ANAEROBIC DIGESTION MEDIUM-SCALE CDM PROJECT FOR DAIRY LIVESTOCK AND AGRICULTURE INTEGRATION

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Abstract. *Dairy producers should specialise their activity with modern production techniques/technologies to meet the requirements of a stricter consumer market. In this sense, crop and livestock systems integration through anaerobic-digestion-based integrated farming systems represents an interesting alternative for using the dairy farm available resources. Anaerobic digestion can be used as basis for supplying energy, fertilizers and feed needs of a farming unit, by means of digestion products usage: the biogas, that can be used in energy conversion systems to provide the required energy by processing/conservation equipments for milk and other farming products; and the effluent, that can be used as replacement for chemical fertilizers and for aquatic plants/fish feeding. Fossil fuels replacement by biogas can be classified as a Clean Development Mechanism (CDM) project, and economical resources obtained by carbon credits commercialisation may support the required production modernisation. The paper analyses the anaerobic digestion process, evaluating biogas generation and usage as energy source for milk chilling in medium-scale dairy farms, as well as the quantification of carbon credits generated by introducing proper manure and culture remains management.*

Keywords*: rural development, medium-scale dairy farm, biogas and effluent utilisation, thermoeconomical analysis*

1. INTRODUCTION

Nowadays, concerns about energy availability, processes optimisation and stricter environmental regulations are motivating researches on energy conversion/ generation systems based on renewable energy as a replacement for petroleum and coal. Depending on geographical aspects, the most promising renewable sources are solar, aeolic and geothermal energy, as well as biomass.

Biomass was the main source of energy until the early 20th century, when petroleum and coal took its place. By the 1990s, environmental concerns led to retaking researches on conversion systems based on this energy resource, mainly studying thermochemical (direct combustion and gasification) and biological processes (anaerobic digestion). Such researches allowed the development of equipment capable of improving the energy potential of this low-density source and the growth of its usage.

The largest biomass resources are in rural areas and agroindustries, where the amount of organic waste (harvest waste, animal manure, agroindustrial effluents and others) is significant and might justify the implementation of decentralised small-scale energy conversion systems for meeting local energy requirements and/or for integration to the energy grid.

Dairy farms present some characteristics that make them very interesting for this kind of implementation. On one hand, there is a great amount of organic waste (mainly the manure), for which a proper final destination is required and, on the other hand, a significant energy demand for proper handling, treatment and conservation of the milk, mainly in farms that are distant from dairy collection centres.

Due to the growing demand for dairy products with extended expiration dates, maintaining their organoleptic, nutritive and quality characteristics, several governmental regulations require, among other procedures, in-situ milk chilling.

The Brazilian dairy sector is characterised by a large number of producers, presenting low productiveness and product quality. In order to change this scenario, the Brazilian government implemented the National Program of Milk Quality Improvement (PNQL) requiring chilling in order to increase the sector competitiveness and to promote its modernisation (Nero et al., 2005). In fact, the implementation of a milk chilling system is necessary for the producer to assure his presence in a very competitive market. Nevertheless, the main drawbacks to a wider use of those systems, besides cultural aspects, are access to financial resources and energy availability.

The implementation of a Kyoto Protocol Clean Development Mechanism (CDM) project for proper manure management in anaerobic digesters, in order to reduce greenhouse gases (GHG) emissions may be a solution for these drawbacks. This kind of project generates financial resources by carbon credit commercialisation, as well as a low-cost energy source (biogas produced by digestion process) and a natural replacement for chemical fertilizers (effluent).

The Integrated Farming System (IFS) resulting from project implementation is an interesting way of reducing farming activity and investment costs (Chan, 1985), particularly for small and medium-scale farms, as well as to minimize the environmental impact from human activity.

2. MILK CHILLING

Milk offers conditions for micro-organisms proliferation in a short time span. Proper procedures for extraction, handling, conservation and transport are important in order to inhibit such proliferation or to destroy micro-organisms. Concerning conservation, both physical, chemical or biological methods can be employed, and must be applied as soon after extraction as possible in order to take advantage of the action of some natural inhibitors present in the milk.

In order to foster milk production specialization in Brazil, producers get economic incentives for delivering cold milk to collecting centres: 5% additional in milk price, and a reduction of 50% in transport fees (Sant'anna et al., 2003).

