Feedstock database

for biogas in Mexico

Danish Climate and Energy Partnership Programme in Mexico 2017-2020
Bioenergy

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INTRODUCTION

The Energy Partnership Programme between Mexico and Denmark pursue the consolidation of a Mexican biomass roadmap that includes an implementation action plan and feasibility studies as well as a proposal for additional incentives to promote the increase of biomass in the energy mix.

The “Feedstock Database for Biogas in Mexico” is intended to build a strategic background for strengthening the National Waste to Energy Industry. The overall objective of this publication is to promote the use of the 20 most promising wet feedstocks for biogas production in Mexico and provide the information necessary for a first evaluation of biogas projects upon each feedstock.

The quantitative figures of this Feedstock Database were fed into the “Biogas Tool”, developed also within this Programme in order to provide decision makers with conceptual process design together with mass and energy balances.

The Feedstock Database was built upon wet organic wastes from agricultural, livestock, industrial, commercial and urban wastes. The selection of the 20-list substrates was a result of the consensus of experts from Biogas Cluster of the Mexican Centre of Innovation in Bioenergy (CEMIE-Bio), in collaboration with the consultancy company IBTech®.

The general requirements for the selection of the feedstock included:

1. Being currently widespread available or at least in some regions in Mexico.
2. Suitable as a substrate for wet anaerobic digestion.
3. Having a conspicuous biogas potential for digestion alone or co-digestion with another feedstock.
4. Availabe at low or no cost.
5. Not being utilized for other economic purposes.

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FEEDSTOCK DATABASE DOCUMENTATION FORM

AGRICULTURAL WASTES
Nopal Residues

Feedstock Database for biogas in Mexico 2018

1. Background

1.1 Selection criteria for the feedstock

Generation potential
Nopal (prickly pear) is classified as a succulent and perennial plant, with spiny and flattened stems (cladodes). It belongs to the cacti family of genera *Opuntia spp* and *Nopalea spp*. Nopal reaches a height of 3 to 5 cm; its woody trunk measures between 30 to 50 cm diameters. In some cases, it has flowers and oval fruits. Nopal is highly productive, easy to adapt, with rapid growth requiring little input, such as water. Therefore, it is considered a viable crop for energy option. Méndez-Gallegos, *et al.* (2010) consider that it is possible to obtain biogas, biodiesel, and bioethanol or semi-finished products that can be used directly from both the stems and the nopal fruits.
According to SAGARPA (2017), in 2016 the production volume was 811 thousand tonnes and the entities that most produced nopal was: Morelos (45%), Mexico City (25%), State of Mexico (11%), Jalisco (4%), and Puebla (3%). The yield of nopal production is, on average, 63 tonnes/ha/year. However, in Morelos and the State of Mexico, the yield is more than 90 tonnes/ha/year. Based on information from SAGARPA (2018), SIAP(2017) and SENER (2018), in 2013 the residues production was 384 thousand tonnes while the production of nopal "vegetable" or "nopalito" was 786 thousand tonnes (e.g. production losses, damaged material). Therefore, the ratio of residues production (on average) is 0.49 tonne/tonne of "nopalito". Enzymatic browning or microbial rot is the main cause of these losses (Ríos Ramos & Quintana-M., 2004). Consequently, 30 tonnes/ha/year of nopal residues are produced on average in the country.

Current use
Méndez-Gallegos *et al*. (2010) considered that nopal can become a solid, liquid or gaseous biofuel for the generation of heat, electricity, and transportation. At present, limited information on energy production from nopal residues is available. In Mexico City, for example, less than 1 percent of the nopal residues (3 tonnes per day) are being utilized in a plant to produce biogas in Milpa Alta (less than 2 percent of the waste generated in the Collection and Market Center of Nopal) (CONACYT Prensa, 2017).

Cost of the residue
Although the cost of nopal for human consumption is high, SAGARPA (2015), the residue has no cost in the Collection and Market Center of Nopal at Milpa Alta, Mexico City.

Biogas potential
Biogas potential may be estimated based on the crop yield of nopal and its corresponding methane yield. The first value will depend on the type of nopal, soil, weather, and other agricultural factors. Biogas production will be related to the nopal chemical composition and the anaerobic process applied. Nopal residues have been identified as a high methane yield biomass. Its high water and low lignin content,

together with the absence of natural inhibitors favor anaerobic digestion processes. Pectin and other soluble sugars are in the nopal juice and therefore can be used directly for biogas production.

1.2 Expected characteristics of the feedstock

Production process

Ríos-Ramos & Quintana-M. (2004) mentions that 50 percent of nopal production becomes a residue (browning and rot). Besides, he describes crop management, where frequent pruning is done to improve production, contributing to the generation of waste. The residues generation reported by Ríos-Ramos & Quintana-M.(2004) corresponds to the determinations made with SIAP and SENER information. As mentioned, on average, the residue is produced at 30 tonnes/ha/year in industrial nopal (vegetable) plantations. The nitrogen and phosphorus content has been reported by Fernández-Pavía *et al*. (2015) as 2.2 and 0.85% (dry matter), respectively, for edible nopal (*Opuntia ficus indica*).

Feedstock conditioning and pretreatment (If applicable)

Before feeding the anaerobic digester, nopal should be ground and coarse-filtered in order to remove long fibers. This results in a solid and a liquid fraction (juice). Prickly pear cladodes (pencas) composition is different from lignocellulosic biomass due to their high content of pectin and a small amount of cellulose and lignin (Sáenz *et al*., 2006). Addition of pectinases can increase twice the amount of soluble sugars in the juice (do Nacimento *et al*., 2016). Also, thermal treatment significantly increased the concentration of soluble sugars in the nopal juice, mainly glucose and mannose.

Considering the solid fraction after juice extraction (mesh), removing lignin may improve the enzymatic saccharification of cellulose and hemicellulose. Removal of lignin can be achieved by some of the pretreatments applied for lignocellulosic biomass (alkaline or oxidative). Also, acid hydrolysis of the solid fraction may release free sugars from the solid fraction. There are few studies about the use of these pretreatments in nopal solid fraction and its effect on biogas production. Acid hydrolysis of the solid fraction of nopal released 60 to 88% of sugars of the cladodes (do Nacimiento *et al*., 2016).

Potential for co-digestion

Nopal is a suitable feedstock for direct anaerobic digestion. However, its high water content and carbohydrates concentration make it a suitable co-digestion material for low C/N feedstock (e.g. manure of all types).

1.3 Examples of Mexican plants in operation

The biogas plant "Planta para tratamiento de residuos orgánicos del Centro de Acopio Nopal-Verdura" located in Milpa Alta, Mexico City utilizes nopal and other organic wastes to produce biogas, energy, and bio-fertilizer. The plant was constructed by Sustentabilidad en Energia y Medio Ambiente (SUEMA) with financial support from the Science, Technology and Innovation Secretariat of Mexico City (SECITI). Besides, in Calvillo, Aguascalientes, the cement cooperative "Cruz Azul" in partnership with the National Council for Science and Technology (CONACYT PRENSA, 2017) developed a project to generate biogas and energy from nopal mash and cow manure. Finally, in Zitácuaro, Michoacán, is located the first biogas plant from nopal crops specifically cultivated for the purpose. Nopalimex, the owner of the biogas plant, was technically supported by the National Polytechnic Institute (IPN), the Autonomous University of Chapingo and the Institute of Electrical Research.

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus) and using Google. Scientific papers, technical publications, and thesis were identified and revised.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C).

The conversion of N-m³/kg VS to N-m³/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (6 and 91%, respectively).

4. Results

Table 1. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	4	Expert judgment
Feedstock handling (as solid or as a liquid)	Slurry (or juice and mesh)	Expert judgment
Recommended anaerobic technology if treated alone	Completely Stirred Tank Reactor	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Grinding and sieving	Expert judgment
Current use of the feedstock	Less than 1% is used to generate biogas	SEDEREC (2016)/CONACYT prensa (2017) /SIAP (2017)
Relative use of the feedstock for other purposes	Low use	Expert Judgment
Expected cost	Low	Expert Judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/ha/year	30.0	SEDEREC (2016)/CONACYT prensa (2017) /SIAP (2017)
Dry matter	TS (%)	5.7 – 6.5	Yang *et al.* (2015)
Volatile Solids fraction	VS/TS	0.91	Do Nascimento Santos(2016)
Density	kg/m³	1.02	Expert Judgment
C/N relation **(Total N)**	C/N kg N/tonne TS	48 (N: 22)	Quintana *et al.* (2017) Fernández-Pavía *et al.* (2015)
Fats content	%	<1	SAGARPA (2015)
Typical methane content in biogas	%	60-65	Do Nascimento Santos (2016)/Arvizu-Fernández (2015)
Typical sulfur content in biogas	%	0.01	Expert judgment
Methane potential (yield)	N-m³ CH_4/tonne VS N-m³ CH_4/tonne fresh biomass GJ/tonne VS	410 – 517 (460) 22.4 – 28.2 (25.1) 14.7– 18.6 (16.5)	Do Nascimento Santos (2016)/Arvizu-Fernández (2015)

5. References

Arvizu-Fernández, J. (2015). *Producción de biogás con nopal*. Junio/Julio. Retrieved from https://www.ineel.mx/boletin022015/tenden01.pdf

do Nascimento-Santos, Taciana, Damilano, Emmanuel, Gomes-do Prado, Adelson, Leite, Fernanda, de Fátima-Rodrigues de Souza, Raquel, Cordeiro-dos Santos, Djalma, Abreu, Cesar, Ardaillon Simões, Diogo, de Morais Jr, Marcos & Menezes, Rômulo. (2016). Potential for biofuels from the biomass of prickly pear cladodes: Challenges for bioethanol and biogas production in dry areas. *Biomass and Bioenergy,* 85.

Fernández-Pavía, Y.L., García-Cué J.L., López-Jiménez A. & Mora-Aguilera G. (2015). Inducción de deficiencias nutrimentales en nopal verdura *Opuntia ficus indica* (L.), *Revista Mexicana de Ciencias Agrícolas,* Vol.6, 6, 1417-1422.

Méndez-Gallegos, J., Rössel, D., Amante-Orozco, A., Gómez-González, A. & García-Herrera, J. (2010). El nopal en la producción de biocombustibles. *RESPYN Revista Salud Pública y Nutrición*, Edición Especial No. 5.

Ríos Ramos, J. & Quintana-M., V. (2004). *Manejo general del cultivo del nopal*. Colegio de Posgraduados – Institución de enseñanza e investigación en ciencias agrícolas México-Puebla-San Luis Potosí-Tabasco-Veracruz-Córdoba.

Sáenz, C., Berger, H., García, R. C., Jiménez, E. A., & Rosell, C. (2006). *Utilización agroindustrial del nopal*. Roma: Organización de las Naciones Unidas Para la Agricultura y la Alimentación.

SAGARPA (2015). *Estudio de factibilidad para el establecimiento de cultivo de nopal (Opuntia) en tierras ociosas en los estados de Aguascalientes, San Luis Potosí, Guanajuato y Zacatecas con fines alimenticios, energéticos y ambientales*. México: Secretaría de Agricultura, Ganadería, Pesca y Alimentación, 28.

SAGARPA (2018) Sistema de Información Alimentaria y Pesquera (SIAP). México: Secretaría de Agricultura, Ganadería, Pesca y Alimentación, Retrieved from https://www.gob.mx/siap

SENER (2018) Atlas Nacional de Biomasa. México: Secretaría de Energía. Retrieved from https://dgel.energia.gob.mx/atlasbiomasa

SIAP (2017). *Atlas Agroalimentario 2017*. México: Secretaría de Agricultura, Ganadería, Pesca y Alimentación, 2017, 120 pp.

Quintana, E., Vázquez, G., Beltrán, I., Coronel, C., Islas, S., Ortega, E. & Lucho, C. (2017). Enhancement of the biogás and biofertilizer production from Opuntia Heliabravoana Scheinvar in arid and semiarid zones. Centro de Investigaciones químicas, UAEH. México*, 2017.*

Yang, L., Lu, M., Carl, S., Mayer, J. C., Cushman, J., Tian, E. & Lin, H. (2015). Biomass characterization of Agave and Opuntia as potential biofuel feedstocks. *Biomass and Bioenergy,* 76.

CONACYT Prensa (2017). Primera planta de valorización de residuos orgánicos en la CDMX. Retrieved from:http://conacytprensa.mx/index.php/ciencia/ambiente/16392-planta-valorizacion-residuos-organicos-cdmx

SEDEREC (2016). En Milpa Alta se producen 9 de cada 10 toneladas de nopal cultivados en la CDMX. Retrieved from http://www.sederec.cdmx.gob.mx/comunicacion/nota/en-milpa-alta-se-producen-9-de-cada-10-toneladas-de-nopal-cultivados-en-la-cdmx

AGRICULTURAL WASTES
Water Hyacinth

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Water hyacinth (*Eichhornia crassipes*) is considered as a noxious weed in many parts of the world as it grows very fast and depletes nutrient and oxygen rapidly from water bodies, adversely affecting flora and fauna (Villamagna & Murphy, 2010). There have been instances of complete blockage of waterways by water hyacinth (WH) making fishing and recreation very difficult. Shoeb & Singh (2002) reported that under favorable conditions WH can achieve a growth rate of 17.5 tonnes per hectare per day on dry basis. With the growing energy crisis supplemented by environmental concerns, biomethanation of WH can serve as a biomass-to-energy generation alternative. WH management problems and environmental concerns as well as the on-going successful shifting from non-conventional to renewable energy technologies has given an impulse for this research to focus on biogas production (Kunatsa *et al.,* 2013).

Current use

Although alternative management has been studied to dispose the residuals of this weed, as organic inputs to soils or as livestock feed (e.g., Woomer *et al*., 2000), so far this residual biomass is not used in Mexico.

Cost of the residue

As a noxious weed there is no demand for this biomass, so no cost is associated. There is a dichotomy of socio-economic impacts associated with invasive species. There are the benefits and costs that result from the presence of WH, and there are the benefits and costs of preventing, managing or eradicating the species, including the ecological impacts of those actions. Invasive species pose an immediate threat to freshwater resources, biodiversity, and society worldwide as a result of greater connectivity within our modern world (i.e., globalization). Invasive species management primarily focuses on minimizing socioeconomic damages in ways that are least costly. Possibly the biomass generation for biogas production is a viable alternative that must be evaluated (Scheffer *et al*., 1993).

Biogas potential

Biogas can be produced from WH, being a promising renewable source of energy in the form of biogas. An example of solution is the Lake Chivero in the capital city of Zimbabwe, where the growing energy crisis supplemented by environmental concerns were resolved with the biomethanation of WH, which served as a biomass-to-energy generation alternative. Dry mass of WH in Lake Chivero was found to be 23 688 tonnes/yr and the biogas yield is 12.1 liters per 1kg of dry mass of WH, consequently with a digester of 10,412 m^3 can produce 1 681 m^3/day (87.56 kW). The rate of production will depend on many factors including the temperature, pH, degree of feedstock dryness among others. It was found through laboratory experiments that the rate of biogas production as well as the quantity of biogas is higher upon using dry WH as compared to fresh WH. Therefore, the WH should be dried before use and inoculation with cow rumen contents or cow dung will increase biogas rate of production and ultimate yield. The biogas can be used in the household for heating, cooking and lighting using domestic biogas stoves and lamps, and electricity can be generated using internal combustion engines (Kunatsa *et al*., 2013).

Early studies on anaerobic digestion of WH examined a conventional mesophilic (35 °C) process, carried out in a continuously stirred tank reactor (CSTR), which resulted in a methane yield of 190 L CH_4/kg VS, with 42% volatile solids (VS) removal (Chynoweth *et al*., 1981). The enhancement of the process increased the methane yield up to 340 L CH_4/kg VS, corresponding to some 66% of the theoretical stoichiometric value (560 L CH_4/kg VS) (Chynoweth *et al.,* 1982), while Chin and Goh reported a yield of 503 L CH_4/kg VS (cited in Malik, 2007).

1.2. Expected characteristics of the feedstock

Production process
WH is a floating Neotropical *Pontederiacea*, which, over the past century, has been spread around the world by humans. Outside of its native range, high densities of WH can drastically affect the appearance and function of a water body. The plant's distribution and density is limited by temperature, salinity, and the force of water flow (Wilson *et al*., 2005). It is most problematic in subtropical and tropical inland water bodies with long residence time and high nutrient concentrations (Mangas-Ramirez & Elias-Gutierrez, 2004) and it can quickly grow to very high densities (over 60 kg/m^2), thereby completely covering water-bodies. This has negative effects on the environment, human health and economic development (Julien *et al*., 1996). The total nitrogen fraction per total solids (dry weight) is 1.1 – 1.8 % and phosphorus 0.3 – 0.6 %.

Feedstock conditioning and pretreatment (if applicable)
WH must be grinded in order to facilitate its treatment as a slurry (the plant has a high water content). Other possibility would be to separate the produced water after grinding, while retaining the solid fraction and sun-dried it for a final grinding to obtain a powder (0.8 mm size is recommended) to increase its degradability (Chuang *et al.,* 2011). WH is lignocellulosic biomass consisting of a complex mixture of lignin, hemicelluloses and cellulose. The conversion of WH to fuels has received significant interest in the last few decades. However, the cellulose content of the WH is much lower if compared with wood and straw (Kumar *et al*., 2009). A pretreatment to remove the lignin and enhance the hydrolysis of cellulose is essential. Xu et al. (2011) reported that pretreatment with 3% NaOH solution could improve methane yield by 20% as well as dilute acid pretreatment could also improve the reducing sugar yield of sugarcane tops. Patel *et al.* (1993) found that thermochemical pretreatment of WH improved biomethanation and the best results were obtained when it was treated at pH 11.0 and at 121 °C.

Co-digestion potential
It has been reported that the co-digestion of water hyacinth and manure increases biogas yields compared to manure alone indicating that the plant biomass contributes more to the biogas production than the manure (Kumar, 2005; Patil *et al*., 2014), but cattle dung has been used in order to increase biogas yield and COD removal (Ganesh *et al*., 2005).

1.3. Examples of Mexican plants in operation

There are no biogas generation plants by digestion or co-digestion of WH in Mexico.

2. Research methods

A variety of data sources for conducting the resource assessment, including:

- Published data by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
- The main national-level government stakeholders in Mexico include the Ministry of Environment and Natural Resources (SEMARNAT) and the Ministry of Agriculture, Rural Development, Fisheries, and Food (SAGARPA).
- Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C) representative of the WH in Mexico.
The conversion of N-m^3/kg VS to N-m^3/kg biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (18 and 86%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results for each column of the database

Table 2. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	3	Kunatsa *et al*. (2013).
Feedstock handling	Solid	Expert Judgment
Recommended anaerobic technology if treated alone	Anaerobic filters and CSTR reactors	Ferrer *et al.* (2010)
Pretreatment required before anaerobic technology	Grinding	Hendriks & Zeeman (2009)
Current use of the feedstock	Without use	-
Relative use of the feedstock for other purposes	Low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/hectare /year	300 (wet basis) 36 (dry basis)	Kunatsa *et al.* (2013)
Dry matter	TS (%)	18.0	Krishania *et al.* (2013)
Volatile Solids fraction	VS/TS	0.86	Kunatsa *et al.* (2013)
Density	tonne/m^3	1.0	*Davies & Mohammed (2011)*
C/N relation **(Total N)**	C/N kg N/tonne TS	25 (N: 15)	Krishania *et al.* (2013) (Malik, 2007)
Fats content	%	4.1	Adeyemi & Osubor (2016)
Typical methane content in biogas	%	55 – 75	Ferrer *et al.* (2010)
Typical sulfur content in biogas	%	< 0.1	Ferrer *et al.* (2010)
Methane potential (yield)	m^3 CH_4/tonne VS	340	Krishania *et al.* (2013)
	m^3 CH_4/tonne fresh biomass	52.6	
	GJ/tonne VS	1.9	

5. References

Adeyemi, O., & Osubor, C. C. (2016). Assessment of nutritional quality of water hyacinth leaf protein concentrate. *The Egyptian Journal of Aquatic Research*, 42(3), 269-272.

