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FEASIBILITY STUDY OF TECHNICAL ECONOMIC AND ENVIRONMENTAL NATURAL GAS ENGINES FOR COGENERATION IN THE FISHING SECTOR

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Abstract. *The present work aims to study the CHP with gasoline engines or diesel to natural gas as fuel and dual fuel used in fishing vessels. Once a small fishing industry is one of the sectors most in need of encouragement, considering that it is necessary to concern about the conservation of fish, which today is made with ice that is carried in the boats, thus limiting the amount of fish from the sea. The environmental advantages of this system are very significant because it exploits the heat energy recovered from the cooling system and exhaust gases. The use of dual fuel gas and providing the reduction of fuel costs, since the internal combustion engine emits less natural gas combustion residues than diesel engine, allowing a reduction in pollutants originating from the combustion. The waste heat will favor the allocation of a refrigeration unit that uses the energy that would otherwise be wasted (absorption refrigeration system) and cooling the exhaust producing enough energy to conservation of fish. The refrigeration cycle as studied here uses a working fluid mixture of water and ammonia is supplied with thermal energy from the direct combustion of natural gas. The goal is to produce cold at low temperatures for applications in food preservation (fish) and for economic reasons. Why did not need more ice, the amount of fish that the boat can carry will be expanded, minimizing the concern for its conservation and reducing the number of trips to sea, thus benefiting the fishing community. The boat engines commonly used and targets of the study work with diesel, with outputs ranging from 50 to 250HP, will look to improve the thermal performance of engines using diesel and naturalgas.*
From the results of thermodynamic analysis, the comparative calculations of internal combustion engines were performed with the help of computer Engineering Equation Solver (EES), which was simulated the operation of the actual cycle engine running on diesel and natural gas

*Keywords**: absorption system, water-ammonia, natural gas / diesel, fishing boats.***

1. INTRODUCTION

This paper analyzes the opportunity to introduce cogeneration to produce absorption refrigeration ammonia-water system in the isolated state, as a way to improve efficiency on the one hand, and on the other, resolve the chronic deficiency of storage of fishery production of Paraíba.

2. THEORETICAL BASIS

2.1 POWER ENGINE

The engine has a capacity defined in terms of power in HP (Horsepower) or CV (Steam Horse). Is the amount of work he is able to perform in unit time.

In internal combustion engines the thermal energy is derived from the reaction of fuel with atmospheric air. Not all thermal energy generated in the combustion is transformed into mechanical energy by internal combustion engines. Thus, we have shown that power is the power within the cylinders. Briefly called IHP (Indicated Horsepower) is the sum of the powers and effective friction in the same test conditions. Theoretical power is the estimated power based on physical properties and fuel consumption. This power considers that all heat from combustion is converted into mechanical energy.

$$P_T = PCI.q.d$$

where:

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P_T = Theoretical power;

PCI = Calorific value of the fuel, kcal.kg-1;

q = Fuel consumption, L.h-1;

d = Density of fuel kg.L-1;

About 1/3 of rated power is converted into shaft power BHP (1/3 is lost in cooling and third in the exhaust. Thus we can estimate the rate of energy released by the engine exhaust, which will be feedstock for cogeneration system that cools the urn of the boat, giving you greater autonomy with regard to the conservation of fish while fishing.

2.2 THERMAL LOAD

It is called thermal load heat (sensible and latent) to be supplied or extracted from the air per unit of time, to maintain the desired conditions in the enclosure.

To calculate the heat load for cooling chambers, freezing and storage of products, plus a correct establishment of the local weather conditions and internal conditions of the chamber, should be considered the following items addressed in the next topics.

2.2.1 THERMAL LOAD DUE TO HEAT TRANSMISSION BY WALLS, CEILING AND FLOOR

The thermal load due to heat transfer is a function of the temperature differential between the external environment and the interior of the chamber of the thermal conductivity of the camera building elements (walls, ceilings, floors, doors, etc..) And the area of the exposed surfaces the temperature differential. Therefore, this heat load can be calculated by:

$$Q_{trn} = \frac{A\,\Delta T}{R_T} 24 \quad \text{[kcal/dia]} \tag{1}$$

In equation (1) Q is the heat flow which enters the chamber through the surfaces of the walls, ceiling and floor, A is the area of these surfaces, Dt is the temperature differential between the external environment and the interior of the chamber, and RT is thermal resistance to heat flow imposed.

