CHEMICAL ENGINEERING TRANSACTIONS

VOL. 65, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Mario Costa

ISBN 978-88-95608-62-4; **ISSN** 2283-9216

Assessment of the Energetic Potential of Different Fast-Growing Species in the Bogotá River Basin

Ivan O. Cabeza[a,*], Claudia Romero[a] , Ana S. Rojas[b], Paola A. Acevedo[a], Mario A. Hernandez[b]

[a]Universidad Santo Tomás, Facultad de Ingeniería Ambiental, Carrera 9 # 51-11, Bogotá, Colombia
[b]Universidad EAN, Calle 79 # 11-45, Bogotá, Colombia
ivancabeza@usantotomas.edu.co

Biofuels are an important alternative to diversify the national energy system improving the sustainable level for supply the energy requirements of the country. Energy crops have become the new trend for several types of biofuels. Nevertheless, in Colombia this sector uses as raw materials first generation crops, despite the agricultural land available to implement fast-growing species. In a general way, there is a lack of information related to the energetic potential of native and foreign species in Colombia. Almost all previous works have been focused on residual biomass from agricultural sectors. This work includes a general evaluation in order to determine species stablished in Colombia and species not yet reported with potential to be energetically valorized. This evaluation was carried out using the Colombia's Biodiversity Information System database (SIB by its Spanish acronym) and previous worldwide works of energetic crops reported in similar latitudes. In addition, physicochemical information such as the percentage of hemicelullose, dry matter, ashes, and apparent humidity was obtained. Eleven (11) families of crops were selected and compiled in twenty two (22) species and then were classified having into account soil type and crop requirements. The cultivation areas were calculated analyzing the Geographic Information System including the information related to crop requirements, protected zones, urban zones and fresh water sources. Specifically, in Cundinamarca were identified species related to families *Fabaceae, Pinaceae* and *Poaceae*. The species *Arundo donax* L. *(Pinaceae* family*)* has the higher specific area for this group of species with a value of around 213.000 hectares in the department of Cundinamarca which corresponds thirty five (35) percentage of the total area in the basin.

Nevertheless, the energy potential calculated as a function of available areas and physicochemical properties is in the range of 18,000 TJ/year less than other species evaluated in this work. The technologies identified to carry out the energetic valorization of the crops are a function of their content of lignin, cellulose and hemicellulose. In this sense, families with a lignin content around 25 % (*Salicaceae and Pinaceae*) could be used as raw materials to gasification and pyrolysis processes and families with cellulose and hemicellulose content around 48 and 64 % (*Myrtaceae* and *Poaceae*) could be valorized through fermentation processes after a pretreatment of the biomass obtained in the Bogota´s river basin. In this case Furans could be a high value product. From them, high octane fuels can be obtained. In a general way, there is a huge potential in the department of Cundinamarca to implement energetic crops in, which can avoid food competition, contribute to sustainable development and improve the quality of life of the citizens.

1. Introduction

The use of biofuels has been studied widely with the purpose to reduce the associated effects of fossil fuels, like the emission of greenhouse gases. Thus, the biofuels have been promoted through strategies and policies, which allow the deployment of different raw materials around the world.

In Colombia, biofuels' production has been developed since 2001, when the law 693/2001 and more recently the law 1715/2014 were approved. This regulatory framework allowed the implementation of different alternatives to diversify the energy basket of the country, having in mind the environmental sustainability, the