Chynoweth, D.P., Gosh, S., Herny, M.P., Jerger, D.E. & Srivastava, V.J. (1981). Biogasification of blends of water hyacinth and domestic sludge. In: *Proceedings of the International Gas Research Conferences*, Los Angeles, 742–755.

Chynoweth, D.P., Dolec, D.A., Gosh, S., Herny, M.P., Jerger, D.E. & Srivastava, V.J. (1982). Kinetics and advanced digester design for anaerobic digestion of water hyacinth and primary sludge. *Biotechnology and Bioengineering Symposium* 12, 381–398.

Chuang, Y. S., Lay, C. H., Sen, B., Chen, C. C., Gopalakrishnan, K., Wu, J. H. & Lin, C. Y. (2011). Biohydrogen and biomethane from water hyacinth (*Eichhornia crassipes*) fermentation: effects of substrate concentration and incubation temperature. International journal of hydrogen energy, 36(21), 14195-14203.

Davies, R. M., & Mohammed, U. S. (2011). Moisture-dependent engineering properties of water hyacinth parts. *Singapore Journal of Scientific Research*, 1(3), 253-263.

Ferrer, I., Palatsi, J., Campos, E., & Flotats, X. (2010). Mesophilic and thermophilic anaerobic biodegradability of water hyacinth pre-treated at 80° C. *Waste management*, 30(10), 1763-1767.

Ganesh, P. S., Ramasamy, E. V., Gajalakshmi, S., & Abbasi, S. A. (2005). Extraction of volatile fatty acids (VFAs) from water hyacinth using inexpensive contraptions, and the use of the VFAs as feed supplement in conventional biogas digesters with concomitant final disposal of water hyacinth as vermicompost. *Biochemical Engineering Journal*, 27(1), 17-23.

Julien, M.H., Harley, K.L.S., Wright, A.D., Cilliers, C.J., Hill, M.P., Center, T.D., Cordo, H.A. & Cofrancesco, A.F. (1996). International co-operation and linkages in the management of water hyacinth with emphasis on biological control. In: Moran, V.C.H.J.H. (Ed.), *Proceedings of the IX International Symposium on Biological Control of Weeds*, University of Cape Town, Stellenbosch, South Africa, 273–282.

Hendriks, A. T. W. M., & Zeeman, G. (2009). Pretreatments to enhance the digestibility of lignocellulosic biomass. *Bioresource technology*, 100(1), 10-18.

Krishania, M., Kumar, V., Vijay, V. K., & Malik, A. (2013). Analysis of different techniques used for improvement of biomethanation process: a review. *Fuel*, 106, 1-9.

Kumar, S. (2005). Studies on efficiencies of bio-gas production in anaerobic digesters using water hyacinth and night-soil alone as well as in combination. *Asian Journal of Chemistry*, 17(2), 934.

Kumar, A., Singh, L. K., & Ghosh, S. (2009). Bioconversion of lignocellulosic fraction of water-hyacinth *(Eichhornia crassipes)* hemicellulose acid hydrolysate to ethanol by *Pichia stipitis*. *Bioresource Technology*, 100(13), 3293-3297.

Kunatsa T., Madiye, L., Chikuku. T., Shonhiwa, C. & Musademba, D. (2013). Feasibility Study of Biogas Production from Water Hyacinth A Case of Lake Chivero – Harare, Zimbabwe. *International Journal of Engineering and Technology*, 3(2), 119-128.

Malik, A. (2007). Environmental challenge vis a vis opportunity: the case of water hyacinth. *Environment international*, 33(1), 122-138.

Mangas-Ramirez, E. & Elias-Gutierrez, M. (2004). Effect of mechanical removal of water hyacinth (*Eichhornia crassipes*) on the water quality and biological communities in a Mexican reservoir. *Journal of Aquatic Health and Management* 7 161-168.

Patel, V., Desai, M. & Madamwar, D. (1993). Thermochemical pre-treatment of water hyacinth for improved biomethanation. *Applied Biochemistry and Biotechnology,* 42 (1), 67–74.

Patil, J. H., AntonyRaj, M. A. L., Shankar, B. B., Shetty, M. K., & Kumar, B. P. (2014). Anaerobic co-digestion of water hyacinth and sheep waste. *Energy Procedia*, 52, 572-578.

SAGARPA. (2013). Avances de la Acuacultura y Pesca en Guanajuato. http://www.sagarpa.gob.mx/delegaciones/Guanajuato/boletines/2013/julio/Documents/2013B011.pdf. *SAGARPA, México.*

Scheffer M., Hosper S.H., Meijer M.L., Moss B. & Jeppesen E. (1993). Alternative equilibria in shallow lakes. *Trends in Ecology & Evolution*, 8, 275-279.

SEMARNAT. (2009). Informe de la situación del medio ambiente en México. *SEMARNAT*, Edición 2008, México, Pp.3-5.

Shoeb F. & Singh H.J. (2002). Kinetic studies of biogas evolved from water hyacinth. *2nd International Symposium on New Technologies for Environmental Monitoring and Agro – Applications*, 138.

Villamagna, A.M. & Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): a review. *Freshwater biology*, 55(2), 282-298.

Wilson, J. R., Holst, N., & Rees, M. (2005). Determinants and patterns of population growth in water hyacinth. *Aquatic Botany*, 81(1), 51-67.

Woomer, P. L., Muzira, R., Bwamiki,D., Mutetikka,D., Amoding, A., Bekunda, M. A. (2000). Biological management of water hyacinth waste in Uganda. *Biological Agriculture & Horticulture,* 17, 181–196.

Xu, J., Wang, Z., & Cheng, J. J. (2011). Bermuda grass as feedstock for biofuel production: a review. *Bioresource technology*, 102(17), 7613-7620.

AGRICULTURAL WASTES
Coffee Pulp

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Coffee is the 7th agricultural crop with the largest cultivated area in Mexico (around 740,000 ha). In the year 2000 the highest production was reached with 1 837 thousand tonnes of cherry coffee (fruit before processing). However, afterwards there was a constant decrease until reaching 835 thousand tonnes in the 2015/16 cycle (55% reduction). The declining trend in national coffee production is mainly explained by the reduction in productivity of coffee plantations in recent years, due in part to the presence of coffee rust, and to low international prices.

Regarding coffee production by states, 61% of the production of this crop during the period 1980-2013 was concentrated in two States: Chiapas (37 %) and Veracruz (24 %); Oaxaca is in the third place.

In Mexico, the cultivation of coffee, which provides income to more than 300 thousand producers (two thirds indigenous population) is located in 12 States:

a) Slope of the Gulf of Mexico: San Luis Potosí, Querétaro, Hidalgo, Puebla, Veracruz and the northern part of Oaxaca and Tabasco.

b) Slope of the Pacific Ocean: Colima, Guerrero, Jalisco, Nayarit and part of Oaxaca

c) Soconusco region: most part of the state of Chiapas.

d) North Central Region: the area that receives the humid winds of the Gulf of Mexico

The coffee season in Mexico begins in October and ends in September, although the harvest takes place mainly from November to March. This is done mostly manually (95%). Coffee production consists of 97% coffee of the Arabica species (*Coffea arabica*) and 3% of the Robusta species (*Coffea canephora*), the latter mainly destined to the production of instant (powder) coffee.

The coffee pulp is the more important weight fraction of a coffee fruit, representing also the main residue (40 to 43% of the fresh coffee cherry, with 77% water). In case wet processing is applied, distinctive residues are the skin (pericarp) and the pulp (mesocarp) as a solid residue, the mucilage and soluble sugars (pectin layer) in a liquid phase, and the hull (endocarp) or parchment as a light solid material. For dry processing, all residues are combined in a solid matter known as coffee husk. In Mexico, 97% of the coffee is produce by wet processing.

Based on the 2015/16 production and on the weight fraction of the pulp, an estimation of 384 000 tonnes of coffee pulp (88 300 tonnes dry matter) were generated in Mexico. This production was concentrated during the winter months (December to March).

Current use

Disperse efforts are carried out for valorizing the coffee pulp as compost (organic soil amendment), animal feeding (silage with molasses), biogas production in small scale rural digesters. If sun-drying is applied, the dry pulp is used as solid fuel. More sophisticated processes are the solid substrate fermentation for

producing enzymes and other high value products, or for fungi production (*Pleurotus* spp.,) for human consumption.
However, these beneficial uses of the coffee pulp remain as isolate experiences due to its complexity and the time limited (seasonal) availability of the raw material.

Cost of residue
Most of the production comes from small, rural producers located in isolated areas. This residue has no market value as there is no demand for further processing.

Biogas potential
The coffee pulp may be anaerobically digested for biogas production (dry digestion); however, its caffeine and polyphenol contents may hinder its biodegradability. In order to reduce the inhibitory effect of these compounds, the addition (co-digestion) of the wastewater discharged from the wet process may be considered.

1.2. Expected characteristics of the feedstock

Production process
The separation of the fresh fruit (cherry) and the bean (seed) is accomplished by two different processes: wet and dry. Their purpose is to eliminate the pulp, mucilage and hull (parchment), leaving the coffee beans ready for commercializing and roasting. The dry route, limited to Robusta coffee, is applied only to 3% of the production in Mexico. This is a non-microbial process, with no water needs. In this method, ripe fruits remain on the tree while they experience partial dehydration. Then they are collected, sun-dried at yards until a moisture content of 10 - 11% is reached. Then they are peeled mechanically, producing a solid waste (coffee husk).
The wet process begins with the reception of the cherry in a tank (siphon) filled with water that prevents fermentation and facilitates its selection by density; subsequently, the raw material passes from the bottom of the tank to the de-pulping section. In this stage, machines perform the separation of the pulp of the coffee bean and the de-pulping wastewater is produced. Then, the coffee beans pass to fermentation, stage in which the mucilage of the grain is removed by microbiological means in tanks for about a day. At the end of this period, fresh water is applied for washing out the mucilage from the surface of the grain (washing wastewater is produced) and then pass to drying (in yards under the sun or with mechanical driers). This operation reduces the humidity of the grain from 52 to 12% approximately. Around 40 to 43% (wet weight) of the fresh cherry fruit ends in the coffee pulp, and 4% as hull or parchment.

Feedstock conditioning and pretreatment (If applicable)
Coarse grinding may be applied for coffee pulp conditioning prior to anaerobic digesters. No specific operations are needed for compost or silage valorization.

Potential for co-digestion
Co-digestion with cow manure may be recommended due to the seasonal production of coffee pulp. By this way, biogas would be produced during the whole year, based on co-substrate feeding. Another approach is to co-digest the solid and liquid wastes from the wet process, in a single anaerobic covered pond.

1.3. Examples of Mexican plants in operation

No anaerobic plants currently in operation were identified in Mexico.

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus) and using Google. Scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm. 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). The in situ conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C) representative of the coffee plantations in Mexico.

The conversion of N-m³/kgVS to N-m³/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (23 and 95%, respectively). The energy conversion factor applied is 35.9 MJ/N-m³ CH_4

4. Results

Table 3. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	2	Expert Judgment
Feedstock handling (as solid or as liquid)	Solid	Expert Judgment
Recommended anaerobic technology if treated alone	Dry digester	Expert Judgment
Pretreatment required before anaerobic technology (if applicable)	Coarse grinding	Expert Judgment
Current use of the feedstock	Marginal (biogas, compost, animal feed)	Houbron *et al*. (2007); Figueroa-Hernández (2015)
Relative use of the feedstock for other purposes	Low	Expert Judgment
Expected cost	Low	Expert Judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/unit/year		
Dry matter	TS (%)	22.2 – 23.3	Braham & Bressani (1979); Houbron *et al*. (2007)
Volatile Solids fraction	VS/TS	0.92 – 0.97	Braham & Bressani (1979); Houbron *et al*. (2007)
Density	kg/m³	270 - 300	Montilla Pérez *et al*. (2008)
C/N relation (N total)	C/N kg/tonne TS	25-31 (N: 17.6)	Figueroa-Hernández *et al* (2015); Blandón Castaño *et al*. (1999)
Fats content	%	2 – 2.5	Murthy & Naidu (2012); Figueroa-Hernández *et al* (2015)
Typical methane content in biogas	%	48 - 60	Calzada *et al*. (1981)
Typical sulfur content in biogas	%	< 0.01	Expert judgment
Methane potential (yield)	N-m³CH₄/ tonne VS	350 – 670 (450)	Calzada *et al*. (1981) Kivaisi & Rubindamayugi (1996)
	N-m³CH₄/ tonne fresh biomass	76 – 146 (100)	After Calzada *et al*. (1981) Kivaisi & Rubindamayugi (1996)
	GJ/tonne VS	12.6 – 24.1 (16.2)	

5. References

Calzada J.F., de León O.R., de Arrlola M.C., de Micheo F., Rolz C., de León R. & Menchú J.F. (1981). Biogas from coffee pulp. *Biotechnology Letters*, 3, 713-716.

Blandón-Castaño G., Dávila-Arias M.T., Rodríguez-Valencia N. (1999). Caracterización microbiológica y físico-química de la pulpa de café sola y con mucílago, en proceso de lombri-compostaje. *Cenicafé,* 50, 5-23.

Braham J.E., Bressani R. (1979). *Coffee pulp: composition, technology, and utilization*. IDRC Canada, 95 pp. Retrieved from https://idl-bnc-idrc.dspacedirect.org/handle/10625/6006

Figueroa-Hernández E., Pérez-Soto F., Godínez-Montoya L. (2015). *La Producción y el Consumo del Café*, Ecorfan editor, España, 170 pp. ISBN 978-607-8324-49-1.

Houbron E., Cano-Hernández V., Reyes-Alvarado L.C., Rustrián E. (2007). En busca de una solución para el tratamiento de los desechos del café. *Gaceta de la Universidad Veracruzana*, 101, 8 pp.

Kivaisi A.K., Rubindamayugi M.S.T. (1996). The potential of agro-industrial residues for production of biogas and electricity in Tanzania*, Renew. Energy* 9, 917–921.

Montilla-Pérez J., Arcila-Pulgarín J., Aristizábal-Loaiza M., MontoyaRestrepo E.C., Puerta-Quintero G., Oliveros-Tascón C.E., Cadena –Gómez G. (2008). Propiedades físicas y factores de conversión del café en el proceso de beneficio. *Avances Técnicos 370*, Cenicafé, Colombia, 8 pp.

Murthy P.S. & Naidu M. (2012). Sustainable management of coffee industry by-products and value addition —A review. *Resources, Conservation and Recycling*, 66, 45–58.

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LIVESTOCK WASTES

Cow Manure

Feedstock Database for biogas in Mexico 2018

1. Background

1.1 Selection criteria for the feedstock

Generation potential

Production of cattle is an activity wide spread in Mexico. Thirty-one states produce cattle. Based on the latest official census conducted in 2007 by INEGI (2009), the three main producers are Veracruz, Jalisco, Chihuahua states (2 454 171, 1 931 546 and 1 708 887 animals, respectively).

In Mexico, most of the manure is produced in a solid form (manure mixed with urine, and litter). Only in the case of the mechanized milking units manure is in a slurry form (manure mixed with urine and water used for cleaning of the milking unit). A particular datasheet has been prepared for that waste slurry, so it is not covered here. Estimated total amount of cow manure produced in Mexico in 2007 was 75 928 914 tonnes/year (INEGI, 2009). This figure is calculated based on the number of bovines at 4 ranges of ages (less than 1 year, 1 to 2 years, 2 to 3 years and more than 3 years) with the corresponding manure production per animal (4, 8, 10, 15 kg/animal.day (Vera-Romero *et al.*, 2014)). Manure production per animal was estimated only for the solid fraction of manure.

Current use

Common practice among cattle producers includes storage of cow manure in piles. The storage time and the associated measures will depend on the size of the production unit and the identified valorization or final disposal opportunities. Usually there is no aeration of the pile during manure storage. Manure from the pile is applied on agricultural land as soil amendment. Depending on the amount of cows that are fattened and the size of the surface that is cultivated for forage, a variable excess of manure is not utilized. This excess is sold to compost/vermicompost producers. The remaining excess is given away to other farmers as soil amendment.

Cost of the residue

The cost of the cow manure in the market varies according to offer and demand. Selling prices may be low, as in Aguascalientes State ($500 MXN pesos per 3 tonne truck), or higher, around $1,000 MXN pesos/tonne in the State of Morelos, when sold to compost/vermicompost producers.

Biogas potential

Cow manure has a medium biogas potential. It should be kept in mind that cow manure is made up of two fractions: a rapidly biodegradable one (which is soluble in water) and a slowly biodegradable part, which is mainly lignocellulosic fiber.

1.2 Expected characteristics of the feedstock

Production process

Confined cattle for meat and dairy production are the main source of manure for anaerobic digestion. Confined cow manure is collected with help of paddles (small size producers) or mechanical paddle loaders (medium and large size producers). A usual practice is to transport manure to designated areas to storage it in piles. A more appropriated storage to avoid loss of nutrients requires the use of special containers (*estercoleros*) to keep manure dry to prevent leak of nutrients by rain water. However, in general *estercoleros* are not used in Mexico.

Feedstock conditioning and pretreatment (If applicable)

In order to treat the solid fraction of manure by wet anaerobic digestion is necessary to dilute it with water. Large pieces of straw should be screened. Alternatively, slurry can be grinded to reduce size of straw. However, in Mexico these pretreatments are uncommon and this leads to decrease in effective pond or reactor working volume.

Although pretreatment is not practiced in Mexico, several literature reports show advantages of using different, more complex procedures. Alkaline and oxidative treatments have been reported to decrease lignin content and increase biogas potential (Ramos-Suárez *et al*., 2017), such as thermochemical pretreatment. However, the techno-economic analysis demonstrated that thermochemical pretreatment was not feasible (Passos *et al*., 2017).

Co-digestion potential

Due to the low C/N ratio, anaerobic co-digestion of manure with lignocellulosic residues, with high C/N ratios, is a convenient alternative (Neshat *et al*., 2017). Manure has been co-digested with diverse residues. Cow manure and sewage sludge were used as primary waste along with kitchen waste, yard waste, floral waste, and dairy wastewater as co-substrates (Kumari, *et al* 2018).

1.3 Examples of Mexican plants in operation

Anaerobic covered ponds have been implemented in different parts of Mexico. No information was obtained regarding specific plants in operation.

2. Research methods

Manure production was estimated based on information reported by Instituto Nacional de Geografia y Estadistica de México (INEGI, 2009) and in the literature (Vera-Romero, I. *et al*, 2014). Characteristics of manure were obtained in the literature (Risberg *et al*, 2013).

