

Utilization of Plantain (*Musa species*) Leaves for Biogas Production

Abstract

Aim: To determine the relationship between the volumes of biogas that can be produced using different biomass/water ratios.

Study design: Biogas was produced by the anaerobic digestion or fermentation of plantain leaves. A practical laboratory scale experimental design was used to find out the effect of biomass/water ratio and retention time on the volume of biogas generated using sun-dried and ground plantain leaves as the feed stock.

Place and duration of study: The research was carried out in Chemistry Department, University of Benin City, Nigeria. Study was done between March and June, 2012.

Methodology: Five (5) biodigesters were used for the biogas production with different biomass/water ratios (1:1, 1:2, 1:3, 1:4 and 1:5) and for a 10-day retention period. The average pH and temperature of the biodigesters were 7.8 ± 0.5 and $30 \pm 20^\circ\text{C}$ respectively. The biogas produced was characterized using a gas chromatography system 6890 series (and 6890 plus)

Results: Certain amounts of Methane, Nitrogen, Oxygen were detected in the gas produced. Proximate analysis of the plantain leaves gave the percentage composition by mass of Nitrogen(0.139%), Crude protein(0.906%), Potassium(1.146%), Sodium(0.063%), Phosphorus(0.085), Calcium(2.003%), Magnesium(0.690%), Sulphate(0.076%), Organic carbon(12.520%), Organic matter(28.002%) and ash content(5.300%).

Conclusion: Using plantain leaves as feed stock, optimum biogas production can be attained using a biomass/water ratio of 1:4, over a ten(10)-day period. But there is need for further work to validate reliability and also reduce the volume of nitrogen in the biogas produced.

1.0 Introduction

The use and availability of energy for domestic and industrial purposes is a major concern for most people these days. Both developed and developing nations of the world now spend a large proportion of their earnings on gas and oil [1, 2]. These fossil fuels are being continuously used to a large extent. However, since these forms of energy are non-renewable, their availability will continue to decrease and costs will continue to be on the rise. [3]. The predicted continuous increase in oil price is due to the limited nature of fossil resources. The turbulence in the Nigerian oil and gas industry as a nation and recent global increase in the price of fuels worldwide, for example, proves that the above is true. Although Nigeria is an oil and gas producing nation, the country faces a severe energy crisis due to continuous disruptions in the supply of petroleum products. Vandals, rebels, energy hackers and criminals find Nigeria's centralized oil and gas distribution networks are easy targets [4].

40 A more serious issue of international concern is climate change. There has been a global
41 movement toward reduced use of fossil resources though energy is a very fundamental tool
42 for development. Nigeria and other developing countries of the world are bedeviled by
43 additional challenges regarding environmental protection due to their heavy dependency on
44 biomass and fossil fuel. According to the study by Adaramola and Oyewola, Nigeria is
45 endowed with enormous amounts of conventional energy resources such as crude oil, tar
46 sands, natural gas and coal, as well as a good number of renewable energy resources such as
47 hydro, solar, wind and biomass. It has been reported that most developing nations of the
48 world are facing serious shortage of fuels, the most commonly used fuel being wood fuel [5].
49 For this reason, the search for new and renewable energy sources has received worldwide
50 attention. One excellent source of renewable energy is biogas.
51 Biogas originates from biogenic material and is a type of biofuel. It is normally produced by
52 the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure,
53 sewage, municipal wastes, green wastes, plant materials and crops [6]. In the absence of
54 oxygen, anaerobic bacteria decompose or digest organic matter and produce a mixture of
55 gases mainly composed of methane (CH_4) and carbon dioxide (CO_2) called biogas.

56 Anaerobic digestion is a natural process and there are digesters that are designed and
57 managed to accomplish this decomposition. As a result of the digestion, organic material is
58 stabilized and gaseous by-products, primarily methane (CH_4) and carbon dioxide (CO_2) are
59 released [7]. The process of biogas production takes place under different temperature
60 regimes. Typically, anaerobic digesters are designed to operate in either the mesophilic (20-
61 45°C) or thermophilic ($45\text{-}60^\circ\text{C}$) temperature ranges. However, methanogenesis is also
62 possible under low temperature ($< 20^\circ\text{C}$), this referred to as psychrophilic digestion [8].
63 Anaerobic digestion at psychrophilic temperatures has not been as extensively explored as
64 either mesophilic or thermophilic digestion, probably due to little anticipation of the
65 development of economically attractive systems using this technology [9]. Generally, the
66 production of methane from anaerobic digestion depends on the temperature, the kind of
67 material added to the digester, the solids loading, the pH and the hydraulic retention time
68 (HRT) [10,11].