In general, to calculate the thermal resistance must be taken into account external convection coefficient, thermal conductivity of the construction material of the wall and external convection coefficient. Thus, taking the urn boat with wooden walls, the thermal resistance is given by:

$$R_T = \frac{1}{h_{ext}A} + \frac{L_m}{k_m A} + \frac{L_i}{k_i A} + \frac{1}{h_{cam} A} \tag{2}$$

where:

h_{ext} = is the coefficient of convection external kcal / h.m ². ° C;
h_{cam} = is the internal convection coefficient, kcal / h.m ². ° C;
k_m = is the thermal conductivity of the wood, in kcal / hm ° C;
k_i = is the thermal conductivity of the insulating kcal / hm ° C;
L_m = Wood is the thickness in m;
L_i = is the thickness of the insulating m.

With respect to the temperature differential that if the camera does not suffer the effects of direct solar radiation, ie, if it is not exposed to the sun, it is the difference between the outside temperature and the temperature of the chamber. However, as the camera (urn) is influenced by the direct solar radiation, the value of Dt must be corrected, depending on the orientation of the wall and its color, and its calculation made according to the following equation, where the value of Dt 'is given in Table 1. In the case of boats effects were considered only radiation directly to the ceiling, in order that the side walls are still trimmed from the boat hull and which have a dark color.

$$\Delta T = (T_{ext} - T_{cam}) + \Delta T' \tag{3}$$

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Table 1 - Correction to the temperature difference in cold (Δt ').

Tipo de superfície	Paredes			Teto Plano
	Leste	Oeste	Norte	
Cor escura (preto, azul escuro, marrom, ardósia, etc).	5,0 °C	5,0 °C	3,0 °C	11,0 °C
Cor Média (cinza, amarelo, azul, etc).	4,0 °C	4,0 °C	2,5 °C	9,0 °C
Cor Clara (branco, azul claro, verde claro).	3,0 °C	3,0 °C	2,0 °C	5,0 °C

Fonte: Referencia [4] PIRANI, Marcelo José

2.2.2 THERMAL LOAD DUE TO THE PRODUCT CONTAINED IN THE HOUSE

The heat load due to the product, which generally corresponds to the higher percentage of heat load of cooling and freezing chambers depends: the sensible heat before freezing, freezing latent heat, sensible heat after freezing, and the heat of respiration . Considering all plots mentioned above, we have:

$$Q_{prod} = G_M\left[c_{p,1}(T_{ent} - T_1) + h_{cg} + c_{p,2}(T_1 - T_2)\right] + G_T\, Q_{resp} \quad \text{[kcal/dia]} \qquad (4)$$

Where:

G_M = is the daily movement of a particular product in the chamber, in kg / day.

$c_{p,1}$ = is the specific heat of the product before freezing in kcal / kg. ° C.

T_{ent} = is the inlet temperature of product in the chamber in ° C.

T_1 = chambers for cooling is the final temperature and for freezing chambers, it is the freezing temperature of the product in ° C

h_{cg} = is the latent heat of freezing of the product in kcal / kg.

$c_{p,2}$ = is the specific heat of the product after freezing in kcal / kg. ° C.

T_2 = is the final temperature of the frozen product in ° C.

G_T = is the total quantity of products in the chamber in kg.

Q_{resp} = is the amount of heat released by respiration of the product, in kcal / kg.dia

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2.2.3 THERMAL LOAD FROM THE EXTERNAL AIR INFILTRATION DUE TO OPENING AND CLOSING DOORS ACCESS CHAMBERS

The thermal load due to the infiltration of air is related to heating air (outside air) and the cold air outlet chamber through ports or other openings.

Thus, the amount of air entering the chamber can be estimated, inter alia, from Air Exchange Factor (ETS) a chamber, which is in turn dependent on the volume and type of the chamber. The FTA expresses the number of air changes per day (Trade / day) and the chamber may be from table 2:

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Table 2 - Factor of Air Exchange of Cold rooms for Conservation.