3. Memory of calculations

As previously mentioned, the total manure production was estimated for each age category multiplying manure production for the corresponding factor and by 365 days to estimate yearly production. The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (10 and 77% as representative values, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results

Table 4. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	3	Expert judgment
Feedstock handling (as solid or as liquid)	solid	Expert judgment
Recommended anaerobic technology if treated alone	Covered anaerobic ponds	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Yes	Expert judgment
Current use of the feedstock	Soil amendment	Expert judgment
Relative use of the feedstock for other purposes (low use→ high availability / high use→ low availability)	Medium use	Expert judgment
Expected cost (high or low)	$300 - 1,000 MXN/tonne	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/unit/year*	a. 1.46** b. 2.92 c. 3.65 d. 5.475	Vera-Romero *et al*., 2014
Dry matter	TS (%)	4 - 15	Risberg *et al*., 2013. Expert judgment
Volatile Solids fraction	VS/TS	0.74 – 0.80	Risberg *et al*., 2013
Density	tonne /m^3	0.9 – 1.05	Expert judgment
C/N relation (Total N)	C/N kg/tonne TS	6.2 – 10.6 (N: 10.1)	Risberg *et al*., 2013. Expert judgment
Fats content	%	Not siginificant	Expert judgment
Typical methane content in biogas	%	50 - 58	Risberg *et al*., 2013
Typical sulfur content in biogas	%	0.14 -0.25	Expert judgment
Methane potential	N-m^3CH_4/ tonne VS	210 – 330 (270)	Risberg *et al*., 2013
	N-m^3CH_4/ tonne fresh biomass	16.2 – 25.4 (20.8)	
	GJ/tonne VS	7.5 - 11.8 (9.7)	

* Unit: cow; **Animal age a. < 1 year; b. 1 to 2 years; c. > 2 years to 3 years; d. > 3 years

5. References

INEGI (2009). Censo Agropecuario 2007. VIII Censo Agrícola, Ganadero y Forestal. Retrieved from http://www3.inegi.org.mx/sistemas/tabuladosbasicos/default.aspx?c=17177&s=est

Kumari, K., Suresh, S., Arisutha, S., Sudhakar, K. (2018). Anaerobic co-digestion of different wastes in a UASB reactor. *Waste Management*. Retrieved from http://dx.doi.org/10.1016/j.wasman.2018.05.007

Neshat, S.A., Mohammadi, M., Najafpour, G.D., Lahijani, P. (2017). Anaerobic co-digestion of animal manures and lignocellulosic residues as a potent approach for sustainable biogas production. *Renew and Sustainable Energy Reviews,* 79:308-322. Retrieved from http://dx.doi.org/10.1016/j.rser.2017.05.137

Passos, F., Ortega, V., Donoso-Bravo. A. (2017). Thermochemical pretreatment and anarobic digestión of dairy cow manure: Experimental and economic analysis. *Bioresource Technology,* 227:239-246. http://dx.doi.org/10.1016/j.biortech.2016.12.034

Vera-Romero, I., Estrada-Jaramillo, M., Martínez-Reyes, J., Ortiz-Soriano, A. (2014). Potencial de generación de biogás y energía eléctrica. Parte I. Excretas de ganado porcino y bovino. *Ingeniería Investigacion y Tecnología*. Vol XV, No. 3. 429 – 436. Retrieved from http://www.scielo.org.mx/pdf/iit/v15n3/v15n3a9.pdf

Ramos-Suarez, J.L., Gómez, D., Regueiro. L., Baeza, A., Hansen, F. (2017). Alkaline and oxidative pretreatments for the anaerobic digestion of cow manure and maize straw: Factors influencing the process and preliminary economic viability of an industrial application. *Bioresource Technology,* 241:10-20. Retrieved from http://dx.doi.org/10.1016/j.biortech.2017.05.054

Risberg K, Sun L, Levén L, Horn SJ, Schnürer A. (2013) Biogas production from wheat straw and manure–impact of pretreatment and process operating parameters. *Bioresource Technology,* 149:232–7. Retrieved from http://dx.doi.org/10.1016/j.biortech.2013.09054

LIVESTOCK WASTES

Dairy Slurry

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

The main milk producers in Mexico are Jalisco (18% of the total production), Durango (10%), Coahuila (10%), Chihuahua (8%), Veracruz (7%), and Guanajuato (7%). The total number of dairy cows in Mexico is about 2.46 million (SAGARPA, 2015). It is estimated that dairy cows whose, average weight is 500 kg, generates approximately 34 kg of dairy slurry (feces + urine + wastewater) per day (Pinos-Rodríguez, *et al.,* 2012). Based on the information reported by SAGARPA (2015) it can be estimated that 83 640 tonnes of total dairy slurry are generated per day, which are characterized by a high Total Solids content (8-12% of total solids). Being a potential resource in the production of renewable energies and soil fertilizer, or a potential risk of contamination. The total amount of nitrogen and phosphorus in the manure are estimated at 111 kg N per dairy cow per year and 42.7 kg P per dairy cow per year, respectively (Melse *et al*., 2017).

Current use

Destination of dairy slurry is closely related to water availability; therefore, it is also correlated to the stockyard cleaning system. The cleaning method most widely used is mixed cleaning. This method consists of shoveling and flushing. After leaving the stockyard, dairy slurry runs into a pit. Waste management techniques most widely used are the following: (a) *application to the soil*: it is the direct application of non-treated slurry to grazing land or arable land; (b) *storage and drying*: It consists of storing waste in slurry storage tanks. Subsequently, this waste is used in cultivation areas, as soil amendment with fertilizing benefits; (c) *solid and liquid separation*: This system allows a better utilization of nutrients for land application. Most separated solids are dry enough to be piled up, while the separated liquid can be handled as any other fluid. In fact, this liquid may be spread through irrigation sprinklers at rates that can be easily controlled as it happens with crude slurry; (d) *compost*: It consists of degradation of a mix of organic material caused by a series of microorganisms in a humid, warm and aerobic environment. Compost can later be used as organic fertilizer: (e) *reutilization of excreta as food for livestock species*: Nutrients are added to these products and then used to feed cattle; and (f) *stabilization ponds*: It is a deep structure in the soil where the dairy slurry is collected. It is left there so that anaerobic bacteria decompose it. In this process, most solids contained in the slurry become liquid or gas, consequently, the organic content and the nutrient value of the dairy slurry decrease (Global Methane Initiative, 2008).

Cost of the residue

Of the existing harnessing methods, none comply with the technical, economic and sanitary good livestock practices referring to dairy slurry management in Mexico. The collected dairy waste only represent 10% of the total generated (SAGARPA, 2011). The cost estimate of the traditional method, which consists of collecting the liquid dairy slurry and watering it as fertilizer, is $3,000 Mexican pesos per tonne of dairy slurry handled (Silván-Hernández *et al.,* 2017). Another possibility for manure management considers the solar dehydration, compaction and subsequent burning of the dairy slurry, which has a cost ranging from $6,000 to $12,600 Mexican pesos per tonne (Silván-Hernández *et al.,* 2017). Biogas production from dairy slurry should consider the cost of transportation to the digester; only large farms may afford this cost, as the transportation item can be minimized due to high substrate availability (INEGI, 2014).

Biogas potential

The intense fermentation of the cellulosic material in the rumen of dairy cows leaves less soluble carbohydrates in dairy slurry, resulting in a relatively low level of organic matter in soluble form and the majority proportion are organic solids in suspension (with a ratio of 0.75 g COD/g VS): Due to this fact, this feedstock has a limited biodegradability and co-digestion with other wastes is recommended (Massé *et al.,* 2003). Orrico *et al.* (2012) observed that the diet had an effect under the biodigestion process; they observed that the proportion with the highest amount of concentrate (40% roughage and 60% concentrate) led to greater efficiency in the gas production compared to the 60% / 40% mixed diet. The methane production potential obtained was 124 and 216 N-m^3 CH_4/kg VS, respectively. Although the main objective of the anaerobic digestion of dairy slurry is the use of biogas as a renewable fuel, Mexico has an incipient market (Global Methane Initiative, 2010).

1.2. Expected characteristics of the feedstock

Production process

In total confinement operations, the dairy slurry is collected by water flushing in the barns and discharged to settling ponds. In partial confinement operations and dual-purpose (meat and dairy) operations, cows spend some part of the day in barns with the remainder on pasture, therefore only the dairy slurry excreted in barns is collected (50% of the total). Based on the Clean Development Mechanism (CDM) dairy projects in Mexico that are registered on the UNFCCC website, the following dairy cow's population would use settling ponds: total confinement 25%, partial confinement 7% and dual-purpose systems 48%. Therefore, only the waste from these systems could be fed to anaerobic digesters (Global Methane Initiative, 2010).

Most large-scale anaerobic digesters currently operating receive a slurry with a total solids content between 8-12%. This concentration hinders the operation of some equipment, such as pumps (viscosity and clogging problems) and the digester itself (solids accumulation and mixing limitations). The gravity separation of liquid and solid fractions from dairy slurry is a desirable process that allows to reduce the volume of the waste to be transported and a better utilization of nutrients, because the liquid effluent can be handled as any other fluid (Global Methane Initiative, 2008).

Feedstock conditioning and pretreatment (if applicable)

Conditioning waste is recommended using mechanical separators of the solid and liquid fractions in dairy slurry, used together with various polymers to improve the separation performance of both fractions (Mohri *et al*., 2000). Since hydrolysis is the limiting step in AD of particulate and complex substrates, such as dairy slurry, pretreatment methods may be applied for solubilizing organic matter and, consequently, increasing anaerobic digestion rate and extent. In fact, abundant research have reported improvements on the AD of several solid and semi-solid substrates by employing pretreatment techniques (Carrere *et al*., 2015). Nonetheless, for dairy cow slurry, few results have been carried out so far, all of them aimed at breaking down the fiber present in the biomass. For this purpose, microwave, chemical pretreatment and alkali along with mechanical pretreatment were assessed (Angelidaki & Ahring, 2000). This pretreatment methods are expensive, so they may be applied in few specific cases. The results obtained showed that acids and bases yield the best results, based on the improvement on the methane potential.

Co-digestion potential

Dairy slurry contains high contents of non-biodegradable substances and has low C/N ratios, thus having a low methane yield in anaerobic mono-digestion (Hartmann & Ahring, 2005). Banks *et al*. (2011) recommended on-farm codigestion of dairy cattle slurry as the most effective means of making dairy slurry digestion economically viable. Co-digestion of dairy slurry can increase biogas production and improve process stability (Zhang *et al*., 2013). Co-digestion of dairy cow slurry, the organic fraction of municipal solid waste, and cotton gin waste resulted in higher methane gas yields (172 m^3 methane/tonne of dry waste) (Macias-Corral *et al.,* 2008). A green seaweed (*Ulva lactuca*), that accumulates on beaches and shallow estuaries subject to eutrophication, was continuously co-digested with dairy slurry at ratios of 25%, 50% and 75% (by volatile solid content), obtaining a yield of 170 m^3 methane/tonne of VS at an organic loading rate of 2.5 kg VS/m^3·d (Eoin *et al*., 2014).

1.3. Examples of Mexican plants in operation

La Montaña dairy farm located in Tizimín, on the Yucatán Península region in the south of Mexico. This dairy farm with 82 cows is located in the Mexican region with the lowest milk production. According to the information gathered about this farm, the herd size is 82 cows but most of them are very young which will lead to herd growth in the coming years. In this case it is optimal to design biogas production with account to the future increase of the herd size to 200 cows, which is basically giving the restrictions to the daily raw material capacity to around 10 tonnes of cattle manure per day (Koldisevs, 2014).

2. Research methods

A variety of data sources for conducting the resource assessment, including:

- Published data by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
- The main national-level government stakeholders in Mexico (Ministry of Environment and Natural Resources (SEMARNAT) and the Ministry of Agriculture, Rural Development, Fisheries, and Food (SAGARPA).
- Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C) representative of the dairy farms in Mexico.

The conversion of N-m^3/kg VS to N-m^3/kg COD was done using the representative dry and volatile content of fresh biomass, as reported in Table 2 (10 and 85%, respectively) and the ratio 0.75 COD/VS. The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results for each column of the database

Table 5. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	2	Expert judgment
Feedstock handling (as solid or as liquid)	Liquid (slurry)	Expert judgment
Recommended anaerobic technology if treated alone	UASB reactors and ponds	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Yes	Expert judgment
Current use of the feedstock	Crop irrigation, soil disposal	Global Methane Initiative (2010)
Relative use of the feedstock for other purposes	Low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/cow/year	34	Pinos-Rodríguez, *et al.* (2012)
Dry matter	TS (%)	8.0 – 12.0	Red temática de Bioenergía A.C. (2012)
Volatile Solids fraction	VS/TS	0.85	Expert judgment
Density	tonne/m^3	0.97	Expert judgment
C/N relation **(Total N)**	C/N kg N/tonne TS	6 – 20 (N: 90)	Koldisevs (2014), Melse *et al.*, 2017
Fats content	%	3.23	Varnero-Moreno (2011)
Typical methane content in biogas	%	55.0	Red temática de bioenergía A.C. (2012)
Typical sulfur content in biogas	%	0.4	Expert judgment
Methane potential (yield)	N-m^3 CH_4/tonne VS N-m^3 CH_4/tonne COD N-m^3 CH_4/m^3 GJ/tonne VS	124 – 216 (136) 165 – 288 (181) 10.5 – 18.4 (15.4) 4.5 – 7.8 (4.9)	Allen *et al.* (2014) Koldisevs, J. (2014)

5. References

Allen, E., Wall, D. M., Herrmann, C., & Murphy, J. D. (2014). Investigation of the optimal percentage of green seaweed that may be co-digested with dairy slurry to produce gaseous biofuel. *Bioresource technology*, 170, 436-444.

Angelidaki, I. & Ahring, B.K.K. (2000). Methods for increasing the biogas potential from the recalcitrant organic matter contained in manure. *Water Science and Technology*, 41, 189 – 194.

Banks, C.J., Salter, A.M., Heaven, S., Riley, K. (2011). Energetic and environmental benefits of co-digestion of food waste and cattle slurry: a preliminary assessment. *Resources, Conservation and Recycling*, 56, 71 - 79.

Carrere, H., Antonopoulou, G., Affes, R., Passos, F., Battimelli, A., Lyberatos, G. & Ferrer, I. (2015). Review of feedstock pretreatment strategies for improved anaerobic digestion: from lab-scale research to full-scale application. *Bioresource Technology*, 199, 386 – 397.

Eoin, A., Wall, D.M., Herrmann, C. & Murphy, D. (2014). Investigation of the optimal percentage of green seaweed that may be co-digested with dairy slurry to produce gaseous biofuel. *Bioresource Technology*, 170 (2014), 436–444.

Global Methane Initiative (2008). Mexico's Profile for Livestock Waste Management.

Global Methane Initiative (2010) Resource Assessment for Livestock and Agro-Industrial Wastes – Mexico.

Hartmann, H &, Ahring, B.K., (2005). Anaerobic digestion of the organic fraction of municipal solid waste: influence of co-digestion with manure. *Water Research,* 39, 1543 - 1552.

INEGI (2014) Directorio estadístico nacional de unidades económicas. México: Instituto Nacional de Estadística y Geografía México.

Koldisevs, J. (2014). *Biogas production in rural areas of Mexico* (Unpublished master's thesis). Energy Technology. Division of Energy Technology, Stockholm.

Macias-Corral, M., Samani, Z., Hanson, A., Smith, G., Funk, P., Yu, H., & Longworth, J. (2008). Anaerobic digestion of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow manure. *Bioresource technology*, 99(17), 8288 - 8293.

Massé, D. I., Croteau, F., Patni, N. K., & Masse, L. (2003). Methane emissions from dairy cow and swine manure slurries stored at 10°C and 15°C. *Canadian Biosystems Engineering*, 45, 6-1.

Melse, R. W., de Buisonjé, F. E., Qiao, W., & Dong, R. J. (2017). Manure nutrient application on a Chinese dairy farm with arable land: A case study based on Dutch experience of equilibrium fertilization. *International Journal of Agricultural and Biological Engineering*, 10(4), 182-188.

Mohri, T., Fukagawa, R., Tateyama, K., Mori, K., Ambassah, N.O. (2000) Slurry dewatering system with planetary rotation chambers. *TM Special Technical Publication*, 1374, 279-292.

Orrico-Júnior, M.A.P., Orrico, A.C.A., Lucas-Júnior, J., Sampaio, A.A.M., Fernandes, A.R.M., Oliveira, E.A. (2012). Biodigestão anaeróbia dos dejetos da bovinocultuta de corte: influência do período, do genótipo e da dieta. *Revista Brasileira de Zootecnia*, 41(6), 1533-1538.

Pinos-Rodríguez, J. M., García-López, J. C., Peña-Avelino, L. Y., Rendón-Huerta, J. A., González-González, C., & Tristán-Patiño, F. (2012). Impactos y regulaciones ambientales del estiércol generado por los sistemas ganaderos de algunos países de América. *Agrociencia*, 46(4), 359-370.

Red Temática de Bioenergía A.C. (2012). Producción de Biogás en México. Estado Actual y Perspectivas. *Cuaderno Temático sobre Bioenergía*, (5), pps. 29–34.

SAGARPA (2011). Manual de Buenas Prácticas Pecuarias: Sistema de Explotación Extensivo y Semi-Extensivo
de Ganado Bovino de Doble Propósito.

SAGARPA (2015). Servicio de información agroalimentaria y pesquera. Población ganadera: bovino lechera 2006 - 2015.

Silván-Hernández, O., De la Cruz-Burelo, F., Macías-Valadez, M., & Pampillón-González, L. (2017). Theoretical and technical biomass resource assessment from swine and cattle manure in Tabasco: A case study in southeast Mexico. *Sustainable Energy Technologies and Assessments*, 23, 83-92.

Varnero-Moreno, M. T. (2011). Manual de biogás. *Minenergía.* Santiago, Chile: Minenergía/PNUD/FAO/GEF.

Zhang, C., Xiao, G., Peng, L., Su, H., Tan, T. (2013). The anaerobic co-digestion of food waste and cattle manure. *Bioresource Technology*, 129, 170 - 176.

LIVESTOCK WASTES

Poultry Manure

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Poultry is an activity widespread in Mexico. The thirty-two states produce poultry. The three main producers including roosters, hens, and chickens in different stages of growth are Jalisco (49 853 367) Veracruz (29 036 425) and Puebla (28 418 523). The estimated total amount of poultry produced in Mexico in 2007 was 2 316 116 Tonnes/year. This amount of poultry manure production was estimated using data reported by the National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía, 2009) and factors of 0.009 and 0.0075 tonnes/unit/year for hen + rooster or chicken respectively, provided by an agriculture ministry expert (SECRETARÍA DE AGRICULTURA, GANADERÍA, PESCA Y ALIMENTACIÓN, s.f.).

Current use

It should be kept in mind that there are two types of poultry manure. Chickens grown for human consumption produce one type of manure (*pollinaza* in Spanish) which is mixed with litter materials that are inorganic or slowly biodegradable. *Pollinaza* is used as a nutritional amendment for cattle forage. There are Mexican regulations regarding handling and sanitization of *pollinaza* intended for this use. Egg-producer hens and roosters produce another type of manure (*gallinaza* in Spanish). *Gallinaza* could be almost free of other materials and is moderately biodegradable. *Gallinaza* is used as fertilizer either in fresh form or after composting

Cost of the residue

The cost of poultry manure depends on the type of manure, the season of the year and location. *Gallinaza* is less expensive than *pollinaza*. During winter both are less expensive than during summer. The cost varies but on average is between $200/tonne to $400/tonne Mexican pesos for *gallinaza*. The cost of *pollinaza* depends on the type of litter and vary with season and location but on average is between $500/tonne and $900/tonne Mexican pesos.

Biogas potential

Poultry manure has medium (*gallinaza*) to low (*pollinaza*) biogas potential.

1.2. Expected characteristics of the feedstock

Production process

Gallinaza is produced by confined hens between 1 year to 4 years of age. Hens are kept in cages and manure can be collected from under the cage. *Pollinaza* is produced by a chicken that is kept in beds (litter) of sand, stubble, straw or sawdust. These chicken are fattened from chicks to 16 – 20 weeks of age. Manure is collected mixed with litter.

Feedstock conditioning and pretreatment (If applicable)

In order to treat poultry manure by anaerobic digestion is necessary to separate feathers, carbonate, sand, and sawdust. If the solid content is 15% or less, dilution with water is needed for wet digestion. If the solid content is 60% or more, solid anaerobic digestion should be applied. Pre-treatment to make more biodegradable the lignocellulose fraction present in a litter is recommended. Several thermochemical pretreatments (Costa *et al*., 2012; Ardic *et al*., 2005) have been proposed.

Potential for co-digestion

Anaerobic digestion of poultry manure is difficult because of the high nitrogen, solid content, and high content of lignocellulose from the litter (sawdust and straw/stubble). Also, the formation of free ammonia during anaerobic digestion of poultry manure inhibits methanogenesis. Therefore, co-digestion with other substrates helps to overcome these limitations (Li *et al*., 2014; Sun *et al*., 2016). Pig manure is an excellent co-substrate because of its high water content and excellent buffer capacity (Regueiro *et al*., 2012; Rodriguez-Verde, *et al*., 2018).

1.3. Examples of Mexican plants in operation

No information was found regarding plants in operation using poultry manure for biogas production.

