Biofuel Research Journal 6 (2015) 223-226

BRTeam
BIOFUEL RESEARCH TEAM

Biofuel
Research Journal
Journal homepage: www.biofueljournal.com

Mini Review

# Biohydrogen production as a potential energy fuel in South Africa

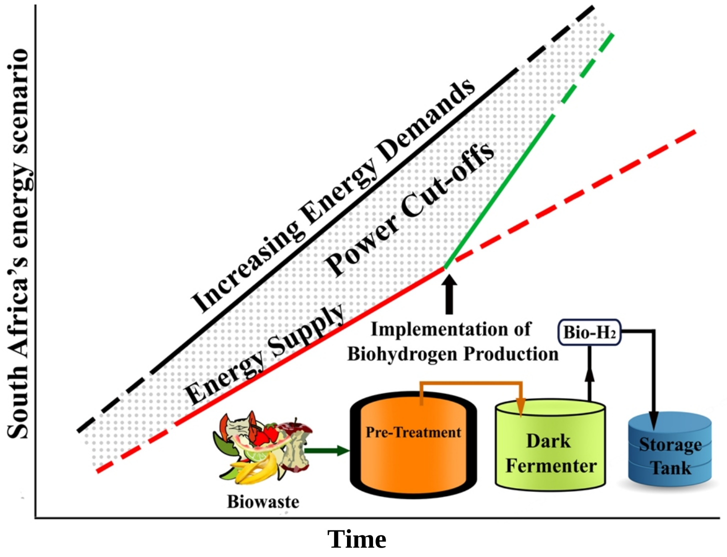
P.T. Sekoai*, M.O. Daramola

*Sustainable Energy & Environment Research Unit, School of Chemical and Metallurgical Engineering, Faculty of Engineering and the Built Environment, University of the Witwatersrand, Wits 2050, Johannesburg, South Africa.*

## HIGHLIGHTS

- ➢Growing energy demands and persistent power cuts throughout South Africa over the past few years
- ➢An urgent need to explore and implement clean and sustainable energy fuels to address this crisis
- ➢Biohydrogen production as a promising energy fuel to potentially overcome South Africa's increasing energy demands

## GRAPHICAL ABSTRACT



## ARTICLE INFO

**Article history:**
Received 2 April 2015
Received in revised form 16 April 2015
Accepted 16 April 2015
Available online 1 June 2015

**Keywords:**
Biohydrogen production
Clean and sustainable energy
South Africa

## ABSTRACT

Biohydrogen production has captured increasing global attention due to its social, economic and environmental benefits. Over the past few years, energy demands have been growing significantly in South Africa due to rapid economic and population growth. The South African parastatal power supplier i.e. Electricity Supply Commission (ESKOM) has been unable to meet the country's escalating energy needs. As a result, there have been widespread and persistent power cuts throughout the country. This prompts an urgent need for exploration and implementation of clean and sustainable energy fuels like biohydrogen production in order to address this crisis. Therefore, this paper discusses the current global energy challenges in relation to South Africa's problems. It then examines the feasibility of using biohydrogen production as a potential energy fuel in South Africa. Finally, it reviews the hydrogen-infrastructure development plans in the country.

---

* Corresponding author at: Tel.: +27 71 818 7504
E-mail address: patricksekoai@gmail.com

Please cite this article as: Sekoai P.T., Daramola M.O. Biohydrogen production as a potential energy fuel in South Africa. Biofuel Research Journal 6 (2015) 223-226.

## 1. Introduction

### *1.1. The need for clean and sustainable energy fuels*

The increasing usage of hydrocarbon fuels has led to challenges of climate change, environmental degradation, energy security, and severe impacts on human health (Davila-Vasquez et al., 2008). The World Health Organization estimates that thousands of people die each year from the adverse effects of climate change (World Health Organization, 2013) i.e. heat stress and flooding, leading to indirect causes including changes in disease transmission and malnutrition in response to increased competition for crop and water resources (VijayaVenkata et al., 2012). In addition, future studies predict that climate change will cause approximately 250,000 deaths per annum between the years 2030 and 2050 (World Health Organization, 2013). Moreover, changing weather patterns are expected to alter the geographical distribution of insect vectors that spread infectious diseases. Energy prices are also predicted to increase significantly over the next decades as a result of economic growth in developing nations and populations throughout the world (Zurawski et al., 2005; Asif and Muneer, 2007).