Câmaras Para Produtos Resfriados				Câmaras Para Produtos Congelados			
Volume $[m^3]$	FTA [trocas/dia]	Volume $[m^3]$	FTA [trocas/dia]	Volume $[m^3]$	FTA [trocas/dia]	Volume $[m^3]$	FTA [trocas/dia]
40	15,00	500	3,60	40	11,00	500	2,80
50	13,00	700	3,00	50	10,00	700	2,30
60	12,00	1000	2,50	60	9,00	1000	1,90
80	10,00	1200	2,20	80	8,00	1200	1,70
100	9,00	1500	2,00	100	7,00	1500	1,50
125	8,00	2000	1,70	125	6,00	2000	1,30
150	7,00	3000	1,40	150	5,50	3000	1,10
200	6,00	5000	1,10	200	4,50	5000	1,00
300	5,00	10000	0,95	300	3,70	10000	0,80
400	4,10	15000	0,90	400	3,20	15000	0,80

Fonte: Referencia [4] PIRANI, Marcelo José.

$$Q_{inf} = V_{cam} FTA\,\Delta H' \quad \text{[kcal/dia]} \tag{5}$$

Once one knows the volume of outside air entering the chamber per day, one can then determine the load of infiltration by equation (5), where Vcam is the chamber volume, in m3, and DH 'refers to heat transferred per cubic meter of air that enters the chamber and is given by Table 3.

Table 3 - Heat transferred to the outside air entering the chamber (ΔH 'in kcal/m3).

Cond. Externas		Temperatura na Câmara [°C]									
UR [%]	T_{ext} [°C]	-40	-35	-30	-25	-20	-15	-10	-5	0	5
40	15,0	23,2	21,3	19,4	17,4	15,5	13,4	11,1	8,5	5,5	2,2
	20,0	26,5	24,6	22,7	20,8	18,8	16,7	14,4	11,8	8,8	5,6
	25,0	30,5	28,6	26,7	24,7	22,7	20,6	18,3	15,7	12,7	9,4
	30,0	35,1	33,2	31,3	29,3	27,3	25,1	22,8	20,2	17,2	13,9
	35,0	40,6	38,7	36,7	34,7	32,7	30,5	28,2	25,6	22,6	19,3
	40,0	47,2	45,2	43,2	41,2	39,1	37,0	34,6	32,0	28,9	25,6
50	15,0	24,5	22,6	20,7	18,8	16,8	14,7	12,4	9,8	6,8	3,5
	20,0	28,4	26,5	24,6	22,6	20,6	18,5	16,2	13,6	10,6	7,3
	25,0	33,0	31,0	29,1	27,1	25,1	23,0	20,6	18,0	15,0	11,7
	30,0	38,4	36,5	34,5	32,5	30,5	28,3	26,0	23,4	20,3	17,0
	35,0	45,0	43,0	41,0	39,0	36,9	34,7	32,4	29,7	26,7	23,4
	40,0	52,8	50,8	48,8	46,7	44,6	42,4	40,0	37,4	34,3	30,9
60	15,0	25,9	23,9	22,0	20,1	18,1	16,0	13,7	11,1	8,1	4,8
	20,0	30,2	28,3	26,4	24,4	22,4	20,2	17,9	15,3	12,3	9,0
	25,0	35,4	33,5	31,5	29,6	27,5	25,4	23,0	20,4	17,4	14,1
	30,0	41,7	39,7	37,8	35,7	33,7	31,5	29,1	26,5	23,5	20,1
	35,0	49,3	47,3	45,3	43,2	41,1	38,9	36,5	33,9	30,8	27,4
	40,0	58,5	56,4	54,4	52,3	50,1	47,9	45,5	42,8	39,7	36,3
70	15,0	27,2	25,3	23,4	21,4	19,4	17,3	14,9	12,3	9,3	6,0
	20,0	32,1	30,1	28,2	26,2	24,2	22,0	19,7	17,1	14,1	10,7
	25,0	37,9	35,9	34,0	32,0	29,9	27,7	25,4	22,8	19,7	16,4
	30,0	45,0	43,0	41,0	39,0	36,9	34,7	32,3	29,6	26,6	23,2
	35,0	53,6	51,6	49,5	47,5	45,4	43,1	40,7	38,0	34,9	31,5
	40,0	64,1	62,0	60,0	57,8	55,7	53,4	50,9	48,2	45,1	41,6