Nevertheless, considering that investment costs are a direct relation to the cooling tank size, as well as investment risks, such incentives may be insufficient for a single small producer to implement an in-situ milk cooling system. A larger collective system implementation would be a more suitable solution in a short-term scenario, and it would also lead to the establishment of a producer cooperative in the future.

3. THE ANAEROBIC DIGESTION

Anaerobic digestion (AD) is a two-stage process to decompose organic residues (volatile solids) in the absence of oxygen, producing biogas and effluent as products. At the first stage, volatile solids (VS) are converted into oleic acids by anaerobic bacteria known as acid formers. At the second stage, acids are converted into biogas by other bacteria known as methane formers.

Biogas is basically a mixture of CH_4 and CO_2, as well as other gases in small amounts. Its heating value and density respectively affect the operation of energy-converting equipment and compression-storage auxiliary systems. Such parameters are a function of biogas composition (Table 1), which is basically dependant on organic residues quality and digestion process characteristics. Typical values of lower heating value (LHV) for a biogas with 50 to 80% of methane ranges from 17,82 to 28,44 MJ/m^3 (Bayer et al., 2000).

Table 2 presents the typical consumption of several biogas usages. The most common of such usages in farms are direct combustion for cooking and lighting and internal-combustion engines operation.

Effluent, the other product resulting from anaerobic digestion, can be used as fertilizer for several types of cultures, since it is composed of organic matter with low carbon and high phosphorus content, and its advanced decomposition state facilitates nutrient absorption by the soil.

Table 1. Biogas typical composition (Walsh et al., 1988)

Component	Amount
CH_4, % vol.	55-70
CO_2, % vol.	30-45
N_2, % vol.	0-2
H_2S, ppm	~500
NH_3, ppm	~100

Table 2. Typical biogas consumption (Werner et al., 1989; Massotti, 2003)

Usage	Consumption
Cooking (one person)	0,24-0,3 m3/day
Lightning (40W lamp)	0,283 m3/h
Lightning (gas lamp)	0,12 m3/h
Electricity generation	0,62 m3/kWh
Absorption fridge	2,5 m3/day
Gas-driven engines	0,424 m3/h/HP

4. FARM BIOGAS-BASED ENERGY SYSTEMS AND ENERGY DEMANDS

A biogas-based energy system is typically composed by a biodigester, a gas-handling unit and one energy-converting equipment or more, as shown in Fig. 1. Removal of CO_2 content raises biogas heating value and eases it compression (Walsh et al. 1988; Jensen & Jensen, 2000), and H_2S removal avoids early deterioration of converting machinery, since such gas, when combined to water forms sulphur acid, which is highly corrosive.

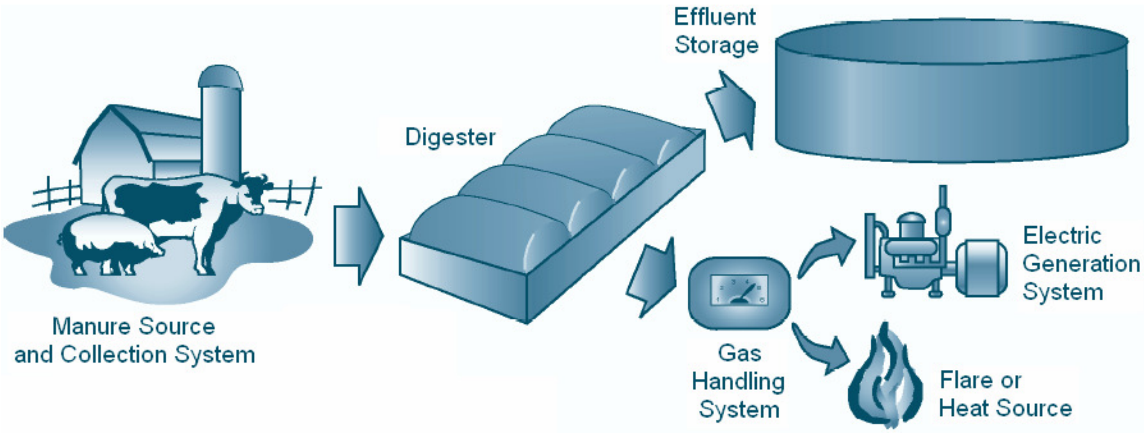

Figure 1. Biogas-based energy generation system (AgStar, 2002)