69 There are four metabolic stages involved in the production of methane using anaerobic
70 digestion process. First, polymers from particulate organic matters are converted into
71 monomers by extra cellular enzymes through the process of hydrolysis. Then the soluble
72 organic matter and the products of hydrolysis are converted into organic acids, alcohols,
73 hydrogen and carbon dioxide by acidogenic bacteria. The third stage involves the conversion
74 of the products of acidogens into acetic acid, hydrogen and carbon dioxide by acetogenic
75 bacteria. Lasty, methanogenic bacteria effect the production of methane from acetogen
76 products. [12]

77 The main advantage in using anaerobic digestion is that while the biogas produced, can be
78 used for steam heating; cooking and generation of electricity [13,14,15], the effluent
79 produced can be used as a biofertiliser or soil conditioner [16].

80 Each year some millions tons of methane are released worldwide into the atmosphere through
81 microbial activities [17]. About 90% of the emitted methane comes from biogenic sources
82 (decomposition of biomass). The remainder is of fossil origin such as through petrochemical
83 processes. In the northern hemisphere, the present methane concentration amounts to about
84 1.65ppm [18]. Unlike fossil fuel combustion, biogas production from biomass is considered
85 CO_2 neutral and therefore does not emit additional greenhouse gases into the atmosphere.
86 However, if biogas is not recovered properly, it will contribute a greenhouse effect twenty
87 times worse than if methane is simply combusted [19]. Therefore, there is a real incentive to
88 transfer biogas combustion energy into heat and/or electricity. Biogas production from
89 anaerobic digestion also helps in treating the organic wastes and reducing the environmental
90 impact of these wastes. It contributes to a better image of the farming community while
91 reducing odour, pathogens and weeds from the manure and producing an enhanced fertilizer
92 easily assimilated by plants [20]. So, unlike the situation where when biomass is totally burnt,

93 it is possible to return much of the original material to the land and thereby improve the soil
94 quality and displace the use of chemical fertilizer.

95 Other advantages of anaerobic production biogas include revenue from possible reuse of
96 digested solids as livestock bedding, reduction of work for firewood collection and cooking,
97 high quality solids for soil amendment and reduced groundwater and surface water
98 contamination potential [21,22].

99 Production of methane-rich biogas through anaerobic digestion of organic materials provides
100 a versatile carrier of renewable energy, as methane can be used in replacement for fossil fuels
101 in both heat and power generation and as a vehicle fuel, thus contributing to cutting down the
102 emissions of greenhouse gases and slowing down climate change. Methane production
103 through anaerobic digestion has been evaluated as one of the most energy-efficient and
104 environmentally benign ways of producing vehicle biofuel [2]. The European Union (EU)
105 had set a target of increasing the utilisation of biofuels in vehicles to 5.75% by year 2010 in
106 each member state [3], while in 2005 the market share of biofuels in Finland was 0.1% [23].
107 Methane production from energy crops and crop residues could be an interesting option for
108 increasing the domestic biofuel production, as it has been estimated that within the
109 agricultural sector in the EU, 1500 million tons of biomass could be anaerobically digested
110 each year, half of this potential accounted for by energy crops [24].

111 Many researchers have studied the production of biogas from sources ranging from crops,
112 human and animal wastes, municipal waste water and sludge [20,24-26], to non-conventional
113 crops [27-29].

114 Plantains (*Musa spp.*, AAB genome) are plants producing fruits that remain starchy at
115 maturity [30] and need processing before consumption. Plantain production in Africa is
116 estimated at more than 50% of worldwide production. West and Central Africa contribute 61
117 and 21%, respectively. Nigeria is one of the largest plantain producing countries in the world
118 [31]. The dried leaves, sheath and petioles are used as tying materials, sponges and roofing
119 material. Plantain leaves are also used for wrapping, packaging, marketing and serving of
120 food [32].