Several energy agencies have postulated that fossil fuel reserves have been declining since the 1960's due to high demand and overuse in developed countries. Besides, it is estimated that the global oil supply will be less than 10 gigabarrels per annum in the year 2030. These findings present a looming energy crisis when taking into account that the current global energy consumption is around 1 gigabarrel per annum (BP, 2013). Another major concern is that fossil fuel reserves are geographically unevenly distributed throughout the world, thus this affects oil prices due to exchange rates and transportation costs (Ru Ying and Fang, 2008).

With regards to carbon footprints, studies have indicated that the major anthropogenic gases are carbon dioxide, methane, nitrous oxide and halocarbons, respectively (Stern, 2008). Carbon dioxide is regarded as the most abundant anthropogenic greenhouse gas in the atmosphere and the main contributor to climate change (Stern, 2008). It is produced from the combustion of fossil fuel reserves and 62% is released into the atmosphere every year. The International Energy Agency predicted that 30 billion tons of $CO_2$ were emitted from hydrocarbon fuels in 2008 and this value has doubled since 1970 (Energy Information Administration, 2011). Other studies show that $CO_2$ levels have increased to 390 ppm since 2007, which is an average increase of 3.30 ppm per year during the last 6 years (Tans and Keeling, 2011). Climatologists have predicted that if no actions are taken, the levels of $CO_2$ in the atmosphere could increase up to 560 ppm by 2035 with an atmospheric temperature rise that could exceed 5 °C (Stern, 2008).

Recently, the World Bank has warned that the ongoing global warming could lead millions of people to poverty. Studies show that Africa and Asia will suffer severely from the adverse effects of climate change (World Bank, 2013). It assumed that 40% of the land used for maize production in Sub-Saharan Africa might not be arable by 2030 due to devastating environmental effects of heat, drought and floods. Asia will experience more intense cyclones and a rise in sea levels (World Bank, 2013). A review by Schmidhuber and Tubiello (2007) indicated that climate change will have huge drawbacks on agricultural outputs. Drought conditions are expected to reduce crop yields and increase livestock mortality in semi-arid areas (Cooper et al., 2008). This will be prevalent in Sub-Saharan Africa and South Asia. Climate models have predicted an increase in evapotranspiration and lower soil moisture levels in dry areas as well (Cooper et al., 2008). In addition, agricultural experts have also warned that some cultivated areas may become unfavourable for farming and various tropical grasslands may become increasingly arid. They have also predicted high risks of flooding coupled with coastal storms in Mediterranean areas due to rises in atmospheric temperature. (Schmidhuber and Tubiello, 2007).

Therefore, energy security coupled with anthropogenic climate change is regarded as one of the greatest threats facing humanity in the twenty-first century (McCartney et al., 2008). The currently-used energy fuel will not be able to cope with future energy demands. Data from the Energy Information Administration shows that more than 87% of the global energy is derived from hydrocarbon fuels with crude oil accounting for 33.5%, coal for 29.6%, and natural gas for 23.8% (Energy Information Administration, 2011). All of these emphasize an urgent need to promote the development of alternative fuels in order to meet the escalating global energy demands and reduce carbon emissions.

## 2. Energy crisis facing South Africa

South Africa is mainly dependant on coal reserves for generation of energy due to their widespread availability. However, mineralogists have indicated that South Africa's heavy reliance on coal for energy generation will result in these minerals being exhausted sooner than it is anticipated. Several authors have presented looming data regarding coal reserves in South Africa. For instance, de Jager (1982) predicted them at 58.4 billion tons. Later, Bredell (1987) estimated the reserves to be at 55.3 billion tons in subsequent years. In the year 2000, the Department of Energy and Minerals of South Africa estimated them at 33.8 billion tons. A decade later, Hartnady (2010) reported the remaining reserves at 15 billion tons. Besides, South Africa is amongst the leading carbon dioxide emitters in the world (Hartnady, 2010).