In small-scale dairy farms, main usage for biogas generated by anaerobic digestion is replacement of kerosene or firewood, mainly used for cooking and lighting (Moog et al. 1997; Rodriguez et al., 1998). In medium and large-scale farms, besides these basic usages, there is also demand of hot water for several equipment and stable cleaning, cold generation for milk chilling, and electricity for lighting and equipment. For instance, the several processes connected to chilling 1 ton of milk require 100 to 120 MJ (Riva, 1992). It must be pointed out that pre-cooling the milk produced by one single cow requires only 15% of biogas generation potential of such cow (Mears, 2001).

It is a common practice, in dairy farms that are far-off electricity distribution network, to use combustion engine-driven generators, based either in Otto or Diesel engines, to generate the energy required for milk extraction and cooling, lightning, cleaning, and other equipment/systems.

Liquid-fuelled internal combustion engines can be easily adapted for partial or total use of biogas as replacement for fossil combustibles (gasoline, kerosene, and diesel). Considering a stationary engine, it is basically necessary to add a biogas mixer, since the digestor itself acts as storage tank, delivering the biogas at pressure levels suitable for a proper engine operation.

5. THE GREENHOUSE EFFECT AND AGRICULTURE

Human activities have always impacted the environment, but after the Industrial Revolution in the 18th century this impact became global and exponentially increased, reaching levels that are severely damaging the Earth, as pointed out by the recent IPCC 4th report on climate change (IPCC, 2007).

Such activities produce greenhouse effect gases (GHG), affecting atmosphere composition and increasing global average temperature (IPCC estimates that such increase ranges from 1,8 to 4,0°C by the year 2100). Among the GHG it must be pointed out the carbon dioxide (CO_2), nitrous oxides (NO_X), methane (CH_4) and hydrofluorocarbons (HFC), derived respectively from fossil combustibles, biomass burning and agricultural activities, refrigeration and sprays (Liborio, 2005).

The Intergovernmental Panel on Climatic Change (IPCC) was created by United Nations in 1988 to investigate and analyse the effect o GHG emissions. Another UN initiative was the Kyoto Protocol, an international agreement imposing reduction targets for developed countries GHG emissions by the year 2012, and demanding from developing countries the commitment with a clean and sustainable development.

Kyoto Protocol also established flexible mechanisms in order to help the developed economies to meet their GHG targets by purchasing GHG emission reductions (the Certified Emission Reductions - CER, also called “carbon credits”) from elsewhere, either from financial exchanges or from projects that reduce emissions in developing economies under the Clean Development Mechanism (CDM), like the implementation of IFS systems based on biodigesters and biogas-generated electricity. The CDM Executive Board is responsible for CER emission and control.

Several developing countries are taking measures to take a significant part of such “carbon market” in order to get investments for their own development. Brazilian government, for example, estimates that carbon credits demand are reaching US$ 30 billions/year by 2012, with a Brazilian market share of at least 10% (Brunacci, 2005).

There was 244 CDM projects running in 2005. Main beneficiary countries are Brazil, India and China, with respectively 74 (30%), 54 (22%) e 14 (8%) projects (Guimarães, 2005). Most of such projects are related to energy generation or waste management/treatment. Several industries (steel producers, paper manufacturers, agroindustries, reforesting companies and others) are already taking advantage of carbon credits market.

Anaerobic digestion usage in dairy farms for biogas recovering and possible use as energy source has the basic characteristics of a CDM project. According to the first Brazilian inventory on cattle methane emissions, by the year 1994 methane emissions were 9,8 million ton. (9,4 million from enteric fermentation and 0,4 million from manure management systems). By that year, Brazilian flock was about 158 million animals, and 13% of that was dairy cattle (Lima et al., 2006).

CDM projects typically have high implementation costs, particularly at the initial stages, because of learning process and methodology is being consolidated, and this is a more serious issue for small-size projects. In order to overcome this drawback, small dairy farms may look for partnership with investors interested in support such kind of CDM projects.