improvement of the fuels quality, the agroindustrial development, job generation and the security of energy supply (UPME, 2015).
On the basis of the foregoing, since 2003 the production of ethanol has reached 1,200,000 liters per day in six refineries. This production is divided between the Cauca river basin (5 industries using sugar cane as raw material) and the Meta department (1 refinery using bitter cassava as raw material). In the case of biodiesel, the approximate production is 10,000 barrels daily divided among six refineries, three in the caribbean coast, one in the department of Santander, one in the department of Cundinamarca and one in the department of Meta (Delgado et al., 2015).
It is important to remark that the biofuels production in the country has been developed around the first generation sources which implies different aspects to have in mind, like the use of the soil, the high requirements of crops, the limitation of the areas available to its implementation, etc. a fact that sometimes compromises the food security and generates competition with the traditional agriculture (Schrama et al., 2016). Colombia has exerted major efforts to find alternatives to avoid these kinds of problems seeking for different sources of biomass to diversify the production of biofuels in the country. The main efforts have been focused on the valorization of residual biomass generated in agricultural and livestock systems (Ivan et al., 2016). Nevertheless, there are few works related to the implementation of energetic crops in degraded soils and under adverse weather conditions in Colombia, despite the available areas in the national territory (Hernández et al., 2017). Then, the first step to develop this sector is to estimate the energetic potential as a function of the lignocellulosic biomass production. This estimation must be based on the understanding of the requirements of the species suitable to be implemented in the territory (Mabrouk et al., 2017). It is clear that the studies of energy recovery from energetic crops allow progress towards the sustainable management and the knowledge of adequate species for this purpose (Yoshimura, 2015).
In this work, different species of crops with a high potential to be implemented as raw materials to produce second-generation biofuels were evaluated. Specifically, this assessment was carried out in the Bogota river basin located in the department of Cundinamarca (Colombia), taking into account the acclimation of the species to the territory (climatic acclimation) and the available areas of the basin. Subsequently, the generation of lignocellulosic biomass was estimated for each of the species selected in order to calculate the energetic potential of the fast growing crops. This research contains important results to analyse the alternatives for the diversification of the energetic matrix in the country and the implementation of the biorefinery concept in Latin America.

2. Materials and Methods

In order to obtain the energetic potential of different fast-growing species in the Bogota river basin a general scheme was followed and it is described in the Figure 1.

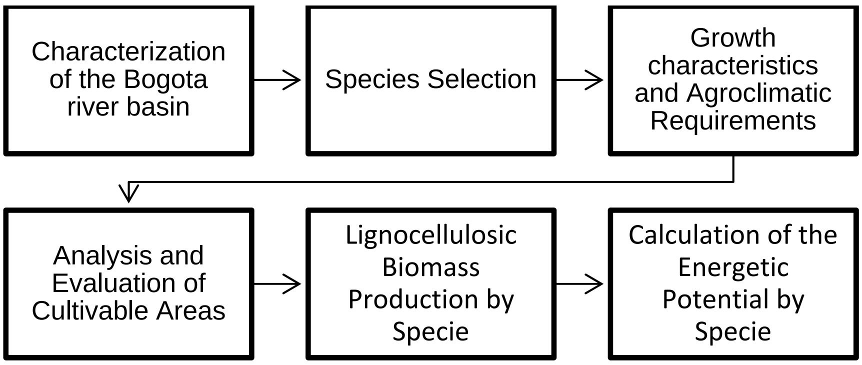

Figure 1: General scheme followed to obtain the energetic potential by species of fast-growing crops in the Bogota river Basin.

2.1 Characterization of the Bogota River Basin

In order to delimitate the study area, the information was collected from official sources like the autonomous regional corporation of Cundinamarca (CAR). Also, a number of government documents was consulted such as the watershed management plan (POMCA), data bases obtained in the Institute of hydrology, meteorology and environmental studies (IDEAM) and information obtained from open data bases like the Colombian Geological Institute (IGAC) through a systematic review of the characteristics of the region taking into account the protected zones, urban zones, ecosystem shape, digital elevation model, annual median rainfall, temperature and fresh water sources present in the basin.

2.2 Species Selection

The selection of the species was carried out from consultation of Colombia´s Biodiversity Information System Database (SIB by its Spanish acronym) and by means of a review of previous works carried out in different countries. The identification of the species was conducted based on a previous study where several areas in Colombia were calculated for different fast-growing crops (Hernández et al., 2017).

2.3 Growth Characteristics and Agroclimatic Requirements

The optimal growth conditions for each energetic crop were identified according to its agroclimatic requirements like the annual median rainfall and temperature, soil pH, elevation above sea level, moisture content and soil requirements.

2.4 Analysis and Evaluation of Cultivable Areas

Once the information of the basin was obtained and the climatic requirements were defined for each species. The Geographical Information System (SIG) was used to determine the suitable growth areas in the Bogota river basin. These areas were calculated cross comparing the requirements of the species obtained in the 2.3 subsection with the characteristic of the zone obtained in the 2.1 subsection.