121 Biogas has been produced from plantain fruit and the peels thereof [20,22,33].

122 However, in this study, the biogas potentials of plantain leaves was examined on a laboratory
123 scale.

124

125 **2.0 Materials and Methods**

126

127 *2.10 Sample Collection*

128 Plantain leaves were collected from Ugbowo axis of Benin City (6°19'N 5°36'E), Nigeria.
129 The leaves were sun dried for two weeks and then milled to powder using a dry grinding
130 machine.

131 *2.20 Gas Production and Measurement*

132 50.00g of the powdered plantain leaves was charged into a Buckner flask (that acts as
133 biodigester) and mixed with appropriate amount of water to give various biomass/water ratios
134 of 1:1, 1:2, 1:3, 1:4 and 1:5. The pH of the slurry was 7.70. The Buckner flask was tightly
135 covered with rubber bungs to avoid gas linkage. The flask was connected to a measuring
136 cylinder which had been filled with water and inverted into a trough resting on a beehive
137 shelve. The experiment was carried out at ambient temperature for 10 days.

138 The volume of biogas produced was measured by water displacement in the inverted
139 cylinder. This measurement was carried out daily for the retention period of 10days.

140 *2.30 Gas Collection and Analysis*

141 The same set up used for the measurement of the gas produced was repeated with some
142 modifications. The measuring cylinder was omitted with the Buckner flask directly

143 connected to an improvised gas storing medium. The gas collected was analyzed using gas
144 chromatograph (GC-6890 model) equipped with a thermal conductivity detector.

145 2.40 Proximate Analysis of Plantain Leaves

146 Proximate analysis of the plantain leaves was carried out using the methods described by
147 AOAC [34]. The parameters determined include: Nitrogen, Crude protein, Potassium,
148 Sodium, Phosphorus, Calcium, Magnesium, Sulphate, Organic carbon, Organic matter and
149 ash content.

150

151 3.0 Results and Discussion

152 The result of proximate analysis of plantain leaves is shown in Table 1. The result shows that
153 plantain leaves have a high concentration of organic matter and organic carbon which is
154 indicative of high biogas yield. The result however shows relatively low contents of
155 phosphorus, nitrogen, potassium, calcium, magnesium and ash. The trend of the various
156 parameters determined is in the order: Organic matter > organic carbon > ash > calcium >
157 Potassium > crude protein > Magnesium > Nitrogen > Phosphorus > Sulphate > sodium.
158

159 **Table 1: Percentage Composition of the Plantain Leaves**

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Parameters	% Composition
Ash	5.300
Nitrogen	0.139
Crude Protein	0.906
Potassium	1.146
Sodium	0.063
Phosphorus	0.085
Calcium	2.003
Magnesium	0.690
Sulphate	0.076
Organic carbon	12.520
Organic matter	28.002

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Parameters	Value, mol %	Agip Standard, mol %
Methane (C ₁)	15.40	96.93
Ethane (C ₂)	0.14	2.55
Propane (C ₃)	0.00	0.40
Isobutene (i C ₄)	0.00	0.00
n-butane (n C ₄)	0.00	0.00
Iso-pentane (i C ₅)	0.00	0.00
n-pentane (n C ₅)	0.00	0.00
Hexane plus (C ₆ ⁺)	0.00	0.00
H ₂ S	0.01	0.00

