Öngen A, Çolpan CO, Ayol A (2022) Biomass gasification for sustainable energy production: A review. International Journal of Hydrogen Energy 47: 15419-15433.

27. Karaeva JV, Timofeeva SS, Kovalev AA, Grigoriev VS, Litti YV (2022) CO-PYROLYSIS of agricultural waste and estimation of the applicability of pyrolysis in the integrated technology of biorenewable hydrogen production. International J of Hydro En 47: 11787-11798.

28. Rosyadi I, Suyitno S, Ilyas AX, Budiono A, Yusuf M (2022) Producing hydrogen-rich syngas via microwave heating and co-gasification: A systematic review. Biofuel Res J 9: 1573-1591.

29. Hosseinzadeh A, Zhou JL, Li X, Afsari M, Altaee A (2022) Techno-economic and environmental impact assessment of hydrogen production processes using bio-waste as renewable energy resource. Renewable and Sustain Energy Rev 156: 111991.

30. Agyekum EB, Nutakor C, Agwa AM, Kamel S (2022) A Critical Review of Renewable Hydrogen Production Methods: Factors Affecting Their Scale-Up and Its Role in Future Energy Generation. Membranes 12: 173.

31. Wijayasekera SC, Hewage K, Siddiqui O, Hettiaratchi P, Sadiq R (2022) Waste-to-hydrogen technologies: A critical review of techno-economic and socio-environmental sustainability. Int J of Hydr Ener 47: 5842-5870.

32. Hassan Q, Hafedh SA, Mohammed HB, Salman HM, Jaszczur M (2022) A review of hydrogen production from bio-energy, technologies and assessments, Energy Harvesting and Systems.

33. Yeşilova N, Kayıkcı CBÇ, Ateş AE, Özcan HK, Aydın S (2022) Biomass Value-Production of H2 as an Energy Carrier. Lecture Notes in Energy 87: 723-754.

34. Banerjee N (2022) Biomass to Energy-an Analysis of Current Technologies, Prospects, and Challenges. Bioenergy Res.

35. Gonzalez-Garay A, Bui M, Freire Ordóñez D, Mac Dowell N, Shah N (2022) Hydrogen Production and Its Applications to Mobility. Annual Review of Chem and Biomole Eng 13: 501-527.

36. Ma Z, Liu X, Li G, Gao J, Cui P (2022) Energy consumption, environmental performance, and techno-economic feasibility analysis of the biomass-to-hydrogen process with and without carbon capture and storage. J of Env Chem Eng 9: 106752.

37. Aziz M, Darmawan A, Juangsa FB (2021) Hydrogen production from biomasses and wastes: A technological review. Int J of Hydro Energy 46: 33756-33781.

38. Dovichi Filho FB, Castillo Santiago Y, Silva Lora EE, Escobar Palacio JC (2021) Evaluation of the maturity level of biomass electricity generation technologies using the technology readiness level criteria. J of Cleaner Prod 295: 126426.

39. Kim S, Dale BE (2015) All biomass is local: The cost, volume produced, and global warming impact of cellulosic biofuels depend strongly on logistics and local conditions. Biofpr 9: 422-434.