2. Research methods

Poultry manure production was estimated based on the number of chicken and hens reported by the Mexican Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía, 2009). Manure production was calculated using factors of manure/animal reported elsewhere (SECRETARÍA DE AGRICULTURA, GANADERÍA, PESCA Y ALIMENTACIÓN, s.f.) and with expert judgment. Characteristics of manure were obtained in the literature (Rodriguez-Verde *et al*., 2018).

3. Memory of calculations

The conversion of N-m^3/kgVS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (*gallinaza*: 30 and 65%, respectively*; pollinaza*: 80 and 61%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results

Table 6. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	1 (*pollinaza*) 3 (*gallinaza*)	Expert judgment
Feedstock handling (as solid or as a liquid)	Solid/slurry	Expert judgment
Recommended anaerobic technology if treated alone	Wet digestion/dry digestion	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Yes	Expert judgment
Current use of the feedstock	*Gallinaza* (soil amendment). *Pollinaza*: forage amendment	Expert judgment
Relative use of the feedstock for other purposes	High	Expert Judgment
Expected cost	High	Expert Judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/unit/year*	a) 0.0075 b) 0.0062-0.009	Expert judgment; SECRETARÍA DE AGRICULTURA, GANADERÍA, PESCA Y ALIMENTACIÓN (s.f.)
Dry matter	TS (%)	a) 80.6 b) 29.9	Rodriguez-Verde *et al*., 2018; Wang, *et al*., 2014
Volatile Solids fraction	VS/TS	a) 0.607 b) 0.653	Rodriguez-Verde *et al*., 2018; Wang, *et al*., 2014
Density	tonne /m^3	0.35	Rodriguez-Verde *et al*., 2018
C/N relation **(Total N)**	C/N kg/tonne TS	9.5 (N: 16)	Wang, *et al*., 2014. Expert judgment
Fat content	%	Not significant	Expert judgment
Typical methane content in biogas	%	65 – 70	Expert judgment
Typical sulfur content in biogas	%	0.35	Expert judgment
Methane potential (yield)	N-m^3CH_4/ tonne VS N-m^3CH_4/ tonne fresh biomass GJ/tonne VS	a) 159 b) 170-181 (175) a) 77.6 b) 33.2 – 35.3 (35.3) a) 5.8 b) 6.1 – 6.5 (6.3)	Rodriguez-Verde *et al*., 2018, Wang, *et al*., 2013

* Unit: tons/hen/year (*gallinaza*) or tonnes/chicken/year (a, *pollinaza, b*, *gallinaza*)

5. References

Ardic, I., Taner, F., (2005). Effects of thermal, chemical and thermochemical pretreatments to increase biogas production yield of chicken manure. *Fresenius Environ. Bull*. 14:373–380. http://refhub.elsevier.com/S0956-053X(17)30801-2/h0045

Costa, J.C., Barbosa, S.G., Alves, M.M., Sousa, D.Z., (2012) Thermochemical pre- and biological co-treatments to improve hydrolysis and methane production from poultry litter. *Biores. Technol*. 111:141–147. http://refhub.elsevier.com/S0956-053X(17)30801-2/h0080

Instituto Nacional de Estadística y Geografía (2009). Estados Unidos Mexicanos. Censo Agropecuario 2007, VIII Censo Agrícola, Ganadero y Forestal. Aguascalientes, Ags. Available at: http://www3.inegi.org.mx/sistemas/tabuladosbasicos/default.aspx?c=17177&s=est

Li, Y., Zhang, R., He, Y., Zhang, C., Liu, X., Chen, C., Liu, G., (2014). Anaerobic codigestion of chicken manure and corn stover in batch and continuously stirred tank reactor (CSTR). *Biores. Technol*. 156, 342–347. Available at: http://refhub.elsevier.com/S0956-053X(17)30801-2/h0140

Regueiro, L., Carballa, M., Álvarez, J.A., Lema, J.M., (2012). Enhanced methane production from pig manure anaerobic digestion using fish and biodiesel wastes as co-substrates. *Biores. Technol*. 123, 507–513. http://refhub.elsevier.com/S0956-053X(17)30801-2/h0170

Rodriguez-Verde, I., Regueiro, L., Lema, J.M., Carballa, M. (2018). Blending based optimization and pre-treatment strategies to enhance anaerobic digestión of poultry manure. *Waste Management* 71:521 – 531. Available at: https://doi.org/10.1016/j.wasman.2017.11.002

SECRETARÍA DE AGRICULTURA, GANADERÍA, PESCA Y ALIMENTACIÓN (s.f.) Utilización de estiércoles. Available at: http://www.sagarpa.gob.mx/desarrolloRural/Documents/fichasCOUSSA/Utilizacion%20de%20estiercoles.pdf

Sun, C., Cao, W., Banks, C.J., Heaven, S., Liu, R., (2016). Biogas production from undiluted chicken manure and maize silage: A study of ammonia inhibition in high solids anaerobic digestion. *Biores. Technol*. 218, 1215–1223. http://refhub.elsevier.com/S0956-053X(17)30801-2/h0195

Wang, X.; Yang, G.; Li, F.; Feng, Y.; Ren, G.; Han, X., (2013). Evaluation of two statistical methods for optimizing the feeding composition in anaerobic co-digestion: Mixture design and central composite design. *Biores. Technol*. 131, 172-178. Available at: http://dx.doi.org/10.1016/j.biortech.2012.12.174

Wang X, Lu X, Li F, Yang G (2014). Effects of Temperature and Carbon-Nitrogen (C/N) Ratio on the Performance of Anaerobic Co-Digestion of Dairy Manure, Chicken Manure and Rice Straw: Focusing on Ammonia Inhibition. *PLOS ONE* 9(5): e97265. https://doi.org/10.1371/journal.pone.0097265

LIVESTOCK WASTES
Pig Manure

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential
Mexico has the 8th largest swine population in the world, with more than 17.4 million pigs according to the Information Service for Farms and Cattle (16.8 million in the 2016 FAOSTAT inventory) (SIAP, 2015). The second most important livestock category in the country, is swine. Swine production is concentrated in the states of Jalisco and Sonora, with a combined total of 3.38 million pigs per year. Guanajuato, Puebla, Veracruz and Yucatán all have more than 1 million pigs each. It is estimated that 46 percent of the pigs in Mexico are raised in large scale, 20 percent in small to medium scale operations and 34 percent in backyard operations. It is noteworthy that, swine farming for domestic consumption is a common practice in many Mexican regions due to relatively low production costs (Global Methane Initiative, 2010). Several calculations have been made to estimate the amount of excreta (feces + urine + water) that are produced in a pig farm; most agree that the annual amount produced per sow unit (which equals one female plus the pigs produced by it in a year) represents 13 tonnes of excreta, with a content of 10% dry matter. So the chemical composition and therefore the polluting power of the excreta is very variable and depends basically on the ages of the swine livestock, the quality of the food, the feeding program and the productive capacity of the pigs of a farm (Martínez-Lozano, 2015; Vera-Romero *et al.,* 2014). The pig cattle, unlike the bovine, is mainly concentrated in pens or a confined spaces, where the collection of the daily excreta is easier, economical and manageable.

Current use
Farmers use storage ponds for manure collection; in some cases there is just one open pond where generation of biogas is evident. In a two pond system, the first one is covered (anaerobic) and the second one is open. Most of the open ponds do not have a subsequent liquid/solids separation so the pond is operated until it is completely filled with sediments, which would dry after some time. The final dry sediments are disposed in many cases on fields as fertilizer, a practice that does not have full public acceptance. In other cases the dry sediments are just leaved in the abandoned pond and a new one is added. "Topoyanes farm" in Puebla has a better practice in their two pond system; the biogas from anaerobic pond is used, while a clarifier receive the effluent of the second open pond. The retained sludge is pumped to drying beds and then composted and used in the field as soil amendment.

Cost of the residue
Pig manure has a market demand as organic fertilizer for various crops (González, 2010) in its solid (undiluted) form, with a selling price around $100 Mexican pesos per tonne (The price of di-ammonium phosphate is almost 10,000 Mexican pesos per tonne). In addition, pig manure is used for fattening of

cattle, with no other costs than the collection and transport to the confinement site (Silván-Hernández *et al.,* 2017). However, it is estimated that only 10% of pig manure is used in Mexico.

Biogas potential

Pig manure is an attractive feedstock for methane production; a digestate with attractive fertilizer proprieties is also produced (González, 2010). This feedstock has a high concentration of organic matter and suspended solids, so high-rate reactors may be limited by the energy requirements for mixing. In fact, the more applied digesters are covered ponds (medium and large units) or bag reactors (plug-flow) for small installations. Methane yield will vary between 244 and 343 N-m^3 CH_4/tonne VS (Gutiérrez *et al*., 2016).

1.2. Expected characteristics of the feedstock

Production process

Pig farming activities produce large quantities of manure, often producing the waste equivalent of a small city (National Resources Defense Council, 2013). The quantity and composition of manure vary depending on the feed, the age of the pigs and the type of farm. Manure production increases as pigs grow from feeders to finishers. Pig manure is made up of urine and faecal material (Ouellet-Plamondon *et al.,* 2010). Pig manure is collected by mechanical (scraping) or hydraulic (flushing) and the volume of water depend of the used method. Manure generated in farms is flushed through slatted floors to a collecting pit. In farms where there are no slatted floors, manure is sent to canals using water jets and then sent to a collecting pit. Slurries are subsequently pumped to a sedimentation pond (Global Methane Initiative, 2010).
In Mexico, it is estimated that 10 percent of pig manure is treated in small farms, approximately 30 to 50 in medium to large farms and up to 80 percent in the case of the largest ones. The more applied digester is the covered anaerobic pond. Other figures are provided by the National Commission of Pig Farmers, which reports that the manure treated in ponds represents about 5 percent of the total from backyard farms, 30 percent of the total from small to medium scale farms, and 50 percent of the total from large scale farms (Global Methane Initiative, 2010). By applying these values to the corresponding number of pig livestock, about 259,000 animals on backyard farms, 900,000 on semi-industrial operations, and 3.5 million at industrial operations are discharging manure to sedimentation ponds (Vera-Romero *et al.,* 2014). More than 3 million pigs in Mexico are on farms with some form of anaerobic digestion process, mostly covered anaerobic ponds. Therefore, the estimate of the number of pigs which manure is treated in open ponds is about 1.6 million. The manure from the rest of the swine in Mexico is either directed to sewage treatment plants or directly applied on cropland (Gutierrez *et al.,* 2016).

Feedstock conditioning and pretreatment (if applicable)

The separation of liquid and solid fractions from pig manure may be needed, depending on the kind of anaerobic digestor. It will be the case for large scale high-rate reactors, operating at total solids content between 8-12% (Global Methane Initiative, 2010). However, direct digestion of raw pig manure is still the most economic method, suitable for covered ponds. In such cases, the solid-liquid separation is not considered to be cost-effective (Hjorth *et* al., 2011).

Potential for co-digestion

Co-digestion of pig manure and crops (residual or energy crops) can increase methane yields (Tian *et al.,* 2015; Wall *et* al., 2013). Grass silage has a high VS content and is considered to be a good feedstock for anaerobic digestion since it can decrease ammonia inhibition; maintain a suitable pH for methanogens and provide a better carbon/nitrogen ratio (Xie *et al.,* 2011). They have also been shown that mesophilic co-digestion of pig manure with glycerine improved the methane production 25%, with a mixture of 80% of pig manure (Astals *et al.,* 2011).

1.3. Examples of Mexican plants in operation

The swine farm Ana Margarita in the municipality of Montemorelos, Nuevo León, has 1,200 sows. The farm also has small numbers of cows, sheep, and chickens. An anaerobic pond with a volume of 8,516 m^3 and a biogas production of 20,478 m^3 per day was installed in 2005. A portion of the biogas is burned to obtain certificates of emissions reduction and the remaining biogas is used to generate electricity. The system has an engine-generator set that consumes nearly 19 m^3 of biogas per hour. The total electricity generation potential of the digester is 812,772 kWh per month; which are needed for operating the farm lighting, ventilation, feeding systems, semen laboratories, and water pumping; and surplus biogas is used to generate more electricity for other farm activities (e.g., chicken building, pumps for irrigation) and directly for heating the farrowing and weaning pens. The digester produces enough electricity to save the farm approximately $20,000 pesos a month on electricity (data from year 2010).

The swine farm Las Palmas in the municipality of Abasolo, Guanajuato, is a complete-cycle (farrow-to-finish) farm. A digester was installed in November 2009 and manages the manure of 75 percent of the fattening stock (approximately 240 heads). The digester is a bag-type digester with a volume of 321.1 m^3 and a daily biogas production of 30.3 m^3. The biogas is currently flared but will later be used for heat in the farrowing unit. The effluent from the bag digester is stored in a pond and is applied to cropland by irrigation. The biogas could be used to generate more electricity for other farm activities (e.g., chicken building, pumps for irrigation) or could be used directly for heating the farrowing and weaning pens.

2. Research methods

A variety of data sources for conducting the resource assessment, including:
Published data by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
The main national-level government stakeholders in Mexico include the Ministry of Environment and Natural Resources (SEMARNAT) and the Ministry of Agriculture, Rural Development, Fisheries, and Food (SAGARPA).
Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C) representative of the pig manure in Mexico. The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (15and 70%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results

Table 7. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	3	Reyes *et al.* (2015)
Feedstock handling (as solid or as liquid)	Semisolid, slurry	Expert judgment
Recommended anaerobic technology if treated alone	Covered ponds. Pre-treated manure: CSTR and UASB reactors,	Nasir *et al.* (2012)
Pretreatment required before anaerobic technology (if applicable)	Solid separation for UASB reactor. (CSTR at lower extent)	Muhammad *et al.* (2015). Expert judgment
Current use of the feedstock	Applied on cropland	Global Methane Initiative (2010)
Relative use of the feedstock for other purposes	Low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/pig/year	1.64	Lozano (2015)
Dry matter	TS (%)	10 - 20	Varnero-Moreno (2011) Taiganides (1963)
Volatile Solids fraction	VS/TS	0.64 - 0.80	Reyes *et al.* (2015) Taiganides (1963)
Density	Tonne/m^3	1.13	Backhurst & Harker (1974)
C/N relation **(Total N)**	C/N kg N/tonne TS	10 (N: 70)	Reyes *et al.* (2015) Taiganides (1963)
Fats content	%	0.0	Reyes *et al.* (2015)
Typical methane content in biogas	%	47.0 – 68.0	Mondaca & Masera (2012)
Typical sulfur (H_2S) content in biogas	%	1.0	Lin *et al.* (2017)
Methane potential (yield)	N-m^3 CH_4/tonne VS	244 – 343 (300)	Gutiérrez *et al.* (2016)
	m^3 CH_4/tonne fresh biomass	25.6 – 36.0 (31.5)	
	GJ/tonne VS	8.8 – 12.3 (10.8)	

5. References

Astals, S., Ariso, M., Galí, A., & Mata-Alvarez, J. (2011). Co-digestion of pig manure and glycerine: experimental and modelling study. *Journal of environmental management*, 92(4), 1091-1096.

Backhurst, J.R., & Harker, J.H. (1974). Evaluation of physical properties of pig manure. *Journal of Agricultural Engineering Research*, 19(2), 199-207.

Global Methane Initiative. (2010). Resource Assessment for Livestock and Agro-Industrial Wastes – Mexico.

González, J. (2010). Energías Renovables. México: Editorial Reverte. *Infraestructura para granjas procinas*. Dirección web: http://razasporcinas.com/pigmarket/categoria-producto/desechos-y-efluentes/. Visitada: 08/11/2014.

Gutierrez, E. C., Xia, A., & Murphy, J. D. (2016). Can slurry biogas systems be cost effective without subsidy in Mexico? *Renewable Energy*, 95, 22-30.
Hjorth, M., Christensen, K. V., Christensen, M. L., & Sommer, S. G. (2011). Solid–liquid separation of animal slurry in theory and practice. *In Sustainable Agriculture Volume 2*. Springer, Dordrecht. pp. 953-986
Lin, H., King, A., Williams, N., & Hu, B. (2017). Hydrogen sulfide removal via appropriate metal ions dosing in anaerobic digestion. *Environmental Progress & Sustainable Energy*, 36(5), 1405-1416.
Martínez-Lozano, M. (2015). Biogas potentiality production using pig manure in Guanajuato state. *Nova Scientia*, 7(15), 96-115.
Mondaca, F. I., & Masera, C. O. (2012). Producción de Biogás en México, Estado Actual y Perspectivas. Red Mexicana de Bioenergía AC.
Muhammad N.I., Ghazi, M., & Idaty, T. (2015). Pretreatment of lignocellulosic biomass from animal manure as a means of enhancing biogas production. *Engineering in Life Sciences*, 15(7), 733-742.
Nasir, I. M., Mohd Ghazi, T. I., & Omar, R. (2012). Anaerobic digestion technology in livestock manure treatment for biogas production: a review. *Engineering in Life Sciences*, 12(3), 258-269.
National Resources Defense Council (2013). Facts about Pollution from Livestock Farms http://www.nrdc.org/water/pollution/ffarms.asp (accessed 5.09.14).
Ouellet-Plamondon, C., Watts, P.J. & McGahan, E.J. (2010). Estimates of Manure Production from Animals for Methane Generation, Rural Industries Research and Development Corporation, Australia, 2010. http://www.fsaconsulting.net/fsa/docs/Methane_Production.pdf.
Reyes, I. P., Díaz, J. P., & Horváth, I. S. (2015). Anaerobic Biodegradation of Solid Substrates from Agroindustrial Activities—Slaughterhouse Wastes and Agrowastes. *In Biodegradation and Bioremediation of Polluted Systems-New Advances and Technologies*. InTech.
Servicio de Información Agroalimentaria y Pesquera (SIAP). (2015). Servicio de Información Agroalimentaria y Pesquera. *SEMARNAT*. http://infosiap.siap.gob.mx/anpecuario_siap_gb_1/indexddr_gb.html
Silván-Hernández, O., De la Cruz-Burelo, F., Macías-Valadez, M., & Pampillón-González, L. (2017). Theoretical and technical biomass resource assessment from swine and cattle manure in Tabasco: A case study in southeast Mexico. *Sustainable Energy Technologies and Assessments*, 23, 83-92.
Taiganides, E.P. (1963) Characteristics and treatment of wastes from a confinement hog production unit, Retrospective Theses and Dissertations. 2366. Iowa State University. https://lib.dr.iastate.edu/rtd/2366
Tian, H., Duan, N., Lin, C., Li, X., & Zhong, M. (2015). Anaerobic co-digestion of kitchen waste and pig manure with different mixing ratios. Journal of bioscience and bioengineering, 120(1), 51-57.
Varnero Moreno, M. T. (2011). Manual de biogás. *Minenergía.* Santiago, Chile: Minenergía/PNUD/FAO/GEF.
Vera-Romero, I., Martínez-Reyes, Estrada-Jaramillo, M., Ortiz-Soriano, A. (2014). Potencial de generación de biogás y energía eléctrica Parte I: excretas de ganado bovino y porcino. *Ingeniería, investigación y tecnología*, 2014, 15(3), 429-436.
Wall, D.M., O'Kiely, P., Murphy, J.D. (2013). The potential for biomethane from grass and slurry to satisfy renewable energy targets, *Bioresource technology*, 149, 425-431.
Xie, S., Lawlor, P. G., Frost, J. P., Hu, Z., & Zhan, X. (2011). Effect of pig manure to grass silage ratio on methane production in batch anaerobic co-digestion of concentrated pig manure and grass silage. *Bioresource technology*, 102(10), 5728-5733.