2.5 Lignocellulosic Biomass Production by Species

All the physicochemical information of the species selected such as percentage of hemicellulose, dry matter, ashes and apparent moisture content was collected. This information was useful to determine the potential use of the biomass obtained and the technology to its valorization. This characterization was performed through previous works and international databases (Hernández et al., 2017).
Additionally, during this stage of the research, the metabolism type (carbon metabolism), crop yield, yearly growth cycle, biomass production per area and current crop use were identified for each species of energetic crop. Subsequently, production yields where established for each fraction of biomass. This data are useful to determine the energetic potential per year of the fast-growing crops in the Bogota river basin.

2.6 Calculation of the Energetic Potential by Species

On the basis of the information gathered in the previous subsections (cultivation areas, growth rates and biomass yield). Energy potential per year for each species of energetic crop was calculated (Hernández et al., 2017).

3. Results and Discussion

The main results obtained during the assessment of the different species are presented below.

3.1 Characterization of the Bogota River Basin

All the information necessary to determine the suitable areas to implement the fast-growing species in the Bogotá river basin was collected using the sources mentioned in previous sections. According to the information supplied by the CAR, the region of interest has an area of 588,143 Ha which corresponds to the 32 % of the total surface of the Cundinamarca department (CAR, 2006).
In general terms, this area has a relief strongly undulating in almost 30% of its total surface with 15-25 % slope. Nevertheless, there are savannah areas with 0-7 % slope and plain reliefs.
The registered data in the meteorological stations located along the basin, the area has an annual median rainfall between 400 and 2200 mm. With respect to the temperature, it varies from 6 to 30 ºC in the entire basin, with temperatures between 9 and 15 ºC at the majority of the total surface (Alcaldía-Mayor-de-Bogota, 2006; CAR, 2006)
Concerning to the soil characteristics of the Bogota river basin, almost all the surface has acidic soils with low content of phosphorus, potassium and calcium. Moreover, all the soils have a moderate to high fertility and moderate contents of organic carbon. The most part of the extension is used in agricultural semi-intensive activities and around 44.6% of the basin has high and low stubble coverage (CAR, 2006)

3.2 Cultivable Areas and Energetic Potential by Species

Once, the basin was characterized, the SIB database was used to obtain the information related to the species with potential to be implemented as fast-growing crops in the region. This first screening was

supported considering previous studies, which evaluated species in regions at similar latitudes (Hernández et al., 2017). In this case, were selected 11 families classified into 30 species of crops.
Subsequently, all the selected species where distributed spatially in the area of the Bogota river basin using the geographical information system tools (SIG). As is shown in Figure 2, the species where located taking into account the fresh water sources, protected areas and urban areas. Different maps were elaborated to assess each of the species of interest. Finally, 7 families were selected and classified into 22 species of crops (Table 1). As is shown in Figure 2, there is a variety of species with high potential to be implemented as energetic crops in the region of the Bogota river basin. Regularly, the suitable areas for two or more species are overlapped among them. For example, although the *Arundo donax L* species is the one with the higher surface available in the basin, other crops could be implemented in the same area. For this reason, the specific suitable area for every species was quantified as is shown in Table 1 (Hernández et al., 2017).