Fonte: Referencia [4] PIRANI, Marcelo José

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2.2.4 THERMAL LOAD BECAUSE THE LIGHTS, PEOPLE, AND OTHER SOURCES OF HEAT IN THE CHAMBER INERIOR

In this case it was considered the thermal load due only to the presence of persons inside the chamber, this being dependent upon the activity that are exerting the type of clothing and particularly of the temperature of the chamber. One way of estimating the heat load is due to people by the following equation:

$$Q_{pes} = (272 + 6T_{cam})\tau\, n\, 0{,}86 \qquad \text{[kcal/dia]} \tag{6}$$

Where:

T_{cam} = the chamber temperature is in ° C.

τ = is the residence time of the people in the chamber in h / day.

n = is the number of people in the chamber.

Therefore, the total thermal load is:

3. ABSORPTION REFRIGERATION

Cooling systems for vapor absorption refrigeration cycles are operated to heat, where a secondary fluid or absorbent in the liquid phase is responsible for primary or absorb the refrigerant fluid in vapor form. Refrigeration cycles operated heat are well defined, because the energy responsible for operating cycle is mostly thermal.

Hot water, steam (low pressure and high pressure) and combustion gases are some of the sources of heat used to operate absorption equipment whose thermal energy can be obtained from the following means:

- Utilization of waste heat from industrial and commercial processes;
- Cogeneration;
- Solar Energy;
- Direct burning (biomass, biodiesel, natural gas and biogas).

3.1 COEFFICIENT OF PERFORMANCE-COP

The coefficient of performance - COP, also known as the coefficient of efficiency characterizes the performance of a refrigeration cycle by relating the desired effect - cooling the you pay for this - the energy consumption. In case of an absorption refrigeration cycle, the COP is defined as the relationship between the cooling rate (Q_l) and the rate of heat added to the generator (Q_h):

$$COP = \frac{Q_l}{Q_h} \tag{8}$$

4. METHODOLOGY

To study the technical and economic feasibility and environmental impact of natural gas engines for cogeneration in the fishing sector, first given as necessary to carry out a mapping of types of fishing boats used on the coast of Paraiba, where we collected data relevant to the project during the month of September 2009, with the Superintendence of Agriculture and Fisheries, these data represented below (table 4):

Table 4: Vessels Coastal Paraiba.

Região	Comprimento (m)	Compartimento (ton)	Arqueação Bruta (ton)	Potência (HP)
PITIMBU	10,55	5,2	7,3	52
PITIMBU	10,55	5,2	7,3	52
BAIA DA TRAIÇAO	7	5	3	54
PITIMBU	9,3	5	5	54

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CABEDELO	10,2	*	6	54
CABEDELO	7,9	3,2	3,6	55
PITIMBU	11,5	7,8	0,7	72
PITIMBU	10,5	10,9	11,7	72
PITIMBU	12	15,2	18,8	72
PITIMBU	11,3	11,1	15,6	72
PITIMBU	12	5,2	9,3	72
PITIMBU	11	5,1	9,8	72
PITIMBU	11,27	*	12,7	72
PITIMBU	11	5,1	9,8	72
CABEDELO	11,98	5,6	12,7	90
CABEDELO	11,9	4,1	12,1	90
CABEDELO	12,8	8	15,8	90
CABEDELO	12,5	12	1,3	90
CABEDELO	12,5	7,7	1,2	90
CABEDELO	12	7,2	9,6	90
PITIMBU	11,45	9	6,7	90
PITIMBU	7,3	4,4	2,2	90
CABEDELO	13,15	3,9	17,4	90
CABEDELO	11,1	5	4,5	90
JOAO PESSOA	12,5	10,7	19,3	90
CABEDELO	12,14	10,7	16,7	90
PITIMBU	11	9,4	9,8	90
PITIMBU	9	8	7,3	90
CABEDELO	12	12,1	16,7	90
PITIMBU	9	8	7,3	90
PITIMBU	12,8	8	15,8	90
PITIMBU	9,9	4,8	7,1	110
CABEDELO	7,6	*	3,79	115
PITIMBU	10,5	5	6,4	120
PITIMBU	11,7	*	8	120
TAMBAÚ	11,8	6,7	6	130
PITIMBU	12	6,7	16,7	140
CABEDELO	12	*	1,3	148
CABEDELO	11,9	9,3	8,8	150
CABEDELO	17,8	3,2	32,8	180
CABEDELO	33,97	62,43	229	304