INDUSTRIAL WASTES
Alcohol Vinasse (sugarcane)

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential.
In Mexico, sugarcane is one of the most important agricultural crop, with 783 315 hectares annually harvested and industrialized for sugar and molasses production; also, in minor extent, alcohol (ethanol) is produced. The agroindustry is located in 15 States, being Veracruz the leader in sugarcane production (41.6 %), followed by San Luis Potosí (11.2 %) and Jalisco (9.6 %) for the 2014-15 harvest (*zafra*). The harvest season starts mid-November and ends late June.
At present, 57 industrial units *(ingenios*) are in operation in Mexico. Some of them have a distillery on premises. However, the production capacity has fallen drastically since the late 80s (around 30 distilleries) to 16 at the beginning of this Century and no more than 3 in 2015: Pujiltic, Chiapas (6 050 m^3), Tamazula, Jalisco (4 180 m^3) and Aarón Saenz, Tamaulipas (1 800 m^3) for a total of 12 030 m^3 of 96° GL alcohol production (harvest 2015-16). There is no alcohol production based on sugarcane juice fermentation in Mexico.
Considering that vinasses are produced at 12 liters per liter of alcohol, the yearly effluent reached 144360 m^3. This volume represents 480 m^3/d discharged by the three distilleries, considering that they operate 10 months per year.
In Mexico, alcoholic beverages are another relevant distillation industry, mainly for tequila and mezcal production, with a total volume 2016 production of 273000 and 3000 m^3, respectively.
The bioethanol (biofuel) industry may grow drastically in Mexico due to the changes in the federal regulations that now allows to add 10% ethanol to gasoline. In such case, the potential raw materials (sugarcane, molasses and maize) would support a new fermentation and distillation industry in Mexico, with the corresponding increase in vinasse production.

Current use.
Alcohol vinasses represent a highly polluted effluent that should be treated before final disposal. In many cases, vinasses are mixed with water for irrigating the sugarcane fields (fertirrigation), a practice that is limited by the growth pattern of the crop, the maximum nutrient load to the soil and surface water and aquifer quality protection. Some tequila major producers have installed modern anaerobic treatment plants for organicv matter removal and biogas recovery for energy production. However, this is not the case of the 3 molasses distilleries presently in operation.

Cost of the residue.
Vinasse is regarded as a problematic, highly polluted liquid waste. There is no demand for this waste material and no market cost.

Biogas potential.
Vinasses have a high methane yield and therefore they may be anaerobically treated either at mesophilic (35°C) or thermophilic (55°C) conditions. The biodegradability and methane yield will depend on the type of raw material used in the fermentation step. The expected chemical oxygen demand (COD) removal efficiencies would be 60 % for vinasses form molasses and 80% from cooked-agave juice and sugarcane juice.

1.2. Expected characteristics of the feedstock

Production process.
The production of alcohol (ethanol) is carried out by yeast fermentation of sugars (hexoses) The process applied in the sugarcane industry may ferment sugar juice (direct fermentation) or molasses (after sugar crystallization). In Mexico, some sugarcane factories (*ingenios*) produce also alcohol from molasses, a valuable raw material for a variety of industries, including alcohol producers.
The alcohol fermentation from molasses, begins with the dilution with hot water, until reaching a density between 20 and 22° Brix. Then sulfuric acid is added to adjust the pH in a range of 4 to 4.5, resulting in the fresh must.
A fraction of the fresh must is pasteurized and inoculated with yeast and nutrients (ammonium sulfate and ammonium phosphate) allowing yeast growth under aerobic conditions. The yeast mixture is then added to the fresh must in the fermentation tanks. This biological reaction is carried out at a temperature between 25 and 30 °C, needing a cooling system as this is an exothermic reaction. After 20 to 30 hours, a 6 – 8 % ethanol concentrations is reached, and the fermentation is stopped allowing the temperature to reach 38° C. The resulting dead must in the fermenter contains a mixture of alcohols, yeast residues and suspended matter.
The dead must is sent to the distillation system for the recovery and purification of ethyl alcohol. In case of 95-96° GL alcohol, an arrangement of three distillation columns in series is needed; for drinking distillates (< 60 ° GL) two columns are applied. In some distillers, the dead must (mash) is separated by centrifugation to remove the inactivated yeasts. The distillation is carried out by steam drag, which is fed by the bottom of a first column (mash column). The lower boiling components exit through the upper part of the column as a mixture of vapors containing water, alcohol and volatile compounds such as aldehydes, which are fed to the second column (extractive or purification column). The vinasses are discarded from the bottom of the first column. This effluent is produced at a rate of 12 to 16 liters per liter of distilled (95 – 96° GL) alcohol, characterized by a high content of organic matter, sulfates, potassium, chlorides, an acidic pH and high temperature.
The diluted alcohol is obtained at the bottom of the purification column, while methanol, ethanol, aldehydes and other impurities are distilled from the top. In the rectification column ethanol of 95-96 ° GL is obtained, while in the lower part, a by-product (tail) is discarded, constituted by amyl alcohols and residues (fusel oil).

Feedstock conditioning and pretratment (If applicable)
A pre-cooling step and pH control are necessary as well as micronutrient addition (Fe, Co, Ni, and Mo) (Espinosa *et al*. 1995). If the dead must is not centrifuged or decanted before being fed to the first distillation column, the vinasse will have a high suspended solids content that should be separated depending on the type of anaerobic reactor chosen for the biogas producing facility. If vinasses are not diluted with water (1:1) sulfide desorption is recommended for improving COD removal efficiencies.

1.3. Examples of Mexican plants in operation

In the three sugar factories with alcohol productions, there is no anaerobic treatment for the produced vinasses. However, there are at least 3 tequila distilleries that applied anaerobic reactors for vinasse treatment (Casa Cuervo in two locations and Casa Herradura)

2. Research methods

Describe the methods for acquiring, analyzing and calculating all the information for the Feedstock Database that will be shown in the Results section below.

3. Memory of calculations

The Methane yield was expressed as N-m^{3}CH$_4$/ tonne VS converting the conventional units for a liquid effluent (N-m^{3}CH$_4$/ kg COD) taking the values presented in Table 2 (VS=78 g TS/L*0.75), a COD of 70 g/L and 60% COD removal, representative of molasses vinasse. The yield reference value is 0.33 N-m^{3}CH$_4$/ kg COD rem. The energy conversion factor applied is 35.9 MJ/N-m^3 CH$_4$

4. Results

Table 8. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	3	Expert judgment
Feedstock handling (as solid or as liquid)	Liquid	Expert judgment
Recommended anaerobic technology if treated alone	UASB or EGSB	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Cooling, pH adjustment	Expert Judgment
Current use of the feedstock	Fertirrigation	Fuess *et al*. (2017)
Relative use of the feedstock for other purposes	Low	Expert Judgment
Expected cost	Low	Expert Judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/unit/year	10 – 15 L/L ethanol	Moraes *et al*. (2015)
Dry matter	TS (%)	7.8 (2.1-14.0)	Noyola (1996)
Volatile Solids	VS/TS	0.75	Noyola (1996)
Density	Tonne/m^3	1.0 – 1.1	Mariano *et al*. (2009), expert judgment
C/N relation (N total)	C/N kg/m^3	10 – 25 (N: 0.6)	Mariano *et al*. (2009), expert judgment
Fats content	%	< 0.01	Expert judgment
Typical methane content in biogas	%	65 (58-68)	Rodríguez Rivera (1993)
Typical sulfur content in biogas	%	2.5	Rodríguez Rivera (1993)
Methane potential (yield)	N-m^3CH_4/ tonne VS N-m^3CH_4/ tonne COD_{inf} N-m^3CH_4/ m^3 GJ/tonne VS	200 200 14 7.18	Espinosa & Noyola (1992). Rodríguez Rivera (1993)

5. References

Espinosa A. y Noyola A. (1992) Tratamiento anaerobio de vinazas: recuperación de un reactor UASB acidificado. *Memorias del VIII Congreso Nacional de la Sociedad Mexicana de Ingeniería Sanitaria y Ambiental*, Cocoyoc, Morelos. 5 pp.

Espinosa A., Rosas L., Ilangovan K., Noyola A. (1995) Effect of trace metals on the degradation of volatile fatty acids during anaerobic treatment of molasses stillage. *Water Science and Technology*, 32, 12, 121-129.

Fuess L., Rodrigues I.J., Garcia M.L. (2017). Fertirrigation with sugarcane vinasse: Foreseeing potential impacts on soil and water resources through vinasse characterization. *Journal Environmental Science and Health, Part A*. 52, 1063–1072.

Mariano A. P., Crivelaro S. H. R., Angelis D. D. F. D., Bonotto D. M. (2009). The use of vinasse as an amendment to ex-situ bioremediation of soil and groundwater contaminated with diesel oil. *Braz. Arch. Biol. Technol*. 52, 1043–1055.

Moraes B. S., Zaiat M., Bonomi A. (2015). Anaerobic digestion of vinasse from sugarcane ethanol production in Brazil: challenges and perspectives. *Renew. Sustain. Energ. Rev*. 44, 888–903.

Noyola A. (1996) Tratamiento de aguas residuales de destilerías. *Memorias del IV Seminario y Taller Latinoamericano sobre Tratamiento Anaerobio de Aguas Residuales*. Bucaramanga, Colombia. 303-311.

Rodríguez Rivera F.J. (1993) *Tratamiento de vinazas empleando reactores anaerobios avanzados (UASB y FA) con eliminación de H_2S*. Tesis Ingeniería Quimica, Facultad de Química UNAM, 168 pp.

INDUSTRIAL WASTES
Cheese Whey

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

In Mexico, almost 53% of the milk production for pasteurization and packaging is for fluid milk (SIAP, 2008) and the rest (47%) is used for dairy products such as cheese and yogurt. The generation of cheese represents 15% of national milk production; in 2007 the production of cheese in Mexico was 154 195 tonnes (Espinosa-Ayala, 2009); it can be estimated that the cheese whey (CW) obtained varies from 4 to 11.3 kg fresh CW/kg cheese, with a representative value of 9 (Valencia, 2008; Venetsaneas *et al*., 2009). The annual discharge of CW in Mexico is about 1.04 million cubic meters (FAO, 2015), which contains almost 50 000 tonnes of potentially transformable lactose and 9000 tonnes of potentially recoverable protein (Carrillo-Aguado, 2006). CW is a by-product rich in lactose (45–50 g/L), lipids (4– 5 g/L), soluble proteins (6–8 g/L), and mineral salts (8–10% of dried extract) (Ergurder *et al*., 2001). Several studies found that treatment of raw CW was a concern due to the tendency for rapid acidification (Kalyuzhnyi *et al*., 1997). For the treatment of CW, biological treatments are the most viable option to comply with current environmental regulations in Mexico (Valencia & Ramírez, 2009).

Current use

Today, CW and its derivatives are highly valued co-products of the cheese and casein production processes. Healthy and rich in protein, lipids, carbohydrates, vitamins and minerals, a wide range of CW and CW-derived products are meeting the ever-changing demands of the food, dairy and nutritional supplement markets (Solak & Akin, 2012). The contaminating capacity and the nutritional value of the CW have led to the development of technologies for its use. In Mexico, of the total CW generated per year, about 53% is used, of which 62% as animal feed, 33% is transformed as lactose derivatives, caseins, caseinates and protein concentrates, 4% is converted into serum powder and only 1% is treated as a liquid waste discharged (Valencia & Ramírez, 2009).

Cost of the residue

Approximately 47% of the CW produced in Mexico every year are disposed of in the environment. This represents a significant loss of resources and causes serious pollution problems. Particularly, for medium size cheese factories, that have growing disposal problems and cannot afford high investment costs for CW valorization technologies. In such cases, physico-chemical and/or biological treatment of this effluent is imperative (Kavacik & Topaloglu, 2010).

Biogas potential

In Mexico, CW is a type of waste with great potential as a substrate for anaerobic co-digestion, since anaerobic digestion has not been adopted in the CW industry, because it is a very fragmented sector with big and small producers. Moreover, raw CW is a quite difficult substrate to treat anaerobically because of the lack of alkalinity, the high chemical oxygen demand (COD) concentration and the tendency to acidify very rapidly (Malaspina *et al.,* 1996). CW is very biodegradable (~99%) with very high organic content (at a COD interval of 60 - 100 kg/m³) and low alkalinity content (2.5 kg/m³ as $CaCO_3$) (Ergüder *et al*., 2001). This may impair biomass granulation during biological treatment, which in turn results in biomass wash-out. Anaerobic treatment of CW has therefore frequently encountered difficulties in maintaining full-scale operations. Alkalinity supplementation can be minimized by using operation conditions directed at obtaining better treatment efficiency, such as using higher hydraulic residence times or the dilution of the influent CW, thus obtain a steady biogas production (Gelegenis *et al*., 2007). CW poses a considerable risk of eutrophication attributable to the total Kjeldahl nitrogen (0.2- 2.2 kg/m³) (Hublin *et al*., 2012; Prazeres *et al*., 2012) and phosphorus (0.06 - 0.5 kg/m³) contents (Prazeres *et al*., 2012).

1.2. Expected characteristics of the feedstock

Production Process

CW is a liquid that separates from the milk coagulation during cheese manufacture. It contains most of the water-soluble components that are not integrated in the coagulation of casein. CW is considered a residue of the dairy industry and corresponds to around 85–90% of the total volume of processed milk, and its cost-effective utilization or disposal has become more and more important due to the legislative demands (Siso, 1996).

Feedstock conditioning and pretreatment (if applicable)

CW should be diluted and neutralized with lime, before being directly fed to anaerobic reactors. However, in most cases CW does not require any pretreatment. Only in some cases pH, thermal, microwave pre-treatments were applied in order to increase the biogas production (Beszédes *et* al., 2009).

Co-digestion potential

CW may present some problems associated with direct anaerobic treatment, such as acidification and instability of the reactor, difficulty to obtain granulation and reduced sludge settling due to the tendency to produce an excess of viscous expolymeric materials, probably of bacterial origin. In order to overcome these drawbacks, co-digestion with suitable substrates may be considered. It has been reported that co-digestion of CW with manure was possible without any need of chemical addition up to 50% content of CW (by volume) to the daily feed mixture. At CW fractions over 50%, the reactor turned to be unstable (Kavacik & Topaloglu, 2010). Comino *et al.* (2012) reported that manure co-digestion based on a high volume of CW (up to 65% in volume) is possible without the use of chemicals for pH control. Also, this kind of mix has a similar energetic potential for anaerobic digestion as energy crops such as maize.

1.3. Examples of Mexican plants in operation

There are no biogas generation plants by digestion or that mention co-digestion of CW with other wastes in Mexico.

2. Research methods

A variety of data sources for conducting the resource assessment, including:

- Published data by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
- The main national-level government stakeholders in Mexico include the Ministry of Agriculture, Rural Development, Fisheries, and Food (SAGARPA).

- Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C) representative of the CW sources in Mexico.
The methane yield was expressed as N-m$^3CH_4$/ tonne VS converting the conventional units for a liquid effluent (N-m$^3CH_4$/ kg COD) taking the values presented in Table 2 (VS= 59 g TS/L*0.7), a COD representative value of 70 g/L. The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results for each column of the database

Table 9. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	3	Expert judgment
Feedstock handling (as solid or as liquid)	Liquid	Expert judgment
Recommended anaerobic technology if treated alone	Downflow fixed-film, and UASB	Demirel *et al.* (2005)
Pretreatment required before anaerobic technology (if applicable)	pH control	Expert judgment
Current use of the feedstock	Dairy and nutritional supplements	Solak & Akin (2012)
Relative use of the feedstock for other purposes	Low	Kavacik & Topaloglu (2010)
Expected cost	Low	Kavacik & Topaloglu (2010)

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes CW/Tonnes Cheese	4.0 - 11.3	Valencia (2008)
Dry matter	TS (%)	5.9	Kavacik & Topaloglu (2010)
Volatile Solids fraction	VS/TS	0.7	Kavacik & Topaloglu (2010)
Density	tonne/m^3	1.04	Expert judgment
C/N relation (total N)	C/N kg N/m^3	8.7 (N: 2.2)	Hublin et al. (2012)
Fats content	%	0.85	Muñoz-Páez *et al.* (2014)
Typical methane content in biogas	%	58	Comino *et al.* (2012)
Typical sulfur content in biogas	%	0.06	Comino *et al.* (2012)
Methane potential (yield)	N-m^3 CH_4/tonne VS N-m^3 CH_4/tonne COD N-m^3 CH_4/m^3 GJ/tonne VS	109 – 383 (246) 280 – 340 (310) 4.5 – 15.8 (10.2) 3.9 – 13.7 (8.7)	Demirel *et al.* (2005) Comino *et al.* (2012) Koldisevs (2014)

5. References

Beszédes, S., Kertész, S., Masa, A., László, Z., Keszthelyi-Szabó, G., & Hodúr, C. (2009). The possibilities of bioenergy production from whey. *Journal of Agricultural Science and Technology*, 4(1), 62 - 68.

Carrillo-Aguado, J.L. (2006). Tratamiento y reutilización del suero de leche. Mundo Lácteo y Cárnico Noviembre–Diciembre: 27–30.

Comino, E., Riggio, V. A., & Rosso, M. (2012). Biogas production by anaerobic co-digestion of cattle slurry and cheese whey. *Bioresource technology*, 114, 46-53.

Demirel, B., Yenigun, O., & Onay, T. T. (2005). Anaerobic treatment of dairy wastewaters: a review. *Process Biochemistry*, 40(8), 2583-2595.

Ergüder, T.H., Tezel, U., Guven, E. & Demirer, G.N. (2001). Anaerobic biotransformation and methane generation potential of cheese whey in batch and UASB reactors. *Waste Management*, 21, 643–650.

Espinosa-Ayala, E. (2009). La competitividad del sistema Agroalimentario localizado productor de quesos tradicionales. México: Universidad Autónoma del Estado de México.

FAO (Food and Agriculture Organization/World Health Organization) (2015). Food Losses and waste in Latin America and the Caribbean. Expert Consultation. Bulletin 2.

Gelegenis, J., Georgakakis, D., Angelidaki, I., Mavris, V. (2007). Optimization of biogas production by co-digesting whey with diluted poultry manure. *Renewable Energy*, 32: 2147-2160.

Hublin A., Ignjati-Zoki T., Zeli B. (2012) Optimization of biogas production from co-digestion of whey and cow manure, *Biotechnology and Bioprocess Engineering,* 17: 1284-1293

Kavacik, B., & Topaloglu, B. (2010). Biogas production from co-digestion of a mixture of cheese whey and dairy manure. *Biomass and bioenergy*, 34(9), 1321-1329.

Klyuzhnyi S.V., Martinez, E.P., Martinez J.R. (1997). Anaerobic treatment of high strength cheese whey wastewaters in laboratory and pilot UASB reactors. *Bioresource Technology*, 60: 59-65.

Koldisevs, J. (2014). Biogas production in rural areas of Mexico. Master of Science Thesis. Energy Technology. Division of Energy Technology. Stockholm.

Malaspina, F., Cellamare, C.M., Stante L., Tilche, A. (1996). Anaerobic treatment of cheese whey with a down-flow upflow hybrid reactor. *Bioresource Technology*, 55: 131-139.

Muñoz-Páez, K. M., Poggi-Varaldo, H. M., García-Mena, J., Ponce-Noyola, M. T., Ramos-Valdivia, A. C., Barrera-Cortés, J. & Rinderknecht-Seijas, N. (2014). Cheese whey as substrate of batch hydrogen production: Effect of temperature and addition of buffer. *Waste Management & Research*, 32(5), 434-440.

Prazeres, A. R., Carvalho, F., & Rivas, J. (2012). Cheese whey management: A review. *Journal of Environmental Management*, 110, 48-68.

SIAP (eds) (2008). Secretaría de Agricultura, Ganadería, Pesca y Alimentación. Retrieved from www.sagarpa.gob.mx.

Siso G.M.I. (1996). The biotechnological utilization of cheese whey: a review. *Bioresource Technology*, 57:1-11.

Solak B.B. & Akin N. (2012). Health Benefits of Whey Protein: A Review. *Journal of Food Science and Engineering*, 2 (2012) 129-137.

Valencia E. & Ramírez, M.L. (2009). La industria de la leche y la contaminación del agua. *Elementos*, 73, 27-31.

Valencia, J. (2008). El suero de quesería y sus posibles aplicaciones. Mundo lácteo. Marzo/Abril. Retrieved from http://www.alimentariaonline.com/apadmin/img/upload/MLC023_suero.pdf

Venetsaneas, N., Antonopoulou, G., Stamatelatou, K., Kornaros, M., Lyberatos, G. (2009). Using cheese whey for hydrogen and methane generation in a two-stage continuous process with alternative pH controlling approaches. *Bioresource technology*, 100(15), 3713-3717.