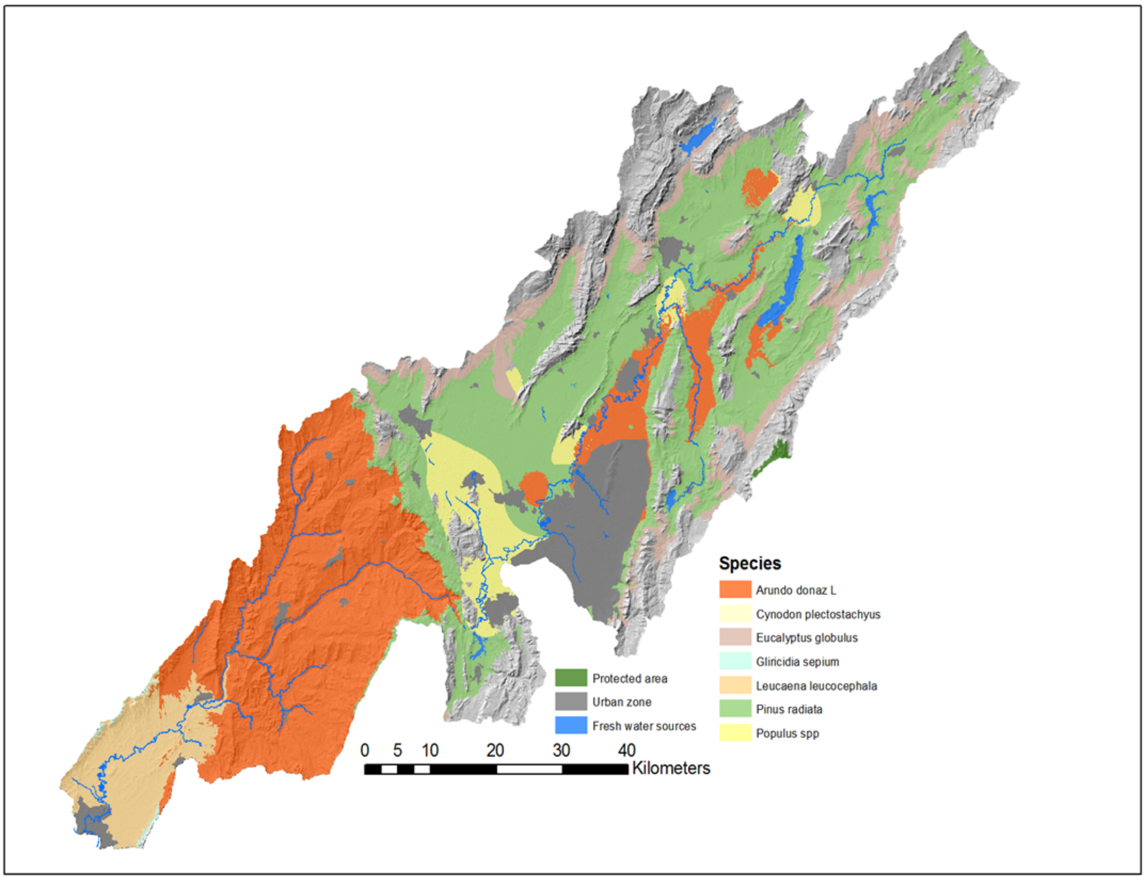

Figure 2: Bogota river basin map example showing the spatial distribution of the species along the Bogota River basin.

The families with the largest suitable areas in the Bogota river basin are: *Myrtaceae*, *Fabaceae*, *Pinaceae* and *Poaceae*. All the species belonging to the families mentioned above have a C_3 or a C_4 metabolism, which indicates that, it is possible to obtain biomass in a short period of time (Schrama et al., 2016).
The *Arundo donax L* is the species with the largest suitable surface in the region of interest, tentatively suggesting that is a crop with a higher energetic potential requiring a deep analysis related to its physicochemical properties and metabolism. This species is called bitter cane or Castile cane, reaching a height between 3 to 6 m with a hollow and thick stem. It is important to remark its capacity to acclimate to various environments and soils (stony, sandy and rocky soils), preferring clay soils, in regions with temperatures above 15 ºC. Its metabolism is completely C_3 having a growing rate of 70 cm per week. Moreover, this species has a hemicellulose and cellulose content around 35 % (d.b) meaning that it could be suitable as raw material for biofuels production prior pretreatments. Actually, this species has a forestry use in Colombia (Scordia et al., 2012).
On the other hand, the *Leucaena leucocephala* which belongs to the *Fabaceae* family, has a C_4 metabolism in slightly acidic and neutral soils, withstanding temperatures up to 28 ºC with annual rainfall requirements of 1300 mm/year approximately. Its main uses are animal feed, and as raw materials in brewing industries. It has

a hemicellulose and cellulose content of 38 % which means that is possible to use this species for second generation biofuels after prior pretreatment such as hydrolysis. Moreover, there are several studies to use the biomass generated by this species as feedstock for thermochemical processes (Anupam et al., 2016).

Table 1: Energy recovery from energetic crops in Bogotá river basin (Hernández et al., 2017).