O ₂	8.01	0.00
CO ₂	1.35	0.00
Nitrogen	75.10	0.13
TOTAL	100.01	100.00

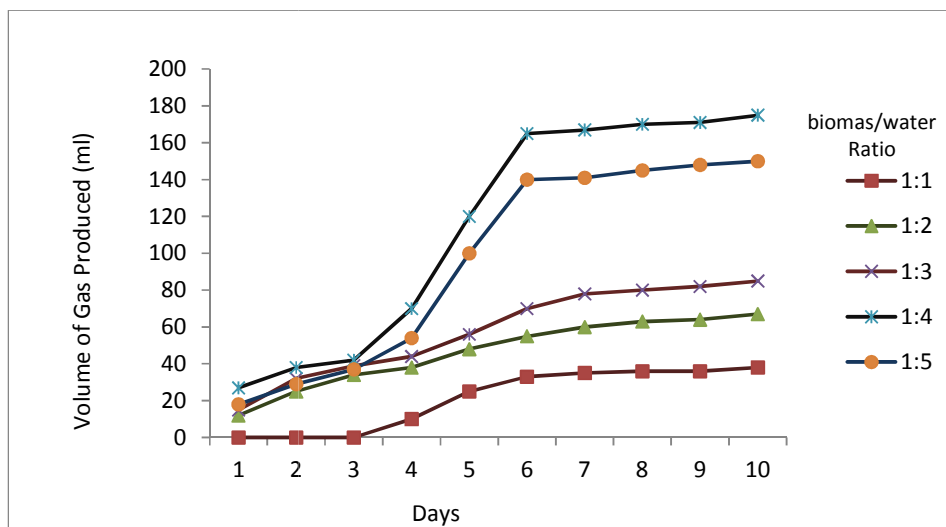
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Table 2: Quality of biogas from Plantain Leaves

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165 The results of the chromatographic analysis of the biogas produced are presented in table 2
 166 above. It shows that the yield of methane gas (15.40%) was considerably higher than that of
 167 other components like CO₂ (1.35%) and O₂ (8.01%). However the high yield nitrogen gas
 168 (75.10%) is undesirable as the Agip standard is 0.13%. The high nitrogen content may be due
 169 to contamination by atmospheric nitrogen as a result of the crude method of using surgical
 170 hand gloves for the gas collection.

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Fig.1: Daily volume of biogas produced for the different biomass/water ratio regimes

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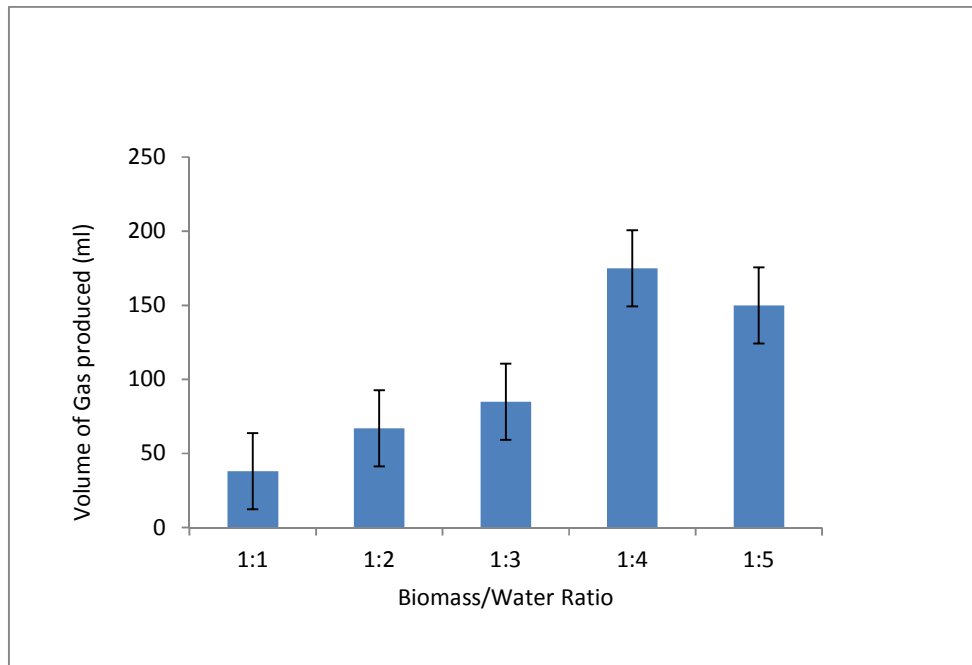


Fig. 2: Cumulative biogas yield from Plantain Leaves

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178 Figures 1 and 2 show the daily biogas production and the cumulative volumes, respectively,
179 for a period of 10 days in five different biodigesters with biomass/water ratios of 1:1, 1:2,
180 1:3, 1:4 and 1:5, corresponding to A, B, C, D and E respectively. Gas production started in all
181 the biodigesters after the first day except for digester A that had a lag phase of 3 days. This
182 may be due to the limited quantity of water in this biodigester.