The storage systems of the boat, has a storage casket of the fish which is also filled with ice for storage of fish, the ratio is generally about 2 parts of ice for each piece of fish, but this amount of ice may vary according to the time that the boat remains at sea during fishing, usually ranging from 3 to 8 days. The casket is integrated into the boat and has an insulating coating of glass fiber. Their size varies according to the size of the boat.

In Table 5 we have a sample of boats with some specifications as engine data, volume of the urn, quantity of fish, and conservation of the same day it is fishing time.

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Tabela 5 - Barcos

Comprimento x Largura (m)	Potência do motor (HP)	Nº de Cilindrados	Capacidade de gelo (kg)	Volume da urna (m³)	Quantidade de pescado (kg)	Dias de conservação do pescado
9,5x3,5	65	3	500	2,15	400	3
9x3	70	3	750	1,92	500	4
8x3	75	4	800	1,33	400	8
11,25x4,25	94	4	8000	12,75	1000	8

Fonte: Própria (2010)

5. IMPORTANT DATA

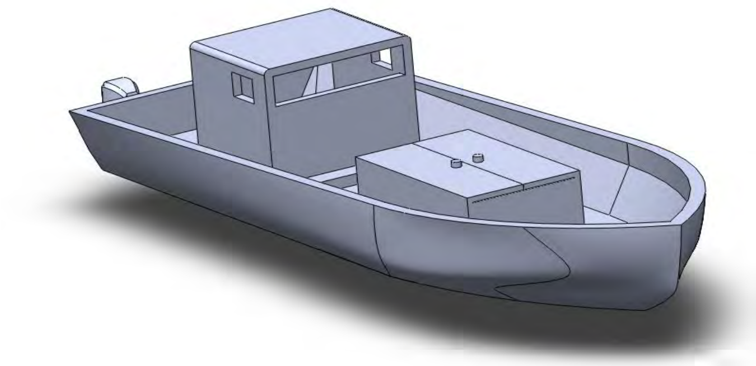

Figure 2. Model chosen: length 11,25 x4, 25 (m), volume of 12.75 urn (m³), engine power 94 HP.

The criterion for choosing the boat was as follows: Most boats have motor power 90 HP, then chose the larger boat with this engine.

Because we have to enter the same absorption system of Robur, two cylinders, the conversion system and maintain the diesel engine. For this we have to decrease the volume of the urn as the same function with a cooling system even by reducing its volume, the quantity of fish still be higher.

The conversion price varies. According to the Natural Gas Committee of the Brazilian Institute of Petroleum, a conversion done in a workshop accredited by INMETRO costs between R $ 2,200 and R $ 3,500, model and engine specifications.

Average cost for conversion:

Kit for conversion of diesel engine to Natural Gas = R $ 2200 / R $ 3,500
Absorption System of Robur = R $ 10,000
CNG cylinder = R $ 750.00 (each)

With the conversion can save 40% to 70% fuel and the expected financial return is between 6 and 22 months.