Since the beginning of 2008, the South African electricity public utility also known as Eskom, has been under intense pressure in meeting the country's high energy demands. The power utility has been functioning at full-scale due to high electricity demands; hence it is predicted to be operating at 40 gigawatts while the country's peak demand is 36 gigawatts (Energy Information Administration, 2013). This has led to widespread and persistent power shortages and blackouts throughout the country, and has also caused an economic decline estimated at 253-282 million US dollars (Energy Information Administration, 2013). This prompts the need for the exploration of clean energy fuels that will contribute to the country's energy demands and reduce carbon footprints.

## 3. Biohydrogen as a potential energy fuel

Biohydrogen production has been attracting global attention due to its social, economic and environmental merits. It has the potential to reduce the heavy reliance on fossil fuels and reduce carbon emissions from the industrial and transportation sectors (Meher Kotay and Das, 2008). Furthermore, biohydrogen gas has a higher energy capacity per unit mass (118.2 $KJ.g^{-1}$) and its combustion with oxygen results in pure water. It has a high energy yield of 122 kJ/g which is 2.75 times greater than hydrocarbon fuels (Kapdan and Kargi, 2006). The International Energy Agency envisions biohydrogen as a potential energy fuel that will be used extensively in various sectors of global economy in the next decades. These include fuel for automobiles, electricity and thermal-energy generation (International Energy Agency, 2011).

In addition, biohydrogen production *via* dark fermentation is considered a more viable approach of producing energy (Azbar et al., 2009; Wang et al., 2010; Zhang et al., 2012; Sekoai and Gueguim Kana, 2013) because it produces a clean hydrogen, it uses diverse feedstocks for its process including waste materials, and requires low-energy. Thus, it is more competitive to commercial hydrogen producing methods such as electrochemical, thermochemical, photochemical, photocatalytic, and photo-electrochemical processes (Das and Veziroglu, 2001; Dong et al., 2009). However, its industrial production faces a challenge of low yield. Research towards its industrialization requires high-throughput optimization of data for enhancing production yield, meaning that the key process conditions coupled with the equipments used for its production need to be thoroughly examined and well understood (Sekoai and Gueguim Kana, 2014).

## 4. Hydrogen-infrastructure development in South Africa

In response to South Africa's escalating energy demands, the Department of Energy of South Africa addressed an urgent need for implementation of clean and sustainable energy resources. Thus, Hydrogen South Africa (HySA) was launched in 2008 which is a 15-year plan aimed at addressing the country's energy needs. This programme is aimed at developing hydrogen-based technologies in South Africa that will contribute to energy production in the country while reducing carbon emissions (Pollet et al., 2014). HySA consist of three key centres which focus on various aspects of hydrogen-based technologies. These include HySA Catalysis, HySA Infrastructure, and HySA Systems respectively (Pollet et al., 2014).

- HySA Catalyst is an academic and industry orientated research group that focuses on providing commercial catalysts to industries in order to improve hydrogen fuel cell technologies.
- HySA Infrastructure research centre deals with the development of bench-scale hydrogen producing reactor designs. They are also actively involved in research pertaining to hydrogen storage materials and processes.
- HySA Systems focuses on the development of hydrogen fuel cell products; they also conduct technology validation and system integration, and focus on system oriented materials.

## 5. Setbacks in biohydrogen scale-up technologies

Despite the merits of biohydrogen production, its implementation has been hindered by low conversion efficiency. Current biohydrogen fermentation processes can only produce 2-3 $H_2$ $mol^{-1}$ glucose, and this incomplete conversion results in 80-90% of the nutritional content in the form of chemical oxygen demand (COD) remaining in solution (Sekoai and Gueguim Kana, 2014). Studies have also confirmed that 60-70% of the COD still remains in solution when biohydrogen fermentation processes are carried out at optimal conditions (Bhaskar et al., 2008; Das et al., 2008). In fact, the theoretical conversion efficiency for biohydrogen production is 33%, but the value generally achieved by most biohydrogen-producing bacteria stands at only about 15% (Logan, 2004; Venkata Mohan et al., 2008).