For instance, in 2005 an Irish company had already installed up to 500 biodigesters in small farms in Brazil and intended to set up another thousand in short time (Souza, 2005). In such implementations, the farmer is responsible for proper operation of equipment and can use the generated biogas and effluent, and the resulting income from carbon credits commercialisation is shared between the company (90%) and the farmer (10%).

6. FARM POTENTIAL EVALUATION

In order to evaluate the potential for implementation of a small/medium size CDM project, Diaz (2006) analysed a dairy farm with a 50 cows cattle that already uses or intend to use in-situ milk chilling equipment in order to meet Brazilian quality regulations as well as improve farm productiveness, competitiveness and profitability. It is assumed that such project is related to a biodigester-based CDM project implemented under a farmer-investor partnership as mentioned before (Souza, 2005). It is considered two possible scenarios:

- one farm that already has electricity-based chilling equipment and intends to replace purchased electricity by local generation using the biogas provided by the CDM project;
- one farm that do not have chilling equipment yet.

For both scenarios, it is evaluated the GHG emission reduction and carbon credits generation of CDM, as well as the best configuration for milk chilling system, considering the thermo-economical aspects involved and the Brazilian perspective.

6.1. GHG emissions and carbon credits generation

As mentioned before, the analysis is based on a 50 dairy cows cattle. It was employed the methodology presented in (IPCC, 1996), assuming for Brazil, particularly for its south-eastern region, similar characteristics to those for North America and Western Europe. It was also adopted the parameters presented in Table 3.

Each cow daily ingests a gross energy of 197,52 MJ and produces 3,45 kg of volatile solids. The manure, liquid-managed and displaced in an anaerobic lagoon (baseline reference configuration), releases a methane amount corresponding to 205,04 $ton_{equiv,CO2}$ per year (195,28 kg_{CH4}/year). N_2O emissions from manure is 4,95 $ton_{equiv,CO2}$ per year in such configuration.

Considering a CDM project that replaces the anaerobic lagoon by a biodigester (CDM-project configuration), manure CH_4 emissions are reduced to 11,38 $ton_{equiv,CO2}$ per year (10,84 kg_{CH4}/year). N_2O emissions in this configuration can be neglected.

Biogas composition is assumed to be 65% of CH_4 and 35% CO_2, with a LHV of 23,10 MJ/m^3 and a density of 1,2 kg/m^3. Daily production is about 50 m^3 of biogas, which is available for flaring or to be used in energy conversion systems. According to Murphy et al. (2004), biogas combustion has an emission factor of 1,96 $kg_{equiv,CO2}/m^3$. Consequently, emissions due to biogas combustion are 35,77 $ton_{equiv,CO2}$ per year.

From the comparison of baseline and CDM project emissions summarised in Table 4, it can be noticed that the implementation of a biodigester-based manure management systems reduces GHG emissions from 209,99 to 47,15 $ton_{equiv,CO2}$ per year (net reduction of 162,84 $ton_{equiv,CO2}$ per year). Considering that in European market the CER (carbon credit) price is about €10,00/$ton_{equiv,CO2}$ (Econergy, 2006), this project would provide an annual income of €1.628,40 during project lifetime, estimated in 10 years. Considering an implementation under a farmer-investor partnership as mentioned before (Souza, 2005), farmer annual income would be €162,84 (10% of total). It must be point out that all such income may be considered profit from farmer's point of view, since it can be considered that there are no extra expenses connected to project implementation when compared to baseline configuration.

Table 3. Parameters adopted for GHG emission evaluation (IPCC, 1996)

Parameter	Value
Feed digestibility	65%
CH_4 conversion factor	6%
Milk production	20 kg/day
Milk fat content	4%
Mature weight	600 kg
Daily average weight gain	0 (mature animals)
Percent of females that give birth in a year	80%
Manure ash content	8%
Manure CH_4 producing capacity	0.24 m^3/kg_{SV}

Table 4. Comparison of GHG Emission for baseline and CDM project (values in $ton_{CO2\text{-}eq}/yr$)

GHG Emission Source	Baseline Scenario	CDM Project	Reduction
CH_4 from manure management	205,04	11,38	193,66
NO_2 from manure management	4,87	——— (*)	4,87
CO_2 from biogas combustion	———	35,77	-35,77
Total	209,91	47,15	162,76

(*)According to the IPCC guidelines, NO_2 emissions for biodigesters can be neglected

6.2. Milk Chilling Scenarios Analysis

6.2.1. Milk Chilling System Capacity

The milk chilling system must supply the cooling load demand for 50 dairy-cow milk production of 20 litres/cow per day, totalling 1.000 litres/day, in two milk extractions: one in the morning and other in the afternoon. It is considered that the same milk volume is attained in each extraction, with a morning extraction peak of 60%.