Natural gas is considered non-polluting, although its combustion, as with any fuel, will produce carbon dioxide (CO2) at high proportions, but the production of particulate matter, soot, carbon monoxide and sulphydryl compounds, such as SO2, is reduced. This can be seen from Table 6:

Tabela 6 - Emissão de poluentes

Sistema	Combustível	CO_2	CO	NOx	HC	SOx	Particulados
		Emissões específicas (g/kWh)					
Motor Diesel	Diesel (0,2% de S)	738	4,08	12	0,46	0,9	0,32
Motor a Gás	Gás natural	577	2,8	1,9	1	~0	~0

Fonte:Valores típicos de emissões gasosas por sistemas de cogeração *(COGEN Europe, 2001)*

6. RESULTS

The comparative calculations of internal combustion engines were made with the help of computational Engineering Equation Solver, which was simulated operation of the actual cycle diesel engine running and natural gas. In Table 7, we have the parameters for the diesel engine, which is Peixo the power shaft, the power is Pindicada indicated and Ql is the energy lost during the engine cycle

Tabela 7-Motor a Diesel

Barco	Peixo (HP)	Pindicada (kW)	Ql (kW)
1	65	145,41	116,31
2	70	156,60	125,94
3	75	167,78	133,33
4	94	210,29	170,23

Fonte: Própria (2010)

In Table 8 we the parameters of natural gas engine, which is Peixo the power shaft, the power is Pindicada indicated and Ql is the energy lost during the engine cycle. This is aimed at converting the diesel engine to natural gas, which is observed in the power loss, but there are devices that prevent this loss.

Tabela 8-Motor a Gás Natural

Barco	Peixo (HP)	Pindicada (kW)	Ql (kW)
1	51,52	115	75,60
2	54,48	121,6	79,92
3	60,17	134,3	88,31
4	73,30	163,6	107,56

Fonte: Própria (2010)

The calculations of the thermal load on the ballot boat were made in spreadsheet in Microsoft Office Excel 2007, using tables of reference [4], for it was considered that the ambient temperature is 32 ° C, relative humidity 70% and the temperature inside the coffin to the preservation of fish is 0 ° C, and that the urn boat is made of wood, with an insulating coating of glass fiber. And in table 9 have the thermal load value calculated for the sample vessels.

Tabela 9-Carga Térmica

Potência do motor (HP)	Nº de Cilindros	Volume da urna (m³)	Quantidade de pescado (kg)	Dias de conservação do pescado	Carga Térmica (kW)
65	3	2,15	400	3	2,99
70	3	1,92	500	4	2,67
75	4	1,33	400	8	1,18
94	4	12,75	1000	8	8,27

Fonte: Própria (2010)

To get the amount of cooling energy that the engine can produce the energy we lost the engine (Ql) equal to the energy supplied to the absorption refrigeration cycle (Qh), considering that we have a COP of 0.45: Table 10 in the values of cooling energy (QI cooling) and its thermal load of the boat, and in Figure 1 we have the analysis of thermal load in relation to this cooling energy.

Tabela 10–Desempenho Térmico

Barco	Ql (resfriamento) em kW		Carga Térmica (kW)
	Diesel	Gás Natural	

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1	52,34	34,02	2,99
2	56,67	35,96	2,67
3	60,00	39,74	1,18
4	76,60	48,40	8,27

Fonte: Própria (2010)

On the issue of supply of gas cylinders, one has to Cabedelo has three stations near the port where suppliers, João Pessoa has two stations, Pitimbu does not have any gas in its vicinity in Paraiba for supplies, and the only alternative to city Pernambuco Goiás which has two stations, and also their situation worsens due to distance of approximately 30 km which causes an increase in spending on supplies.

It was found natural gas engines with the specific function to boat, but there are already engines with application mainly for urban buses in view of the demand in the sector

7. CONCLUSION

With this study is that cogeneration is in the fishing sector is perfectly applicable under the technical point of view, considering that the lost energy can meet the demand of refrigerated vessels for the conservation of fish, but should consider the size of the boat, the horsepower of the engine, and the ability of the urn. Once a small fishing industry is one of the sectors most in need of encouragement, given that it is necessary to concern for the conservation of fish, which today is made with ice that is brought in boats, thus limiting the quantity and quality fish from the sea.

The use of natural gas and dual-fuel provides the reduction of fuel expenses, since the internal combustion engine with natural gas emits less than combustion residues from diesel engine, enabling a reduction in pollutants arising from combustion. By not need more ice the amount of fish that the boat can carry will be increased by minimizing the concern for its conservation and reduces the number of trips to the sea, thus benefiting the fishing community.

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