183 Fig. 1 shows that optimum biogas production was achieved on the sixth day. This is because
184 the marginal volume of biogas produced daily was in incremental amounts up to the sixth
185 day. Therefore, the marginal increase in the volume of biogas produced, with respect to days,
186 became very minimal. This is expected since the population of the microbes responsible for
187 the digestion decreases with time.

188 Fig. 2 shows that the highest cumulative volume of biogas occurred in digester D, with
189 dilution ratio of 1:4, while lowest volume was observed in biodigester A (1:5). This shows
190 that the daily and cumulative volumes of biogas produced was substrate dependent, with a
191 maximum at a dilution ratio of 1:4. This is consistent with previous work on Elephant grass
192 [35], in which the dilution regime of 1:4 produced the highest volume of biogas. Generally
193 the order of biogas production with respect to dilution ratio was 1:4 > 1:5 > 1:3 > 1:2 > 1:1.

194 **5.0 Conclusion**

195 Using plantain leaves as feed stock, optimum biogas production can be attained using a
196 biomass/water ratio of 1:4. But there is need for further work to validate reliability and also
197 reduce the volume of nitrogen in the biogas produced.

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200 **6.0 References**

2011. Kerr RA. Oil resources: The looming oil crisis could arrive uncomfortably soon. *Science*.
202 2007;316: 351.
2032. L-B-Systemtechnik LBS. Well-to-Wheel analysis of energy use and greenhouse gas
204 emissions of advanced fuel/vehicle systems – A European Study. 133 p., GmbH, Ottobrunn
205 Germany; 2002.
2063. European Parliament. Directive 2003/30/EC of the European Parliament and of the Council
207 of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.
208 Official J. European Union. 2003;123: 42–46.
2094. Abdulrahim A. Nigeria’s biogas potential estimated at 600,000MW: Quicknote bioenergy
210 potential. *Biopact*. ;2006.
2115. Adaramola MS, Oyewole OM. Wind speed distribution and characteristics in Nigeria. *ARNP*
212 *J. Eng. Appl. Sci.* 2011; 6:2.
2136. Barker, James C Methane fuel gas from Livestock wastes: A summary.EBAE. 2001;71-80
2147. Mshandete AM, Parawira W. Biogas technology research in selected sub-saharan africa. *Afr.*
215 *J Biotech.* 2009;8(2):116-125.
2168. Bitsadze A. *Recommendations for Construction of Biogas Installations at small Farms(in*
217 *Georgian.)* energy efficiency centre of Georgia, Tbilisi; 2001.
2189. Urmila Bala, Eric Buysman, Niccoló Meriggi, Lionel S. Zisengwe and Grietje Zeeman.
219 Biogas production in climates with long cold winters. Wageningen University, The
220 Netherlands. 2008; Page 6.
22110. Dinamarca S, Aroca G, Chamy R, Guerrero L. The influence of pH in the hydrolytic stage of
222 anaerobic digestion of the organic fraction of urban solid waste. *Wat. Sci. Technol.* 2003;
223 48(6): 249–254.
22411. Ilori OM, Adebusoye AS, Lawal AK, Awotiwon AO. Production of Biogas from Banana and
225 Plantain Peels. *Adv. Environ. Biol.* 2007;1(1): 33-38.
22612. Vavilin VA, Rytov SV. A description of hydrolysis kinetics in anaerobic degradation of
227 particulate organic matter. *Bioresour. Technol.* 1996; 56(2–3):229–237.
22813. Mata-Alvarez J, Cecchi F, Llabres P, Pavan P. “Anaerobic digestion of the Barcelona central
229 food market organic wastes: Experimental study”, *Biores.Technol.* 1992;39: 39-48
23014. Misi SN, Forster CF. Semi-continuous anaerobic co-digestion of agrowaste. *Environ.*
231 *Technol.* 2002; 23:445-451.
23215. Ahring B K, Mladenovska Z, Iranpour R, and Westermann P. “State of the art and future
233 perspectives of thermophilic anaerobic digestion”, *Water science and Technology.* 2002; 45:
234 298-308.
23516. Ali R, Tekin, Coskun Dalgic A. “Biogas production from olive pomace”, *Resources,*
236 *Conservation and recycling.* 2000; 30: 301-313.
23717. EPA (US Environmental Protection Agency). A comprehensive analysis of Biodiesel impacts
238 on exhaust emission. Draft technical report: EPA 420-P-02-001. 2002; Page118. internet:
239 www.epa.gov/otaq/models/biodsl.html.
24018. EEA: (European Environmental Agency). How much bioenergy can Europe produce without
241 harming the environment. 2006; **7**: 67.
24219. IPCC [Inter Governmental Panel on climate change 2001]; climate change -The scientific
243 Basis; Third Assessment Report; 2001.
24420. Dahunsi SO, Oranusi US. Co-digestion of Food Waste and Human Excreta for Biogas
245 Production. *British Biotechnol. J.* 2013; 3(4): 485-499
24621. Arvanitoyannis S, Kassaveti A, Stefanatos S. Current and potential uses of thermally treated
247 olive oil waste, *International Journal of food Science and Technology.* 2007;42(7):852-867.