## 6. Conclusions and future outlook

Even though there has been an extensive research in biohydrogen production in recent years, several process barriers need to be tackled. They include low conversion efficiency, accumulation of fermentative organic acids that compete with biohydrogen production pathways, optimization of process conditions, improved bioreactor designs, integration of hydrogen purification systems, and hydrogen storage systems. Thus, to accelerate the development of a sustainable biohydrogen-driven economy, these recommendations are proposed for future studies:

- Exploitation of diverse organic waste materials for biohydrogen fermentation processes will result in further development by reducing the production cost because these materials are abundant, cheap, renewable, and rich in nutritional content.
- More studies need to focus on molecular biology of biohydrogen-producing microorganisms as this will generate more knowledge on the metabolic pathways of biohydrogen production. This will help in the elimination of biohydrogen-consuming methanogens and homoacetogens in order to sustain the biohydrogen production rates. Research can also focus on genetic tools to overcome the metabolic barriers by modifying the electron flux in biohydrogen-producing bacteria.
- Integration of hybrid processes is significant for enhanced biohydrogen conversion efficiency. These include biohydrogen and methane generation, biohydrogen and Microbial Fuel Cells (MFCs), biohydrogen and Microbial Electrolysis Cells (MFCs), as well as dark and photo-fermentation processes.
- High-throughput experimentations are pivotal in biohydrogen fermentation processes in order to obtain consistent data for scale-up studies. This will require novel reactor designs with high-level of parallelization combined with on-line computer systems for assessing the critical process conditions during biohydrogen production.
- Application of mathematical and statistical tools in biohydrogen fermentation processes is also essential in order to investigate the synergistic effects of various process parameters on the overall yield.

## References

Asif, M., Muneer, T., 2007. Energy supply, its demand and security issues for developed and emerging economies. Ren. Sust. Energ. Rev. 11, 1388-1413.

Azbar, N., Cetinkaya Dokgöz, F., Keskin, T., Korkmaz, K.S., Syed, H.M., 2009. Continuous fermentative hydrogen production from cheese whey wastewater under thermophilic anaerobic conditions. Int. J. Hydrog. Energ. 34, 7441-7447.

Bhaskar, Y.V., Venkata Mohan, S., Sarma, P.N., 2008. Effect of substrate loading rate of chemical wastewater on fermentative biohydrogen production in biofilm configured sequencing batch reactor. Bioresour. Technol. 99, 6941-6948.

BP Energy Report for 2013. London, United Kingdom. Available at http://.www.bp.com/content/dam/bp/pdf/statistical-review. (accessed on 18 March 2015).

Bredell, J.H., 1987. South African coal resources explained and analysed. Geol. Surv. South Africa. 1-39.

Cooper, P., Dimes, J., Rao, K., Shapiro, B., Shiferaw, B., Twomlow, S., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? Agri. Eco. Environ. 126, 24-35.

Das, D., Khanna, N., Veziroglu, T.N., 2008. Recent developments in biological hydrogen production processes. Chem. Ind. Chem. Eng. Quart. 14, 57-67.

Das, D., Veziroglu, T.N., 2001. Hydrogen production by biological processes: a survey of literature. Int. J. Hydrog. Energ. 26, 13-28.

Davila-Vazquez, G., Alatriste-Mondragón, F., de León-Rodríguez, A., Razo-Flores, E., 2008. Fermentative hydrogen production in batch experiments using lactose, cheese whey and glucose: influence of initial substrate concentration and pH. Int. J. Hydrog. Energ. 33, 4989-4997.

de Jager, F.S.J., 1982. Coal Reserves of the Republic of South Africa, Geological Survey. Bulletin.74, 289-330.

Dong, L., Zhenhong, Y., Yongming, S., Xiaoying, K., Yu, Z., 2009. Hydrogen production characteristics of the organic fraction of municipal solid wastes by anaerobic mixed culture fermentation. Int. J. Hydrog. Energ. 34, 812-820.

Energy Information Administration. Annual Energy Outlook-2011, with Projections to 2035. Washington DC, USA. Available at http://www.eia.gov/oiaf/aeo/aeoref_tab.html .(accessed on 18 March 2015).

Energy Information Administration. Electricity demands in South Africa, 2013. Available at http://www.eia.doe.gov/cabs/South_Africa/Electricity.htmls. (accessed 18.03.2015).