INDUSTRIAL WASTES
Fishery Wastes

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential
Fishing and aquaculture are economic activities of great importance in Mexico, with a national production of fish and seafood in 2011 of 1 122 600 tonnes in weight landed, the participation of the main species that are marketed for consumption are: flake (28%), sardine and mackerel (18%), shrimp (15%), tuna (13%) and bream (7%). Its long-term viability depends, among other factors, on the use of residual biomass generated in fishery and aquaculture products processing plants, in order to increase eco-efficiency and profitability in its operations. The organic waste generated by the aquaculture and fishing industry is rich in proteins, oils and fats, being considered a very good option for the production of biogas. In Mexico, approximately 673 560 tonnes of fishery waste are generated annually (approximately 60% of the total weight of the fish and seafood used as raw material), but only 4% of these wastes were used (INECC, 2012).

Current use
In the last 20 years, the fishing industry has become aware of the economic, social and environmental aspects that represent the use of the produced residues (a resource), as well as the reduction of post-capture phase's losses. The use of fish by-products such as heads, spines, viscera, gills, dark muscle, fins and skin, receives more and more attention because these can be an important source of minerals, proteins and fat for use in various products (SEAFISH, 2001). In Mexico, the use of fishery waste is still incipient and is basically oriented to the production of food and oil. These are easily commercialized, and thus represent a considerable source of income and a very important ingredient for the elaboration of foods destined for aquaculture (Arvanitoyannis & Kassaveti, 2008). The final waste of the fish-processing industry in Mexico currently are not treated and it is dumped in the sea.

Cost of the residue
The processing of fishery final waste does not have an identified market, so there is no price for this waste. Although there is a demand on some by-products, as previously mentioned, the final waste should be handled as such, with the treatment and disposal cost associated to this process (Msangi *et al.,* 2013).

Biogas potential
Fishery wastes may be anaerobically digested depending on their origin. The oil-free fish waste (cake) has been used in biogas production (Salam *et al.,* 2009). The cake has 1.5–3.3% of total (dry) solids, with 32% nitrogen, 8.5% phosphorous (Arvanitoyannis & Kassaveti, 2008), low potassium and heavy metal content, and high levels of volatile fatty acids (Yuvarai *et al*., 2016). Lanari & Franci (1998) examined the potential of biogas production from fishery wastes using a mesophilic upflow anaerobic digester, followed by a sedimentation column, an aerobic filter and a zeolite column for final treatment. Methane production was 280-390 m^3/tonne VS, and a remarkable reduction of volatile solids (92–97%), suspended solids (96–99%)

and total ammonia nitrogen content (59–70%) were reported. However, biodegradation of fishery wastes has limitations due to the high protein content, which produces ammonia in concentrations between 3.5 and 4.2 g/L. In such case, anaerobic digestion is only possible after an adaptation period (Soto *et al.,* 1991). Other characteristics of these wastes that may hinder biogas production are lack of macro- and micronutrients, low carbon/nitrogen ratio and the generation of toxic compounds (Tomczak-Wandzel *et al*., 2013).

1.2. Expected characteristics of the feedstock

Production process

The activities that characterize the fish-processing sector depend on the type of fish being processed and the desired final product. Fish processing today broadly consist of removing the edible parts of fish and preserving them for consumption. The main fish processing stock in Mexico includes, sardine, shrimp, tilapia, trout and tuna. Products for human consumption range from mollusks, whole fish to fillets especially products that may be sold canned, frozen or preserved. Wild caught marine fish processing facilities are typically located at commercial point or harbor. They include areas where stages of washing, gutting, heading, cooking, cooling, pressing, drying and packaging are implemented (SAGARPA, 2012). Each of these processing stages has an industrial waste or by-product associated with it.

Feedstock conditioning and pretratment (If applicable)

The biodegradability (putrefaction) of fish industry wastes results on minimum pretreatment for their anaerobic digestion. Hence, after fish evisceration, heads, guts, fin, scales can be immediately, with a coarse grinding, digested to produce biogas. Usually, these wastes are mixed with other waste material, high in carbon content in order to balance the C/N ratio and to enhance the digestion of other non-easily degraded ligno-cellulosic organic materials (Nnali & Oke, 2013).

Co-digestion potential

Co-digestion of fishery waste (FW) with pig manure (PM), grass, sewage sludge (primary and secondary) or biodiesel waste (BW) could upgrade biogas volume and composition with compared to sole FW digestion due to an improved C/N ratio (Regueiro *et al*., 2012; Tomczak-Wandzel *et al*., 2013). Co-digestion of FW and bagasse could improve the stability and biogas potential, also reducing the time required to obtain 70% of the total biogas production (Panpong *et al*., 2014). Kafle *et al*. (2013) studied the potential of fishery waste silage prepared by addition of brewery grain waste (BGW) for biogas production, obtained a maximum biogas production with 50% fishery waste and 50% of BGW.

1.3. Examples of Mexican plants in operation

There are no biogas generation plants by digestion or co-digestion of fishery wastes in Mexico.

2. Research methods

A variety of data sources for conducting the resource assessment, including:

- Published data by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
- The main national-level government stakeholders in Mexico include the Ministry of Agriculture, Rural Development, Fisheries, and Food (SAGARPA).
- Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2T_2/V_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (1.0 atm, 28°C) representative of the fishery wastes in Mexico.

The conversion of N-m³/kg VS to N-m³/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (38.5 and 94%, respectively). The energy conversion factor applied is 35.9 MJ/N-m³ CH_4

4. Results for each column of the database

Table 10. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	4	Expert judgment
Feedstock handling (as solid or as liquid)	Semisolid	Nnali & Oke (2013)
Recommended anaerobic technology if treated alone	Leach bed reactor followed by UASB, anaerobic filter	Yuvaraj *et al.* (2016)
Pretreatment required before anaerobic technology (if applicable)	No	Nnali & Oke (2013)
Current use of the feedstock	Food and oil production	FAO (2002)
Relative use of the feedstock for other purposes	High use	FAO (2002)
Expected cost	High	FAO (2002)

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonne fishery waste/Tonne fish	0.60	FAO (2016)
Dry matter	TS (%)	38.5	Kafle *et al.* (2013)
Volatile Solids fraction	VS/TS	0.94	Kafle *et al.* (2013)
Density	tonne/m³	1.05	Law *et al.* (2014)
C/N relation **(Total N)**	C/N kg N/tonne TS	4.1 (115)	Kafle & Kim (2012) Arvanitoyannis & Kassaveti, 2008)
Fats content	%	4.0 – 8.0	Petricorena (2015)
Typical methane content in biogas	%	50 – 75	Yuvaraj *et al.*, (2016)
Typical sulfur content in biogas	%	< 1.0	Yuvaraj *et al.*, (2016)
Methane potential (yield)	m³ CH_4/tonne VS m³ CH_4/tonne fresh biomass GJ/tonne VS	280 – 390 (335) 101.3 – 147.1 (121.2) 10.0 – 14.0 (12.0)	Callaghan *et al.* (1999) Mshandete *et al.* (2004)

5. References

Arvanitoyannis, I. S., & Kassaveti, A. (2008) Fish industry waste: treatments, environmental impacts, current and potential uses. *International Journal of Food Science & Technology*, 43(4), 726-745.

Callaghan, F.J., Wase, D.A.J., Thayanithy, K., Forster, C.F. (1999) Co-digestion of waste organic solids: batch studies. *Bioresource Technology*, 67, 117–122.

FAO (2002). FAO Fisheries Statistical Yearbook 2002. Pp. 27–39. Rome: Food and Agricultural Organization of the United Nations.

FAO (2016). Seafish Insight: The global picture – fishmeal production and trends July 2016.

Instituto Nacional de Ecología y Cambio Climático (INECC) (2012). Diagnóstico básico para la gestión integral de los residuos. *Instituto Nacional de Ecología y Cambio Climático (INECC)-Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT).*

Kafle, G. K., & Kim, S. H. (2012) Evaluation of the biogas productivity potential of fish waste: a lab scale batch study. *Journal of Biosystems Engineering*, 37(5), 302-313.

Kafle, G. K., Kim, S. H., & Sung, K. I. (2013) Ensiling of fish industry waste for biogas production: a lab scale evaluation of biochemical methane potential (BMP) and kinetics. *Bioresource technology*, 127, 326-336.

Lanari, D. & Franci, C. (1998). Biogas production from solid wastes removed from fish farm effluents. *Aquatic Living Resources*, 11, 289–295.

Law, B. A., Hill, P. S., Maier, I., Milligan, T. G., & Page, F. (2014). Size, settling velocity and density of small suspended particles at an active salmon aquaculture site. *Aquaculture Environment Interactions*, 6(1), 29-42.

Mshandete, A., Kivaisi, A., Rubindamayugi, M., Mattiasson, B. (2004) Anaerobic batch co-digestion of sisal pulp and fish wastes. *Bioresource Technology*, 95, 19–24.

Msangi, S., Kobayashi, M., Batka, M., Vannuccini, S., Dey, M. M., & Anderson, J. L. (2013). Fish to 2030: prospects for fisheries and aquaculture. *World Bank Report*, 83177(1), 102.

Nnali, K.E. & Oke, A.O. (2013). The utilization of fish and fish farm wastes in biogas production: "a review". *Advances in Agriculture, Sciences and Engineering Research*, 3(1), 656 – 667.

Panpong, K., Srisuwan, G., Sompong, O., & Kongjan, P. (2014). Anaerobic co-digestion of canned seafood wastewater with glycerol waste for enhanced biogas production. *Energy Procedia*, 52, 328-336.

Petricorena, Z. C. (2015). Chemical Composition of Fish and Fishery Products. *In Handbook of Food Chemistry* (pp. 403-435). Springer Berlin Heidelberg.

Regueiro L., Carballa M., Álvarez J.A., Lema J.M. (2012). Enhanced methane production from pig manure anaerobic digestion using fish and biodiesel wastes as co-substrates. *Bioresource Technology*, 123(0), 507-513.

SAGARPA. (2012). 6° Informe de Labores. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. 1 de Agosto de 2012.

Salam, B., Islam, M., Rahman, M.T. (2009) Biogas from Anaerobic Digestion of Fish Waste. *International Conference on Mechanical Engineering (ICME2009)*, 26- 28 December 2009, Dhaka, Bangladesh.

SEAFISH (2001), Fish waste production in the United Kingdom. The quantities produced and opportunities for better utilisation. *SEAFISH*, report number SR537.

Soto, M., Méndez, R., & Lema, J. M. (1991). Biodegradability and toxicity in the anaerobic treatment of fish canning wastewaters. *Environmental Technology*, 12(8), 669-677.

Tomczak-Wandzel, R., Levlin, E., & Ekengren, Ö. (2013) Biogas production from fish wastes in co-digestion with sewage sludge. In IWA Specialist Conference Holistic Sludge Management 6-8 May 2013 Västerås Sweden. Svenska miljöinstitutet (IVL).

Yuvaraj, D., Bharathiraja, B., Rithika, J., Dhanasree, S., Ezhilarasi, V., Lavanya, A., & Praveenkumar, R. (2016) Production of biofuels from fish wastes: an overview. *Biofuels*, 1-7.

INDUSTRIAL WASTES

Nejayote (corn nixtamalization wastewater)

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Nejayote is a by-product from nixtamalization of corn (alkaline cooking process usually calcium hydroxide) to produce the tortillas, using large quantity of water (between 3:1 - 5:1, water: corn weight) (González-Martínez, 1984). In the country there are between 10 000 and 12 000 mills of nixtamal, mostly microenterprises that together make the dough with which approximately 54% of the tortillas consumed in the country are produced. The rest of the nixtamal is produced by the biggest companies, such as Maseca and Minsa, which commercialize the product as maize flour. The estimated monthly volume of nejayote generated in Mexico is about 1.2 millon m^3 (Valedrrama-Bravo *et al*., 2012). The resulting waste water has the pericarp, germ, and endosperm fractions, starch, carbohydrates and excess of calcium hydroxide).

Current use

At present, there is no demand for this wastewater. In Mexico, there is no particular regulation for nejayote treatment and discharge, other than the one applied to industrial discharges to municipal sewer systems (NOM-002-SEMARNAT-1996) or to water bodies or land (NOM-001-SEMARNAT-1996). In spite of this, nejayote is rarely treated and usually it is discharged in the municipal sewage system.

Cost of the residue

There is no current reclamation practices for this effluent, so no cost is associated.

Biogas potential

This residue have a high potential to be used in the methane production

1.2. Expected characteristics of the feedstock

Production Process

Nixtamalization is an important process in Mexico, Central America, the southern United States. This process is the basis of commercial methods to produce corn flour, tortilla, and other corn-based foods. Nixtamalization is a three-step process: i) the corn kernels are cooked in a saturated calcium hydroxide solution, ii) next, the cooked kernels are steeped for 8–15 h, and iii) the kernels are washed to remove the excess of calcium and organic matter to obtain the sub-product named “nixtamal”, that is the basis for the dough “masa” for tortillas.

The nejayote wastewater have some differences in the physicochemical characteristics due to the differences in the local nixtamalization process (Gutierrez-Uribe *et al*., 2010). However the values are rather homogeneous

in all the Mexican territory. The nejayote wastewater shows a pH between 10 and 14, TS ranging from 13.3-25 g/L, TSS 2.5 g/L, COD of 13-40 g/L, BOD_5 of 7-14 g/L, TOC of 2.8 g/L, alkalinity (180-3260 $mgCaCO_3$/L), and a high carbohydrate content (71-75% of the total solids) (Gonzalez-Martinez 1994; Ibarra-Mendivil *et al*., 2008; Rosentrater *et al*., 2006; Valedrrama-Bravo *et al*., 2012; Castro-Muñoz *et al*., 2015; España-Gamboa *et al*., 2018).
The nejayote presents very low content in proteins , resulting in low total nitrogen and ammonia (118 -209 mg/L and 2 ±1 mg/L, respectively), and low sulfate content (13 mg/L) (Brenes *et al*. 1987; Rosentrater *et al*., 2006; Gonzalez-Martinez *et al*., 1984). The fiber content in unfiltered nejayote is 0.581 ± 0.013%, while in filtered nejayote is 0.271 ± 0.014% (Valderrama-Bravo *et al*., 2012).

Feedstock conditioning and pretratment (If applicable)
No pretreatment other than pH neutralization is required. Depending on the type of anaerobic digester, primary settling may be recommended.

1.3. Examples of Mexican plants in operation

No examples of anaerobic plant/pilots currently in operation

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus), review from scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

Estimation of Yearly feedstock generation per population or area unit was made taking into account the value given by the reports presented by Valderrama-Bravo *et al*., (2012), and the population reported by the Mexican Institute of statistics and Geography, INEGI (2015).
The Methane yield was expressed as N-m^3CH_4/ tonne VS converting the conventional units for a liquid effluent (N-m^3CH_4/ kg COD) taking the values presented in Table 2 (VS=22 g TS/L*0.80), a COD of 25 g/L. The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results

Table 11. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	5	Expert judgment
Feedstock handling (as solid or as liquid)	liquid	Expert judgment
Recommended anaerobic technology if treated alone	Wet digester (UASB)	Expert judgment
Pretreatment required before anaerobic technology (if applicable)		
Current use of the feedstock	No current use	Expert judgment
Relative use of the feedstock for other purposes	Low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation	m^3/tonne maize Millons m^3/year	3 – 5 14.4	Gutierrez-Uribe *et al*., (2010); González-Martínez, (1984)
Dry matter	TS (%)	2.2 – 2.3	España-Gamboa *et al*. (2018), Valderrama-Bravo *et al*. (2012).
Volatile Solids fraction	VS/TS (%)	0.8	Expert judgment
Density	tonne/m^3	1.00 – 1.05	Rosentrater *et al*., (2006), Valderrama-Bravo *et al*. (2012).
C/N relation **(Total N)**	C/N kg N/m^3	13.9 (N: 0.3)	Castro-Muñoz *et al*., (2015); España-Gamboa *et al*., (2018); Valderrama-Bravo *et al*. (2012); Gonzalez-Martinez (1984)
Fats content	%	0.008 ± 0.002	Valedrrama-Bravo *et al*. (2012).
Typical methane content in biogas	%	58-79	Civit *et al*. (1984), Gonzalez-Martinez *et al*. (1984), Ferreira-Rolón *et al*. (2014).
Typical sulfur content in biogas	%	<0.01	Expert judgment
Methane potential (yield)	N-m^3CH_4/ tonne VS	370	Gonzalez-Martinez *et al*. (1984), Expert judgment
	N-m^3CH_4/ tonne COD	260	
	N-m^3CH_4/ m^3	6.5	
	GJ/tonne VS	13.3	

5. References

Brenes, R.P.D., Bazúa, C.D.D. (1987). RBC characteristics for nejayote aero- bic treatment. *Environ Technol Lett* 8, 579–588.

Castro, Muñoz R., Ceron-Montes, G.I., Barragan-Huerta, B.E., Yanez-Fernandez, J. (2015). Recovery of carbohydrates from nixtamalization wastewaters (nejayote) by ultrafiltration. *Revista Mexicana de Ingeniería Química* 14(3), 735-744.

Civit, E., Bazúa, C.D., Engelmann, G., Gonzalez, S., Hartmann, L. (1984). Anaerobic treatment of maiza processing waste water (nejayote) in a packed bed reactor cascade. *Environ Technol Lett* 5, 89–96.

España-Gamboa, E., Domínguez-Maldonado, J.A., Tapia-Tussell, R., Chale-Canul, J.S., Alzate-Gaviria, L. (2018). Corn industrial wastewater (nejayote): a promising substrate in Mexico for methane production in a coupled system (APCR-UASB). *Environmental Science &Pollution Research*, 25, 712–722

Ferreira-Rolon, A., Ramirez-Romero, G., Ramírez-Vives, F. (2014). Granular sludges methanogenic activity increase due to CO2 bubbling calci- um precipitation over nejayote. Rev Mex Ing Quím 13, 517–525

Gonzalez-Martinez, S. (1984) Biological treatability of the wastewaters from the alkaline cooking of maize (Indian corn). *Environ Technol Lett* 5, 365–372.

Gutierrez-Uribe, J.A., Rojas-Garcia, C., Garcia-Lara, S., Serna-Saldivar, S.O. (2010). Phytochemical analysis of wastewater (nejayote) obtained after lime-cooking of different types of maiz kernels processed into masa for tortillas. *J Cereal Sci* 52, 410–416.

Ibarra-Mendívil M.H., Gallardo-Navarro Y.T., Torres P.I., Wong B.R. (2008). Effect of processing conditions on instrumental evaluation of nixtamal hardness of corn. J Texture Stud 39, 252–266.

INEGI (2015). Encuesta Intercensal (EIC) 2015. https://www.inegi.org.mx/temas/estructura/

NOM-001-SEMARNAT-1996. (1996). Que establece los límites máximos permisibles de contaminantes en las descargas de aguas residuales en aguas y bienes nacionales. Secretaría de medio ambiente, recursos naturales y pesca, México.

NOM-002-SEMARNAT-1996. (2016). Que establece los límites máximos permisibles de contaminantes en las descargas de aguas residuales a los sistemas de alcantarillado urbano o municipal. Secretaría de medio ambiente, recursos naturales y pesca, México.

Rosentrater, K.A. (2006). A review of corn masa processing residues: generation, properties, and potential utilization. *Waste Manag* 26, 284–292.

Valderrama-Bravo, C., Gutiérrez-Cortez, E., b, Contreras-Padilla, M., Rojas-Molina, I., Mosquera, J.C., Rojas-Molina, A., Beristain, F., Rodríguez-García, M.E. (2012). Constant pressure filtration of lime water (nejayote) used to cook kernels in maize processing. *J Food Eng* 110, 478–486.