Family name	Scientific name	Metabolism type	Area (ha)	%*	Biomass (kt) [a]	TJ/y
Euphorbiaceae	*Hura crepitans*	C4	44,945.4	7.5	4,090.0	10,469.5
	Pedilanthus tithymaloides	C4	17,259.1	2.9	552.3	1,409.6
Fabaceae	*Gliricidia sepium*	C4	106,282.9	17.7	3,719.9	32,684.5
	Leucaena leucocephala	C4	188,070.3	31.3	6,582.5	96,393.5
Maliaceae	*Cedrela odorata*	C3	87,668.1	14.6	526.0	11,004.1
Myrtaceae	*Eucalyptus globulus*	C3	35,253.6	5.9	758.0	16,675.0
	Eucalyptus grandis	C3	110,330.0	18.4	1,930.8	38,776.2
	Eucalyptus spp	C3	38,842.6	6.5	1,068.2	19,439.6
Pinaceae	*Pinus patula*	C3	5.4	0.0	0.2	4.6
	Pinus radiata	C4	27,718.8	4.6	859.3	15,034.9
Poaceae	*Arundo donax L.*	C3	213,548.3	35.6	3,737.1	18,004.6
	Brachiaria brizantha	C4	145,261.1	24.2	1,961.0	35,004.3
	Brachiaria humidícola	C3	128,659.8	21.4	3,087.8	12,451.4
	Brachiaria mutica	C3	9,678.2	1.6	193.6	772.2
	Cenchrus ciliaris	C3	120,669.2	20.1	1,689.4	20,773.8
	Cynodon dactylon	C4	116,099.6	19.3	3,076.6	11,069.8
	Cynodon plectostachyus	C4	9,515.3	1.6	299.7	3,317.0
	Dichanthium aristatum	C4	144,107.1	24.0	2,738.0	46,282.0
	Digitaria decumbens	C3	109,167.7	18.2	1,146.3	17,783.4
	Echinochloa polystachya	C4	30,139.5	5.0	602.8	2,772.8
	Pennisetum purpureum	C4	7,607.2	1.3	467.8	1,229.3
Salicaceae	*Salix spp*	C4	102,188.1	17.0	3,321.1	25,012.0

[a]Samples over dry basis (d.b.) * percentage of the total basin area

As was exposed in Table 1, the species which have agroenvironmental requirements similar to those which has the Bogotá river basin, are *Arundo donax L* and *Leucaena leucocephala* with percentages above 30%. In this case, *Leucaena leucocephala* has a faster metabolism (C_4) than *Arundo donax L* (C_3), therefore its biomass production could be achieved in a shorter period of time. This would improve the biomass availability in shorter periods of time supporting harvesting systems to energy recovery process. The calculated potential must be adjusted because the different fractions of the plants could change in characteristics such as moisture content, volatile matter, ash content, fixed carbon, specific gravity and bulk density which affect the energy recovery (Rasat et al., 2016). In addition, the biomass generation rate of *Arundo donax L* is almost twice smaller than *Leucaena leucocephala*, which affects energy recovery (Table 1). Other species with an important energy recovery are *Brachiaria brizantha* and *Brachiaria humidícola*, *Cenchrus ciliaris* and *Dichanthium aristatum*. The cultivation of these species would help to reduce streamflow, tile flow, erosion and nutrient losses, which are relevant to the Bogotá river basin, and to keep water quality (Guo et al., 2018). According to this analysis, it is clear that species with C_4 metabolism represent a better option for energy recovery. This is a consequence of the direct fixation of the carbon by the internal cells of the plant and is evidenced in the annual energy recovery potential that reaches a maximum of 96,393.5 TJ/y. However, it is important to evaluate several stress conditions that may occur in the basin as this would directly influence biomass production rates (Sánchez et al., 2016).

In terms of the energetic potential, all the main species evaluated have a high content of hemicellulose and cellulose with a medium content of lignin. This permits the valorization of this kind of biomass via fermentation after pretreatments such as hydrolysis. Nevertheless, the content of lignin found in many of the species enables to obtain biofuels like biochar, which is produced through thermochemical processes. Additionally, chemically modified lignin such as lignosulfonates has different applications which could be developed and specified in future research works.

4. Conclusions

The soil characteristics and climatic conditions of the Bogotá river basin are suitable to develop the implementation of fast growing crops. This fact could diversify the economy of the communities and the energetic matrix of the country while degraded soils are valorized, the erosion and nutrient losses of the soil in the basin are avoided and entire ecosystem is protected. Nevertheless, an economical assessment is required before complete implementation of the systems, in order to analyse the competition of actual uses vs energetic uses of the biomass produced by the 22 species in the Bogotá river basin.