Hartnady, C., 2010. South Africa's Diminishing Coal Reserves. South African J. Sci. 106,18-22.

International Energy Agency. Annual Energy Report, 2011. Paris, France. Available at http:// www.iea.org/pdf. (accessed on 18 March 2015).

Kapdan, I.K., Kargi, F., 2006. Bio-hydrogen production from waste materials. Enzyme Microb. Technol. 38, 569-582.

Logan, B.E., 2004. Biologically extracting energy from wastewater: biohydrogen production and microbial fuel cells. Environ. Sci. Technol. 38,160-167.

McCartney, G., Hanlon, P., Romanes, F., 2008. Climate change and rising energy costs will change everything: A new mindset and action plan for 21st Century public health. Public Health. 122, 658-663.

Meher Kotay, S., Das, D., 2008. Biohydrogen as a renewable energy resource-prospects and potentials. Int. J. Hydrog. Energ. 33, 258-263.

Pollet, B., Pasupathi, S., Swart, G., Mouton, K., Lototskyy, M., Williams, M., et al., 2014. Hydrogen South Africa (HySA) Systems Competence Centre: Mission, objectives, technological achievements and breakthroughs. Int. J. Hydrog. Energ. 3577-3596.

Ru Ying, L., Fang, H.H.P., 2008. Hydrogen production characteristics of photoheterotrophic *Rubrivivax gelatinosus* L31. Int. J. Hydrog. Energ.33, 974-980.

Schmidhuber, J., Tubiello, F.N., 2007. Global food security under climate change. Pro.Nat. Aca. Sci. 104, 19703-19708.

Sekoai, P.T., Gueguim Kana, E.B., 2013. A two-stage modelling and optimization of biohydrogen production from a mixture of agro-municipal waste. Int. J. Hydrog. Energ. 38, 8657-8663.

Sekoai, P.T., Gueguim Kana, E.B., 2014. Semi-pilot scale production of hydrogen from Organic Fraction of Solid Municipal Waste and electricity generation from process effluents. Biomass Bioenergy. 60, 156-163.

Stern, N., 2008. The economics of climate change. American Econ. Rev. 98, 1-37.

Tans, P., Keeling, R., 2011. Trends in atmospheric carbon dioxide. Available at http://www.esrl.noaa.gov/gmd/ccgg/trends. (accessed on 18 March 2015).

Venkata Mohan, S., Mohanakrishna, G., Sarma, P.N., 2008. Integration of acidogenic and methanogenic processes for simultaneous production of biohydrogen and methane from wastewater treatment. Int. J. Hydrog. Energ. 33, 2156-2166.

VijayaVenkata, R.S., Iniyan, S., Goic, R., 2012. A review of climate change, mitigation and adaptation. Ren. Sust. Energ. Rev. 16, 878-897.

Wang, H., Fang, M., Fang, Z., Bu, H., 2010. Effects of sludge pretreatments and organic acids on hydrogen production by anaerobic fermentation. Bioresour. Technol. 101, 8731-8735.

World Bank, 2013. Toward a Sustainable Energy Future For All: Directions for the World Bank Group Energy Sector. Geneva, Switzerland. Available at http://www.wds.worldbank.org. (accessed on 18 March 2015).

World Health Organization. Protecting Health from Climate Change. World Health Day 2013. World Health Organization, Geneva, Switzerland. Available at http://www.who.int/globalchange/publications. (accessed on 18 March 2015).

Zhang, Y., Zaijuan, W., Hong, Z., Gu, X., Xu, N., 2012. Hydrogen-selective zeolite membrane reactor for low temperature water gas shift reaction. J. Chem. Eng. 197, 314-321.

Zurawski, D., Meyer, M., Stegmann, R., 2005. Fermentative production of biohydrogen from biowaste using digested sewage sludge as inoculum. In: Proceedings of 10th International Waste Management and Landfill Symposium. Cagliari, Italy.

Please cite this article as: Sekoai P.T., Daramola M.O. Biohydrogen production as a potential energy fuel in South Africa. Biofuel Research Journal 6 (2015) 223-226.