Milk collection is to be performed every two days, according to Brazilian Normative Instruction IN51 (2002), which means that storage tank volume should be of 2.000 litres. This same Instruction establishes that the milk must be cooled in less than three hours after milk extraction ends. Considering such parameters and regulations, milk chilling system rated capacity is to be of 5,85 kW.

6.2.2. New implementation

For such scenario, this analysis intended to verify which is the most suitable configuration for implementation of a milk chilling system in a dairy farm that do not have such equipment yet. It was considered the following configurations:

1. a cooling tank with electric-driven vapour compression condensing unit and purchased electricity (Fig. 2a);
2. the same configuration of (1), with electricity provided by a generator driven by a Otto engine using biogas (Fig. 2b);
3. the same configuration of (1), with electricity provided by a generator driven by a Diesel engine using a biogas/diesel mixture (60%/40%) (Fig. 2c);
4. a cooling tank with a biogas direct-burning absorption chiller (Fig. 2d).

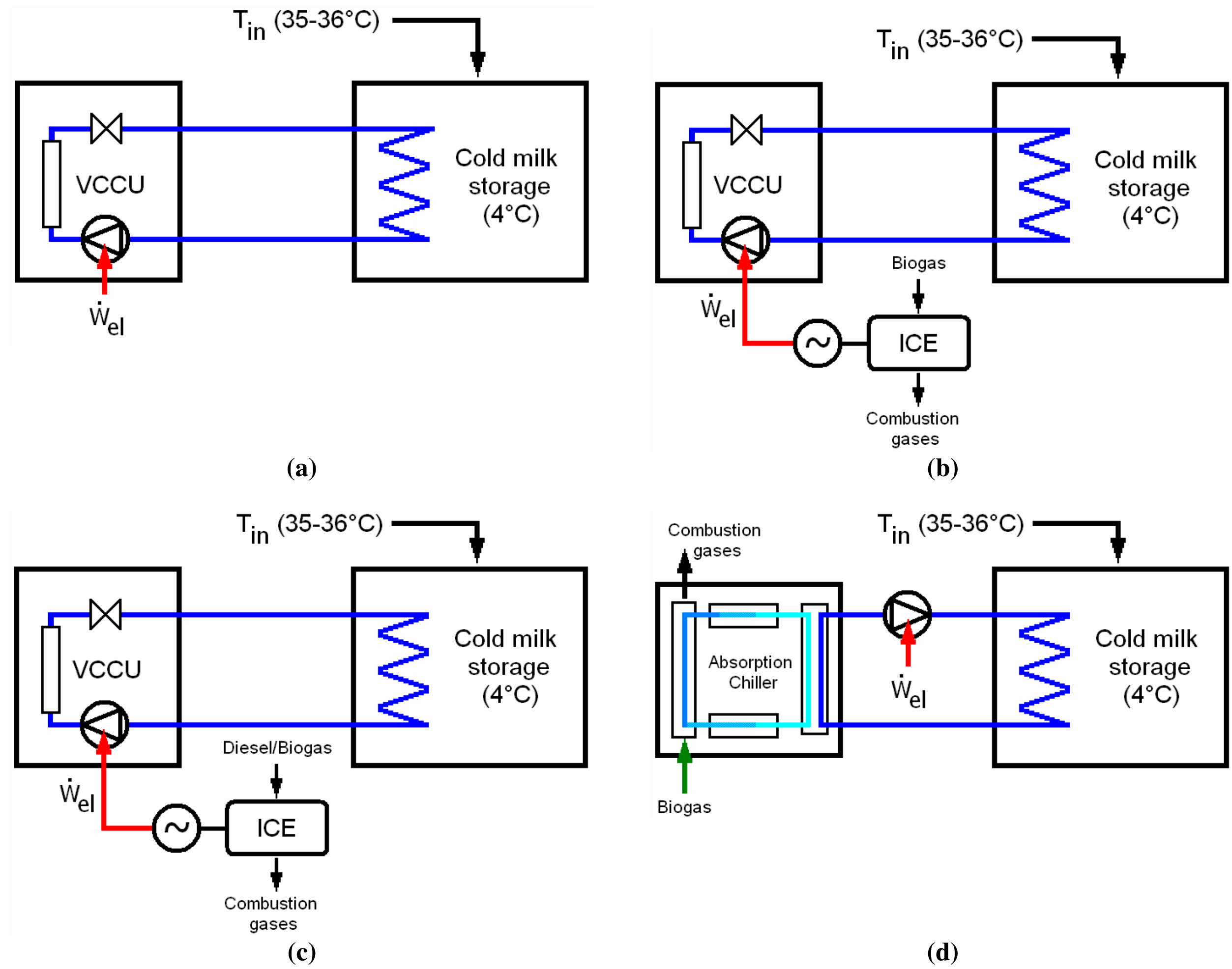

Figure 2. Milk chilling system configurations considered for the present analysis

Table 5 presents the investment (IT), operational (OC), maintenance (MC) and total costs (TC) at present values (PV) for the considered configurations. Operational costs are due to electricity and diesel purchase costs. For such analysis it is considered that the biogas is available to the farmer at no cost, since it results from biodigester operation. Table 5 shows that configuration (2) is the best choice for such scenario.

Table 5. Cost analysis for a new milk chilling implementation scenario(1).

Configuration	IT	OC	MC	TC(PV)
1	18.000,00	1.417,69	900,00	33.039,24
2	21.160,00	———	2.427,33	32.667,87
3	22.150,00	2.879,47	2.905,83	54.118,15
4	61.000,00	403,69	3.050,00	83.410,61

(1) Values in Brazilian currency (€1.00 ≈ R$ 2.70).

6.2.3. Purchased energy replacement

In this scenario it is considered one farm that already has electricity-based chilling equipment (baseline configuration A). The goal is to verify if it is economically viable to replace purchased electricity by local generation using the biogas provided by the CDM project (new configuration B).

Table 6 compares costs for the above configurations considering present values and evaluates the lifecycle savings (LCS). It can be noticed that configuration B provides a small positive LCS, indicating that the replacement is economically viable. The payback for such replacement is about 27 months.