INDUSTRIAL WASTES
Slaughterhouse (Green stream)

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

In Mexico, slaughterhouses denominated "*Tipo Inspección Federal*" (TIF), are facilities for slaughter animals and industrialize meat products and by-products, which are subjected to a permanent sanitary inspection, complying with the regulations of the "*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (SAGARPA)". TIF slaughterhouses produces two streams. First, the red wastewaters that are generated mainly in slaughter and cutting up areas, and the second stream, known in Mexico as green wastewaters, that comes from the processes of viscera extraction and washing of confinement areas. The green stream has a high content of lignocellulosic solid material (fat, intestines residues, rumen content, whiskers, etc.) and a liquid fraction (some blood, washing water, dilute manure, etc.). This mixture has a high biogas potential in wet digestion and as a co-digestion material with other stream.
In Mexico, the species processed in slaughterhouse vary depending the federal states (regions). For example, according to INEGI (2015), in the case of bovine, the sacrificed heads in 2014 were concentrated in the states of Jalisco (16%), Michoacan (10%), Guanajuato (9%), Estado de Mexico (6%), Veracruz (6%) and Coahuila (5%). For swine, the percentages were: Jalisco (17%), Estado de Mexico (12%), Guanajuato (8%), Michoacan (7%), Puebla (7%) and Veracruz (6%).
Estimation of yearly feedstock generation was done taking into account the number of sacrificed cattle per year (bovine, swine), according to the INEGI (2015). Data reported are made taking into account the residues obtained during the sacrifice step (blood and wastewater) and cutting (skin, head, tails, pieces of meat, fat, etc.) For each group, the average of residues was calculated taking into account the percentages reported by COFEPRIS (2016): Average weight for head of cattle: bovine (250 kg) and swine (100 kg); Blood recovered from sacrifice step per animal: bovine (12 L), and swine (4 L); wastewater produced per animal: bovine (7 L), swine (10 L). Viscera extraction per animal: bovine (83 kg), swine (19 kg) and chicken (0.13 kg) and wastewater produced per animal: bovine (100 L), swine (40 L) and chicken (6 L). Total values for sacrifice vary every year, for this reason a range was made for two different years (2010 and 2014). Other species as goat and ovine were not taken into account for the calculation since represent less than the 3% of the species processed in slaughterhouses.

Current use

There is no use for this waste; landfill is usually the final disposal site.

Cost of the residue

There is no demand for this waste or any beneficial use.

Biogas potential

The high content of TS, proteins and fat of this feedstock is associated with a high methane potential for a single stream digestion. In such arrangement, it is necessary to control the process in order to avoid methanogenesis inhibition. Protein degradation releases ammonium, which at high concentrations has inhibitory effects on anaerobic microorganisms. High concentrations of lipids can also cause problems with the anaerobic digestion process as they tend to float, carrying the active biomass along. High fat content can also lead to the accumulation of intermediate degradation compounds, such as long chain and volatile fatty acids, which can inhibit their conversion to methane (Escudero *et al*., 2014).

1.2. Expected characteristics of the feedstock

Production Process

The slaughter of livestock involves three distinct stages: preslaughter handling, stunning, and slaughtering. By-products are the nonmeat materials collected during the slaughter process and some of them can be valorized as food product including livers, brains, hearts, sweetbreads (thymus and pancreas), fries (testicles), kidneys, oxtails, tripe (stomach of cattle), and tongue. Bones and rendered meat are used as bone and meat meal in animal feeds and fertilizers. The viscera waste (that are not part of valorized sub-products) and the paunch manure (partially digested feed) are washed and mixed with some blood, washing water, manure, etc.

The characteristics of the slaughterhouse wastes are very variable in time, however similar characteristics (blood, intestine residue, and digestive tract content) are given for a specific butchered species. For the case of piggery slaughterhouse wastes, a characterization showed 180 g of blood /kg-TS, of which 93% was protein; intestine residues contained 297.5 g/kg-TS, of which 40.1% was protein and 15.3% was fat. Digestive tract content, consisting of vegetable materials remaining in the digestive tract, was 297.4 g/kg-TS that was 15.1% protein and 6.6% fiber. VS contents were 170.2 (blood), 256.4 (intestine residue), and 253.6 (digestive tract content) g/kg, with VS to TS as 94.6%, 86.2%, and 85.3%, respectively (Yoon *et al*., 2014b).

Other studies complement the information with TS and VS of blood of 17.9% and 16.8%, and the internal organs and piggery fatty wastes ranged from 49-50% TS and 36-49% VS (Hejnfelt and Angelidaki, 2009; Rodríguez-Abalde *et al*. 2011). Blood nitrate and sulfate are present in considerable quantities in slaughterhouse wastewater. Intestine residues can present protein content of 45%, 280 g/kg, total nitrogen (TKN) 65 g/kg (Yoon *et al*., 2014a).

Feedstock conditioning and pretreatment (If applicable)

Coarse and medium sieving should be installed in order to retain fibers and rough suspended material. Also, grinding may be applied to reduce the amount of such materials and the cost for their final disposal (landfills).

Potential for co-digestion

Co-digestion with manure may be advantageous considering that excreta is usually available on premises. Also, combined treatment (green and red streams) may be recommended for biogas production and environmental protection purposes.

1.3. Examples of Mexican plants in operation

Some TIF facilities have wastewater treatment plants for both effluents (red and green streams). Usually the treatment process is based on ponds in series arrangement. A modern wastewater treatment (anaerobic, aerobic, filtration and disinfection is located in Buenaventura Grupo Pecuario (Villaflores, Chiapas), a poultry slaughterhouse.

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus), review from scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

The conversion of N-m³/kgVS to N-m³/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (20 and 90%, taken as representative, respectively). The energy conversion factor applied is 35.9 MJ/N-m³ CH_4.

4. Results

Table 12. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	2	Expert judgment
Feedstock handling (as solid or as liquid)	Slurry/Semisolid	Expert judgment
Recommended anaerobic technology if treated alone	Sieve and digester (UASB). Grinding and CSTR	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Sieving or grinding	Expert judgment
Current use of the feedstock	Marginal (agricultural compost, animal feed)	Yoon *et al*. (2014a), Expert judgment
Relative use of the feedstock for other purposes	low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/ year	7-7.5 M tonne	Expert judgment
Feedstock per animal*	kg/animal	7 (swine) 17 (cow)	Data from COFEPRIS (2016)
Dry matter	TS (%)	10.0- 50.7	Yoon *et al*. (2014a), Yoon *et al*. (2014b), Hejnfelt & Angelidaki (2009), Rodríguez-Abalde *et al*. (2011), Moukazis *et al*. (2018)
Volatile Solids fraction	VS/TS	0.87 – 0.95	Yoon *et al*. (2014a), Yoon *et al*. (2014b), Hejnfelt & Angelidaki (2009), Rodríguez-Abalde *et al*. (2011), Moukazis *et al*. (2018)
Density	tonne/m^3	1.2	Estimation
C/N relation (Total N)	C/N kg N/tonne TS	6.2-35.9** (N: 60)	Moukazis *et al*. (2018). Expert judgment
Fats content	%	8.5 - 28.9	Yoon *et al*. (2014a), Escudero *et al*. (2014)
Typical methane content in biogas	%	55-74%	Escudero *et al*. (2014), Ware *et al*. (2016)
Typical sulfur content in biogas	%	<0.5%	Expert Judgment
Methane potential (yield)	N-m^3CH_4/ tonne VS	250 – 1076***	Yoon *et al*. (2014a), Pitk *et al*. (2012), Yoon *et al*. (2014b), Hejnfelt & Angelidaki (2009), Rodríguez-Abalde *et al*. (2011), Afazeli *et al*. (2014), Pitk *et al*. (2012), Ware *et al*. (2016)
	N-m^3CH_4/ tonne fresh biomass	45- 193***	
	GJ/tonne VS	9.0 - 38.6***	

* Taking into account an average of the animal weight of 100 kg for swine and 250 Kg for cow.
**A C/N ratio for fat (371) was obtained by Pitk *et al*. (2012), but not was considered for the reported range.
***Highest BMP can be obtained from digestive tract content (1076 N-m^3CH_4/ tonne VS), Intestine residue (848 N-m^3CH_4/ tonne VS) and blood (799 N-m^3CH_4/ tonne VS) with a substrate/Inoculum ratio of 0.10. In this case (high BMP) the data is also related to the high mass of fat matter that is included in this value. The corresponding yields are also presented.

5. References

Afazeli, H., Jafari, A., Rafiee, S., Nosrati, M. (2014). An investigation of biogas production potential from livestock and slaughterhouse wastes. Renewable and Sustainable Energy Reviews 34, 380–386.

COFEPRIS (2016). Evaluación de riesgos de los rastros y mataderos municipales. Consejo Técnico consultivo Nacional de sanidad animal/Comisión Nacional del Agua. 62 pp.

Escudero, A., Lacalle, A., Blanco, F., Pinto, M., Diaz, I., Dominguez, A. (2014). Semi-continuous anaerobic digestion of solid slaughterhouse waste. Journal of Environmental Chemical Engineering 2, 819–825

Hejnfelt, A., Angelidaki, I. (2009) Anaerobic digestion of slaughterhouse by-products. Biomass & Bioenergy, 33 (8), 1046-1054.

INEGI (2015). Encuesta Intercensal (EIC) 2015. https://www.inegi.org.mx/temas/estructura/

Moukazis, I., Pellera, F., Gidarakos, E. (2018). Slaughterhouse by-products treatment using anaerobic digestion. Waste Management 71, 652–662.

Pitk, P., Kaparaju, P., Vilu, R. (2012). Methane potential of sterilized solid slaughterhouse wastes. Bioresourse Technology, 166, 42–46.

Rodríguez-Abalde, A., Fernández, B., Silvestre, G., Flotats, X. (2011) Effects of thermal pre-treatments on solid slaughterhouse waste methane potential. Waste management. 31, 1488-1493.

Yoon, Y., Kim, S., Oh, S., Kim, C. (2014a). Potential of anaerobic digestion for material recovery and energy production in waste biomass from a poultry slaughterhouse. Waste Management 34, 204–209.

Yoon, Y., Kim, S., Shin, K., Kim, C. (2014b). Effects of Substrate to Inoculum Ratio on the Biochemical Methane Potential of Piggery Slaughterhouse Wastes. Asian Australas. J. Anim. Sci. 27 (4), 600-607.

Ware, A., Power, N. (2016). Biogas from cattle slaughterhouse waste: Energy recovery towards an energy self-sufficient industry in Ireland. Renewable Energy 97, 541-549.

INDUSTRIAL WASTES
Slaughterhouse (Red stream)

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Slaughterhouse effluents have great variability in composition and concentration, not only from day to day, but even over the course of a single day according to the operations being carried out at any given time. In Mexico, the slaughterhouses denominated "*Tipo Inspección Federal*" (TIF) are facilities for slaughter animals and industrialize meat products and by-products, which are subjected to a permanent sanitary inspection, complying with the regulations of the "*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (SAGARPA)".

TIF slaughterhouses discharge two different waste streams. The stream from viscera extraction and washing of confinement areas (green wastewaters) and the red wastewaters that are generated mainly in slaughter and cutting up areas, containing lipids (meat) and proteins (blood). In many cases, these streams are discharged in the municipal sewage system. In general, slaughterhouse effluents produce high environmental impacts, as they increase nitrogen, phosphorus, solids and BOD levels of the receiving water body. In Mexico less than 37% of the slaughterhouse effluents are treated.

According to the INEGI (2015), the number of head of cattle sacrificed vary from one year to other. For the case of cows, the range goes from 2,052,303 to 2,924,706 for 2014 and 2011 respectively; for swine ranged from 4,659,749 (2013) to 4,392,517 (2014); for ovine from 135,264 (2013) to 172,254 (2011 and for goat from 60,929 (2014) to 114,292 (2011). The slaughterhouse industry produces 44, 275 m^3 of blood per year (COFEPRIS, 2016).

Estimation of yearly feedstock generation can be done taking into account the number of sacrificed cattle per year (bovine, swine), according to the INEGI (2015). Data reported can be made taking into account the residues obtained during the sacrifice step (blood and wastewater) and viscera extraction (intestinal tract, gut, other organs, washing, etc.) In this report, for each group the average of residues was calculated taking into account the percentages reported by COFEPRIS (2016). The average weight for head of cattle vary, but can be taking into account as an average for bovine (250 kg) and swine (100 kg). Based on this assumption, the materials and wastewater obtained from the different steps in the slaughterhouse are: Blood recovered from sacrifice step per animal: bovine (12 L) and swine (4 L); wastewater produced per animal: bovine (7 L) and swine (10 L). Solids recovered from cutting step per animal (skin, meat, fat, etc.): bovine (31 kg) and swine (2 kg); wastewater produced per animal: bovine (5 L) and swine (60 L).

In Mexico, the species processed in slaughterhouse vary depending the federal states (regions). For example, according to INEGI (2015), in the case of bovine, the sacrificed heads in 2014 were concentrated in the states of Jalisco (16%), Michoacan (10%), Guanajuato (9%), Estado de Mexico (6%), Veracruz (6%) and Coahuila (5%). For swine, the percentages were: Jalisco (17%), Estado de Mexico (12%), Guanajuato (8%), Michoacan (7%), Puebla (7%) and Veracruz (6%). Other livestock, such as goat and ovine, was not taken into account for the calculation since represent less than the 3% of the species processed in slaughterhouses.

Current use

These wastes may be reclaimed by the meat rendering industry. An unknown number of small installations exist in Mexico, producing protein-rich animal meals and fat matter for a diversity of products.

Cost of the residue

There is no demand for this waste or any beneficial use.

Biogas potential

The high content of proteins and fat of this feedstock is associated with a high methane potential for a single stream digestion. In such arrangement, it is necessary to control the process in order to avoid methanogenesis inhibition. Protein degradation releases ammonium, which at high concentrations has inhibitory effects on anaerobic microorganisms. High concentrations of lipids can also cause problems with the anaerobic digestion process as they tend to float, carrying the active biomass along. High fat content can also lead to the accumulation of intermediate degradation compounds, such as long chain and volatile fatty acids, which can inhibit their conversion to methane (Escudero *et al*., 2014).

1.2. Expected characteristics of the feedstock

Production Process

Slaughterhouses represent one of the most important elements in the chain value of the meat industry. The slaughter of livestock involves three distinct stages: preslaughter handling, stunning, and slaughtering. The animals are driven from the holding pens to the slaughtering area where the following activities take place: Stunning, suspension from an overhead rail by the hind legs; Sticking and bleeding over a collecting trough part (collection of blood), decapitation, opening of the carcass by cutting and evisceration and finally the meat is chilled or freeze. The collected blood may be sewered and is combined with the meat waste (red stream), before the evisceration process.

The effluent characteristics of the red stream, due to the combination of wastewater plus blood, have a similar characteristics, independently of the butchered livestock (Bovine, porcine, ovine or caprine). The average composition of their liquid effluent, once separated from the voluminous solids, is: total solids 4000 mg/L, volatile solids 2000 mg/L, pH range from 6.3-7.7, COD total 29000 – 131000 mg/L and nitrogen 250 mg/L (Marcos *et al*., 2010; Rodriguez-Martinez *et al*., 2002). Nitrate (e.g., 0.96 mg/L) and sulfate (0.97 g/L) are also present in slaughterhouse wastewater (Rodriguez-Martinez *et al*., 2002). For piggery slaughterhouse wastes, a characterization showed 18% of TS was associated to the collected blood, with 93% protein (Yoon *et al*., 2014b).

Feedstock conditioning and pretreatment (If applicable)

Coarse sieving or grinding may be needed.

Potential for co-digestion

Co-digestion with manure may be advantageous considering that excreta is usually available on premises. A combined treatment (green and red streams) may be recommended for biogas production and environmental protection purposes (effective wastewater treatment before final discharge).

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus), review from scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

Total values for sacrifice vary every year, for this reason a range was made for two different years (2010 and 2014.

The methane yield expressed as N-m^3 CH_4/kg COD_{inf} was calculated using a VS/COD conversion factor of 0.5 kg VS/kg COD. The estimation of the volumetric yield (N-$m^3$$CH_4$/ m^3) was done taking a COD concentration of 80 kg/m^3, based on data in Table 2. The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results

Table 13. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	3	Expert judgment
Feedstock handling (as solid or as liquid)	Liquid	Expert judgment
Recommended anaerobic technology if treated alone	UASB with pretreatment. CSTR	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Sieving, grease trap for UASB	Expert judgment
Current use of the feedstock	Marginal (compost, animal feed, biogas)	Expert judgment
Relative use of the feedstock for other purposes	Low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/year	3- 3.5 M tonne	Expert judgment
Feedstock per animal*	kg/animal	8 (swine) 23 (cow)	Data from COFEPRIS (2016)
Dry matter	TS (%)	1% (TSS: 270-6400 mg/L) (COD: 29 – 131 g/L)	Rodriguez-Martinez *et al*., (2002), Yoon *et al.* (2014b), Bustillo-Lecompte *et al.* (2015),
Volatile Solids fraction	VS/TS	0.45 - 0.66	Rodriguez-Martinez *et al*., 2002), Pitk *et al.* (2012), Yoon *et al.* (2014b),
Density	tonne/m^3	1.2*	Expert judgment
C/N relation **(Total N)**	C/N kg/m^3	5.3 - 6.2 (N: 0.25)	Pitk *et al.* (2012),
Fats content	%	5 -	Sayed *et al.* (1987),
Typical methane content in biogas	%	50 - 60	Bustillo-Lecompte *et al.* (2015),
Typical sulfur content in biogas	%	< 0.1	Expert Judgment
Methane potential (yield)	N-m^3CH_4/ tonne VS N-m^3CH_4/ kg COD_{inf}	300 – 900** 0.15 – 0.45**	Afazeli *et al.* (2014), Pitk *et al.* (2012), Salminen *et al*., (2002)
	N-m^3CH_4/ m^3	12 – 36**	
	GJ/tonne VS	10.8- 32.3**	

* Taking into account an average of the animal weight of 100 kg for swine and 250 kg for cow.
** Higher methane potential is taking into account the fat content in the stream

5. References

Afazeli, H., Jafari, A., Rafiee, S., Nosrati, M. (2014). An investigation of biogas production potential from livestock and slaughterhouse wastes. Renewable and Sustainable Energy Reviews 34, 380–386.

Bustillo-Lecompte, C.F., Mehrvar, M. (2015). Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry: A review on trends and advances. Bioresourse Technology,85, 235-241.

COFEPRIS (2016). Evaluación de riesgos de los rastros y mataderos municipales. Consejo Técnico consultivo Nacional de sanidad animal/Comisión Nacional del Agua. 62 pp.

Escudero, A., Lacalle, a., Blanco, f., Pinto M., Diaz, I., Dominguez, A. (2014). Semi-continuous anaerobic digestion of solid slaughterhouse waste. Journal of Environmental Chemical Engineering 2, 819–825.

INEGI (2015). Estadística de sacrificio de ganado en rastros municipales por entidad federativa 2009-2014. Instituto Nacional de Estadística y Geografia. Mexico. 153 pp.

Marcos, A., Al-Kassir, A., Mohamad, A.A., Cuadros, F., López-Rodríguez, F. (2010) Combustible gas production (methane) and biodegradation of solid and liquid mixtures of meat industry wastes. Applied Energy 87, 1729–1735

Pitk, P., Kaparaju, P., Vilu, R. (2012). Methane potential of sterilized solid slaughterhouse wastes. Bioresourse Technology, 166, 42–46.

Rodrıguez-Martınez, J., Rodrıguez-Garza, I., Pedraza-Flores, E., Balagurusamy, N., Sosa-Satillan, G., Garza-Garcıa, Y. (2002). Kinetics of anaerobic treatment of slaughterhouse wastewater in batch and upflow anaerobic sludge blanket reactor. Bioresource Technology 85,235–241.

Salminen, E., Rintala, J. (2002) Anaerobic digestion of organic solid poultry slaughterhouse waste – a review Bioresource Technology 83, 13–26.

Sayed, S., van Campen, L., Lettinga, G. (1987). Anaerobic Treatment of Slaughterhouse Waste Using a Granular Sludge UASB Reactor. Biological Wastes 21, 11-28.