24822. Eze JI, Ezeudu CC. Evaluation of biogas generating potentials of animal and food wastes .Int.
249 J. of Biosci. 2012;2:10(1)73-81.
25023. Commission of the European Communities COM 628 Biomass action plan, communication
251 from the Commission. 2005; Page47, Commission of the European Communities, Brussels.
25224. Amon T, Hackl E, Jeremic D, Amon B, Boxberger J. Biogas production from animal wastes,
253 energy plants and organic wastes. In: van Velsen, A. F. M. & Verstraete, W. H. (eds), Proc.
254 9th World Congress on Anaerobic Digestion: Technology Institute, zw, Antwerp. 2001;
255 381–386.
25625. Ojolo SJ, Oke SA, Animasahun OK, Adesuyi BK. Utilization of poultry cow and kitchen
257 wastes for biogas production: A comparative analysis. Iranian J. Environ. Health Sci. Eng.
258 2007;4: 223-228.
25926. Mata-Alvarez J, Macé S, Llabres P. Anaerobic digestion of organic solid wastes. An
260 overview of research achievements and perspectives. Biores. Technol. 2000;74: 3–16.
26127. Parawira W, Read JS, Mattiasson B. A study of two-stage anaerobic digestion of solid potato
262 waste using reactors under mesophilic and thermophilic conditions. Environ. Technol. 2007;
263 28:1205-1216.
26428. Kalia A, Kanwar S. Anaerobic fermentation of Ageratum for biogas production. Biol.
265 Wastes. 1990; 32: 155–158.
26629. Parawira W. Biodiesel production from *Jatropha curcas*: A Review. *Scientific Research and*
267 *Essays*, 2010; 5(14):1796-1808.
26830. Marriot J, Lancaster P. Bananas and plantains. In: H.T. Chan (ed.), Handbook of Tropical
269 Food. Dekker, New York. 1983; 85-143.
27031. Food and Agriculture Organization Production Yearbook 2004. FAO, Rome; 2006.
27132. National Agricultural Extension and Research Liason Services. 2005. Annual Agricultural
272 Performance Survey Report of Nigeria for 2005. NAERLS Press, Ibadan.
27333. Velmurugan B, Alwar Ramanujam R. Anaerobic Digestion of Vegetable Wastes for Biogas
274 Production in a Fed-Batch Reactor. Int. J. of Emerg. Sci. 2011; 1(3) 455-486.
27534. AOAC Method of analysis of the Association of Official Analytical Chemist, 15th ed.
276 Washington D.C. USA; 1990.
27735. Olugbemide AD, Ufuah MOE, Igbonnazobi LC, Osula JE. Effect of Alkaline pre-treatment
278 on anaerobic batch digestion of elephant grass (*Pennisetum purpureum*). J. Chem. Soc. Nig.
279 2010; 36(1):176-179.
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