The largest energetic potential found was of 96,393.5 TJ/y (*Leucaena leucocephala*) and the lowest energetic potential found was of 4.6 TJ/y (*Pinus patula*). Additionally, it was found that different areas of the basin are suitable for more than one of the species evaluated and that large suitable areas do not indicate greater energetic potentials necessarily.

The specific potential found in almost all the species is between the range of 2000 TJ/y and 10000 TJ/y which is classified as medium to high potential according to the residual biomass atlas of Colombia.

The main energetic valorization route identified for the species with higher potential, is the biological route after pretreatment. Although, the thermochemical processes are suitable depending of the biomass lignin content ($\geq$ 20%)

Acknowledgments

This work was carried out within the project Energetic Crops, supported by Universidad Santo Tomás - EAN.

References

Alcaldía-Mayor-de-Bogota, 2006, Plan de manejo y ordenamiento de una cuenca (POMCA del río Bogotá), Bogotá (Colombia).

Anupam, K., Sharma, A.K., Lal, P.S., Dutta, S., Maity, S., 2016, Preparation, characterization and optimization for upgrading *Leucaena leucocephala* bark to biochar fuel with high energy yielding, Energy,106, 743-756.

CAR, 2006, Plan de ordenación y manejo de la cuenca hidrográfica del río Bogotá, Bogotá, Colombia.

Delgado, J.E., Salgado, J.J., Perez, R., 2015, Perspectivas de los biocombustibles en Colombia, Revista Ingenierías Universidad de Medellín, 4(27), 13-28.

Guo, T., Cibin, R., Chaubey, I., Gitau, M., Arnold, J.G., Srinivasan, R., Kiniry, J.R., Engel, B.A., 2018, Evaluation of bioenergy crop growth and the impacts of bioenergy crops on streamflow, tile drain flow and nutrient losses in an extensively tile-drained watershed using SWAT, Science of the Total Environment, 613-614, 724-735.

Hernández, M.A., Romero, J., Jaime, C., León-Pulido, J., Cabeza, I.O., 2017, Lignocellulosic biomass from fast-growing species in Colombia and their use as bioresources for biofuel production, Chemical Engineering Transactions, 58, 541-546.

Ivan, C., María, T., Aura, V., Paola, A., Mario, H., 2016, Anaerobic co-digestion of organic residues from different productive sectors in Colombia: Biomethanation potential assessment, Chemical Engineering Transactions, 49, 385-390.

Mabrouk, A., Erdocia, X., Alriols, M.G., Labidi, J., 2017, Techno-economic evaluation for feasibility of lignin valorisation process for the production of bio-based chemicals, Chemical Engineering Transactions, 61, 427-432.

Rasat, M.S.M., Wahab, R., Mohamed, M., Ahmad, M.I., Amini, M.H.M., Wan Abdul Rahman, W.M.N., Razab, M.K.A.A., Yunus, A.A.M., 2016, Preliminary study on properties of small diameter wild *Leucaena Leucocephala* species as potential biomass energy sources, ARPN Journal of Engineering and Applied Sciences, 11(9), 6128-6137.

Sánchez, E., Gil, S., Azcón-Bieto, J., Nogués, S., 2016, The response of Arundo donax L. and Panicum virgatum to different stresses, Biomass and Bioenergy, 85, 335-345.

Schrama, M., Vandecasteele, B., Carvalho, S., Muylle, H., van der Putten, W.H., 2016, Effects of first- and second-generation bioenergy crops on soil processes and legacy effects on a subsequent crop, GCB Bioenergy, 8(1), 136-147.

Scordia, D., Cosentino, S.L., Lee, J.W., Jeffries, T.W., 2012, Bioconversion of giant reed (Arundo donax L.) hemicellulose hydrolysate to ethanol by *Scheffersomyces stipitis* CBS6054, Biomass and Bioenergy, 39, 296-305.

UPME, 2015, Integración de las energías renovables no convencionales en Colombia, (Ed.) M.d.M.y. Energia, Vol. I, La Imprenta Editores S.A. Bogotá, 188.

Yoshimura, Y., 2015, Re-examination of occurrence of Plants in Japan, Japanese Journal of Crop Science, 84(4), 386-407.