It is important to point out that only the replacement of electricity required for milk chilling equipment is under consideration. If the generation of electricity for other farm requirements (lightning, heating systems, pumping systems, etc.) is to be considered, it is probable that such implementation become economically more attractive to the farmer, but further analyses are required.

Table 6. Cost analysis for purchase energy replacement scenario(2).

Configuration	IT	OC	MC	TC(PV)
A	————	1,417.69	————	9,199.24
B	3,160.00	————	1,527.23	9,054.69
		LCS		144,55

(2) Values in Brazilian currency (€1.00 ≈ R$ 2.70).

7. CONCLUSIONS

The Brazilian dairy sector is characterised by a great number of producers, presenting low productiveness and product quality. Concerning to quality it is necessary the implementation of cooling systems for milk conservation on farm. Nevertheless, main drawbacks to a larger use of those systems, besides cultural aspects, are the access the financial resources and energy availability.

In this context, the goal of this work was to determine the best configuration of a milk chilling system for medium-size dairy farms to be included in an anaerobic digestion manure management project based on the Clean Development Mechanism of Kyoto Protocol, to be implemented by an investor interested in commercialise the carbon credits generated.

It was evaluated that the implementation of such project for a 50-cow dairy cattle generates GHG emissions reduction of about 78% when compared to a manure management system based on an anaerobic lagoon, and produces 50 m3/day of biogas that can be used for supply farm energy requirements for heating and electricity generation.

The analysis showed that a biogas-fuelled Otto-engine electrical generator is an interesting alternative for electricity purchase replacement for an existing milk chilling system. For new systems, the best configuration is a cooling tank with electric-driven vapour compression condensing unit using the generated electricity. If the generation of electricity for other farm requirements (lightning, heating systems, pumping systems, etc.) is to be considered, it is probable that such implementations become economically more attractive to the farmer, but further analyses are required.

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