Yoon, Y., Kim, S., Shin, K., Kim, C. (2014). Effects of Substrate to Inoculum Ratio on the Biochemical Methane Potential of Piggery Slaughterhouse Wastes. Asian Australas. J. Anim. Sci. 27 (4), 600-607.

INDUSTRIAL WASTES
Spent earths from the edible oil industry

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Mexico ranks 11th internationally as a producer of oil seeds and oleaginous fruits, with a production of 6.9 million metric tonnes per year for 2015. The main seeds from which the oil is extracted are soybean (61%), safflower (38%) and canola (0.1%) (Fideicomiso de Riesgo Compartido, 2012).

The National producers association -*Asociación Nacional de Industriales de Aceites y Mantecas Comestibles, A.C* (2015) indicates that the Mexican volume of production in the sector was 3.02 million tonnes of edible oils and fats and 6.3 million tonnes of oleaginous pasta (also known as meal, seed cake, or edible oil refining bagasse), a valued byproduct. Also, the production of oil represents 8.7% of the Gross Domestic Product of the food sector in the country and 2% in the manufactory industry. The value of these products amounts to 3.825 million dollars. The 2015 figures result in a yield factor of 0.4 oil tonne/seed tonne.

Vegetable oil industry produces two byproducts: the oleaginous pasta, which is largely utilized as feedstock for animal husbandry and spent earth for bleaching (bleaching earths). The world production of oils in 2006 was more than 60 million tonnes, while it is estimated that about 600,000 tonnes of bleaching earth were utilized worldwide for the refining (Kheang *et al*., 2006); therefore it is estimated that 1 tonne of spent earth was produced per 100 tonnes of refined oil in that year (0.01 factor). With the previous factor, the estimated production of spent earth in Mexico was 690 000 tonne for 2015.

Current use

The spent earths are recycled by means of patented processes for cleaning and oil recovery. Once the earth is no longer suitable for oil purifying, the waste is incinerated or landfilled.

Cost of the residue

There is no current use of the bleaching earths.

Biogas potential

Spent earths are not anaerobically digested, unless mixed with other organic wastes, such as cow manure. It has been shown that this waste material is an excellent co-digestion substrate, as it provides better methane yield potential at lower unit mass loadings than another kind of organic co-digestion waste (Ward, 2012).

1.2. Expected characteristics of the feedstock

Production Process

The agroindustry chain of oilseed is divided into three stages: 1. The harvest of seeds, 2. The grinding of the oilseed to obtain crude oils and protein pastes, 3. Partition of the grinding products resulting in a) oils, fats,

refined shortenings from human consumption; b) raw oils and pasta for balanced feed for the livestock sector; c) oils, fats, shortenings to make cookies, pasta, ice cream, preserves and another kind of food.
The extraction of oil from the seed is done by applying mechanical pressure or by means of solvents (hexane). After oil extraction, refining is carried out where odors and undesirable flavors are eliminated. The next step is neutralization, where acidity is eliminated with the addition of sodium hydroxide. This process is carried out in boilers with high temperatures. Subsequently, the natural pigments are removed by filters such as activated carbon or adsorbent earth (activated bleaching earths); then the phospholipids and glycolipids that are dissolved in the oil are removed (degumming) by incorporating water in a 2% portion and at a temperature of 70ºC. Finally, the deodorization will evaporate the substances that cause unpleasant odors at temperatures of 150ºC.
The filtering media after being used to purify the vegetable oil is named spent earth. The main constituent is the spent clay (mostly montmorillonite or bentonite), with the retained materials and adsorbed oil. The vegetable oil proportion varies between 30-50% in weight. It is common that the spent earths also contain non-biodegradable material and trace elements (phosphorous, potassium, calcium and magnesium). Water is also present, as it is common practice to spray water to the filter during the operation to prevent auto-ignition of the warm spent earth cake.

Feedstock conditioning and pretreatment (If applicable)

Milling is required to reduce the particle size. Homogenization also is needed for preparing the slurry that will enter the stirred tank reactor.

Potential for co-digestion

The use of co-digestion of a vegetable substrate with oil waste increases the production of biogas by 30% (Thanikal *et al.*, 2015). Also, Champagne and Anderson (2015) claim that this kind of co-digestion process is a low-cost and commercially viable approach worldwide. Addition of 10% (w/w) bleaching earth increase the methane production up to 35 % if the feedstock is cow manure (Ward, 2012).

1.3. Examples of Mexican plants in operation

There is currently no plant in the country that utilizes solid waste from vegetable oil for biogas generation.

2. Research methods

The information for the vegetable oil Industry waste feedstock relies upon an expert judgment in general and upon scientific and technical publications for specific quantitative information.

3. Memory of calculations

When applicable, all the gas-related properties were normalized to 1 atmosphere and 273 K. The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (17.4% and 97.3% respectively) for a co-digestion with 90% manure. The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results

Table 14. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	3	Expert judgement
Feedstock handling (as solid or as a liquid)	Solid	Expert judgement
Recommended anaerobic technology if treated alone	Completely Stirred Tank Reactor (co-digestion)	(Ward, 2012)
Pretreatment required before anaerobic technology (if applicable)	None	Expert judgement
Current use of the feedstock	Waste	(Gunstone, Harwood, & Dijkstra, 2007)
Relative use of the feedstock for other purposes	Low	(Gunstone *et al*., 2007)
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonne spent earth / tonne oil	0.01 – 0.015	(Comisión Nacional del Medio Ambiente, 1998)
Dry matter	TS (%)	84.16 (alone) 17.4 (mix)	Spent earth Cattle manure and 10 % bleaching earth (Ward, 2012)
Volatile Solids fraction	VS/TS	0.355 0.973	Spent earth Cattle manure and 10 % bleaching earth (Ward, 2012)
Density	tonne/m^3	1.8	(Saleh Alhamed & Al-Zahrani, 1999)
C/N relation **(Total N)**	C/N kg/tonne TS	256 (N: 0.8)	(Moshi, 2017)
Fats content	%	13.2 - 40	(Ward & Løes, 2011) & (Asociación Nacional de Industriales de Aceites y Mantecas Comestibles, A.C, 2008)
Typical methane content in biogas	%	65 -67	(Ward, 2012)
Typical sulfur content in biogas	%	<0.1	Expert Judgement
Methane potential (yield)	N-m^3CH_4/ tonne VS	310	Cattle manure and 10 % bleaching earth (Ward, 2012)
	N- m^3CH_4/ tonne fresh biomass	52.5	Cattle manure and 10 % bleaching earth (Rios & Kaltschmitt, 2016)(Ward, 2012)
	GJ/tonne VS	11.1	Cattle manure and 10 % bleaching earth (Ward, 2012)

5. References

Asociación Nacional de Industriales de Aceites y Mantecas Comestibles, A.C. (2015). Disposición de adsorbentes usados y otros sub-productos de la refinación de aceites. Retrieved May 6, 2018, from http://portal.aniame.com/imp_100.shtml

Comisión Nacional del Medio Ambiente. (1998). Guia para el control y prevencion de la contaminación industrial - Fabricación de grasas y aceites vegetales y subproductos. Santiago, Chile.

Fideicomiso de Riesgo Compartido. (2012). Estudio de gran visión y factibilidad económica y financiera para el desarrollo de infraestructura de almacenamiento y distribución de granos y oleaginosas para el mediano y largo plazo a nivel nacional. Informe.

Gunstone, F. D., Harwood, J. L., & Dijkstra, A. J. (2007). *The Lipid Handbook with CD-ROM*.

Kheang, L. S., Foon, C. S., May, C. Y., & Ngan, M. A. (2006). A Study of Residual Oils Recovered from Spent Bleaching Earth: Their Characteristics and Applications. *American Journal of Applied Sciences*, 3(10), 2063–2067. https://doi.org/10.3844/ajassp.2006.2063.2067

Moshi, A. (2017). Characterization of Spent Bleaching Earth and Its Utilization for Improving Manure-based Biogas Production. *Biotechnology Journal International*, 17(4), 1–13. https://doi.org/10.9734/BJI/2017/31601

Rios, M., & Kaltschmitt, M. (2016). Electricity generation potential from biogas produced from organic waste in Mexico. *Renewable and Sustainable Energy Reviews*, 54, 384–395. https://doi.org/10.1016/j.rser.2015.10.033

Thanikal, J. V, Torrijos, M., Rizwan, S. M., Yazidi, H., Kumar, R. S., & Sousbie, P. (2015). Anaerobic Co-Digestion of Vegetable Waste and Cooked Oil in Anaerobic Sequencing Batch Reactor (ASBR). *International Conference on Chemical, Environmental and Biological Sciences* (CEBS-2015), 2(March 18-19), 4–7.

Ward, A. J. (2012). Biogas potential of soapstock and bleaching earth. Retrieved from http://www.bioforsk.no/ikbViewer/Content/97643/A_

Ward, A. J., & Løes, A.-K. (2011). The potential of fish and fish oil waste for bioenergy generation: Norway and beyond. *Biofuels*, 2(4), 375–387. https://doi.org/10.4155/bfs.11.114

COMMERCIAL WASTES
Fats, Oils and Grease (FOG)

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Fat, oil, and grease (FOG) is a term commonly used to define the lipid-rich material from wastewater generated during cooking and food processing, this can include animal fat and FOG from the pretreatment of municipal and industrial wastewater treatment plants (WWTP). Grease and oil from the petroleum industry is not considered here. The grease removal is most commonly accomplished at the source by the use of grease abatement devices referred to as “grease traps” for smaller sources or “grease interceptors” for bigger or industrial level.

The yearly feedstock generation as 0.31 kg/inhabitant/year can be calculated taking into account the value given by Tacias Pascacio *et al.* (2016) for the analysis of the FOG from a restaurant at Tuxtla Gutierrez, Chiapas (Mexico), but estimations taking account other studies in USA can increase the value to 7.1 L FOG/inhabitant/year (Wiltsee, 1998).

Current use

In addition to FOG final disposal (landfilling), some reclamation options are composting, production of industrial soaps, incineration, anaerobic co-digestion, or biodiesel production. However, in Mexico the most common procedure is landfill disposal. Collection of FOG from restaurants has been implemented by local services in some cities of the center of Mexico, which may re-sold the feedstock for soap production or as complementary feedstock for cattle (animal feed additive).

Cost of the residue

At present, there is no cost for the collector of this residue. In fact, the FOG-producing establishments dispose this residue through payed private service providers that collects the FOG material and take in charge its final disposal or reclamation.

Biogas potential

Due to its high methane potential, FOG is a very interesting substrate or co-substrate, even more when it is an in-house waste. Nonetheless, FOG dosing rate must be limited in order to avoid high concentration of long chain fatty acids LCFA (result of lipid degradation) in the digester, a potential inhibitor of the methanogenic activity (Mata-Alvarez *et al*. 2014). Researchers have suggested that the detrimental effect on methanogenic bacteria may be due to sludge flotation and washout; for this reason the co-digestion with waste sludge can be an important alternative for the use of FOG in anaerobic digestion. In this regard, FOG collected from the food service industry has been cited to increase biogas production by 30% or more when added directly to sludge anaerobic digester and may allow wastewater treatment plants to meet over 50% of their electricity demand through on-site generation (Long *et al*. 2012). Razaviarani *et al*. (2013) found that the co-digestion of FOG with municipal wastewater sludge increased the COD and VS removal rates between 55 to 164% compared with no co-digestion system.

1.2. Expected characteristics of the feedstock

Production Process

Grease traps are typically around 190 L in size and are installed inside the food preparation facility, directly below the sink. Other option is a grease interceptor (typically 3700–7500 L) that are generally installed below ground and outside the building (Long *et al*., 2012). Both devices for FOG retention results in similar waste characteristics.

The chemical characteristics of grease trap waste can vary greatly depending on the type of restaurant or food service establishment, the device configuration (i.e., size, inlet/outlet piping, number of baffles), and the pump out frequency. FOG may have variable biochemical oxygen demand (BOD), and total solids (TS) content depending on the frequency of pump outs. The FOG characteristics in terms of the chemical oxygen demand (COD) typical values range from 20 to 321 g/L with pH from 3.9 to 6.2 (Long *et al*. 2012; Xu *et al*. (2018); Silvestre *et al*. (2014).

This waste is pumped-out by vacuum trucks for industrial installations or submersible pumps in case of small production facilities (restaurants).

Feedstock conditioning and pretratment (If applicable)

Some operational challenges for the anaerobic digestion include the inhibition of acetoclastic and methanogenic microorganisms, sludge flotation, digester foaming, blockages of pipes and pumps, and clogging of gas collection and handling systems (Long *et al*. 2012). For this reason, co-digestion is one economically option especially with OFMSW, food waste and sewage sludge (primary and secondary sludges). Studies in full-scale reactors in California and Vancouver showed that co-digestion of FOG and sewage sludge increase between 32 to 82% of the biogas and 5-6%of the methane content.

1.3. Examples of Mexican plants in operation

No examples of anaerobic plant currently in operation for FOG as sole substrate

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus), review from scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

The TS % and VS/TS % are considered from grease tramp from restaurants and grease trucks transportation. For the case of dewatered FOG, a different value need to be considered going from 42 to 97% for the TS%, and VS/TS % from 96 -100% (Kabouris *et al*., 2009, Parry *et al*. 2008).

The FOG in grease trap can be divided in floatable layer and bottom (aqueous and sludge) layer. VS in table 2 is considered without this separation. Differentiating the two layers, the TS can be as follows: Floatable layer 2.5-303.4 g/L, bottom layer 7.3-51.9 g/L (Long *et al*. 2012).

The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (representative values: 10 and 90%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results

Table 15. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	4	Expert judgment
Feedstock handling	Liquid/Semisolid	Expert judgment
Recommended anaerobic technology if treated alone	Wet digester (CSTR) in co-digestion	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	None (should be co-digested)	Expert judgment
Current use of the feedstock	Marginal (animal feed, biogas, soap production, typically landfill)	Expert judgment
Relative use of the feedstock for other purposes	Low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/inhabitant/year	0.003	Tacias Pascacio *et al* (2016)
Dry matter	TS (%)	1.3 -22	Xu *et al*. (2018), Long *et al*. (2012)
Volatile Solids fraction	VS/TS (%)	0.86 - 0.98	Xu *et al*. (2018), Silvestre *et al*. (2014), Long *et al*. (2012)
Density	tonne/m³	0.907	Tacias Pascacio *et al* (2016)
C/N relation **(Total N)**	C/N kg/tonne TS	22.1 – 39 (N: 33)	Xu *et al*. (2018), Silvestre *et al*. (2014),
Fats content	%	75.4 - 99.5	Xu *et al*. (2018), Long *et al*. (2012), Silvestre *et al*. (2014)
Typical methane content in biogas	%	50 - 69	Rasit *et al*. (2015), Expert judgment
Typical sulfur content in biogas	%	< 0.1	Expert judgment
Methane potential (yield)	N-m³CH_4/ tonne VS N-m³CH_4/ tonne fresh biomass GJ/tonne VS	400-1100 (600) 36 – 100 (54) 14.4 – 39.5 (21.5)	Xu *et al*. (2018), Mata-Alvarez *et al*. (2014), Silvestre *et al*. (2014), Rasit *et al* (2015)

5. References

Kabouris, J.C., Tezel, U., Pavlostathis, S.G., Englemann, M., Dulaney, J.A., Todd, A.C., Gillette, R.A. (2009). Mesophilic and thermophilic anaerobic digestion of municipal sludge and fat, oil, and grease. *Water Environmental Research* 81 (5), 476–485.

Long, J.H., Aziz, T.N., de los Reyes III, F.L., Ducoste, J.J. (2012). Anaerobic co-digestion of fat, oil, and grease (FOG): A review of gas production and process limitations. *Process Safety and Environmental Protection* 90, 231–245.

Mata-Alvarez, J., Dosta, J., Romero-Güiza, M.S., Fonoll, X., Peces, M., Astals, S.(2014). A critical review on anaerobic co-digestion achievements between 2010 and 2013. *Renewable and Sustainable Energy Reviews* 36 (2014) 412–427.

Parry, D.L., Vandenburgh, S., Salerno, M.B., Finger, R. (2009). Codigestion of organic waste. In: Proceedings of the Water Environment Federation, pp. 210–229.

Rasit, N., Idris, A., Harun, R., Ghani, W.A.W.A.K. (2015). Effects of lipid inhibition on biogas production of anaerobic digestion from oily effluents and sludges: An overview. *Renewable and Sustainable Energy Reviews* 45 (2015) 351–358.

Razaviarani, V., Buchanan, I.D., Malik, S., Katalambula, H. (2013). Pilot-scale anaerobic co-digestion of municipal wastewater sludge with restaurant grease trap waste. *Journal of Environmental Management* 123, 26-33.

Silvestre, G., Illa, J., Fernández, B., Bonmatií, A. (2014). Thermophilic anaerobic co-digestion of sewage sludge with grease waste: Effect of long chain fatty acids in the methane yield and its dewatering properties. *Applied Energy 117*, 87–94.

Tacias Pascacio, V.G., Rosales Quintero,, A., Torrestiana Sánchez B. (2016). Evaluación y caracterización de grasas y aceites residuales de cocina para la producción de biodiésel: un caso de estudio. *Rev. Int. Contam. Ambie.* 32 (3) 303-313.

Wiltsee, G., 1998. Waste grease resource in 30 US metropolitan areas. In: The Proceedings of Bioenergy 98 Conference, Wisconsin, pp. 956–963.

Xu, F., Li, Y., Ge, X., Yang, L., Li, Y. (2018) Anaerobic digestion of food waste – Challenges and opportunities. *Bioresource Technology* 247, 1047–1058.

COMMERCIAL WASTES
Food Waste

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential
Food waste includes uneaten food, food preparation leftovers from residences, commercial establishments such as restaurants and cafeterias. This residue represents an environmental problem, particularly in large cities where the typical method of disposal is in landfills. Food waste is primarily composed of carbohydrates (abundant amounts cellulose and starch), lipids and proteins, making it suitable as a substrate for the anaerobic digestion process.
Reports presented at the International Workshop on Food Loss and Food Waste (2016), showed an estimation of 20,418,214 tonnes of food waste per year in Mexico. In Mexico, 72% of the food waste occurring in the first link of the production chain and processing phases of consumption while the rest occurs at the retail and consumer levels. In this sense, the market and restaurant food waste are the main sources of this substrate. However, there is high variability in the food waste characteristics and volume depending on the source. Food waste generation has a high correlation with the Mexican states with more population. The availability of this kind of residues is not well defined, but it has been reported that 32 to 34 % of total solid waste in Mexico is food waste (Armijo de Vega *et al*., 2010), resulting in a range of 6.5 to 6.9 millions of tonnes of food waste/year.
As an example of a Mexican buffet restaurant, the variation from one day to other are related to the differences in the menu. The following values were determined: fruits and vegetables residues 63 ± 4%, residues from flour (bread and tortillas) 14 ± 3%, meet 8 ± 2% , and other 15 ± 3%, with physicochemical characteristics of moisture 79 ± 2%, TS 155 ± 13.6 g/L, VS 142.8 ± 12.6 g/L, density 1090 kg/m^3, total COD 32.8 ± 2.4 g/L, and N-NH_3 490 ± 5.8 mg/L (Santiago, 2015). Total Kjeldahl nitogen was determined as 14.9 g/kg in a university restaurant (Forster-Carneiro *et al*. 2008).

Current use
The current final disposal of this feedstock is the landfills. Small/local restaurants may dispose of this residue free of charge through collectors for animal feeding. Composting in combination with garden residues is carried out in marginal cases.

Cost of residue
The cost of the residue feedstock in the market can be low, or free of charge. In several cases, no separation of the food waste is carried out at the source, so other residues (for example, in restaurants food waste are mixed with kitchen non-biodegradable residues as metal, glass, plastic, etc.) may be part of the waste. In such cases, the cost of separation need to be considered.

Biogas potential
The food waste may be anaerobically digested for biogas production. Two main types of anaerobic digestion processes are distinguished for organic waste as the food waste, which are generally referred to as wet (<10–20% TS) and dry systems that have high operating solids (20–>40% TS). Wet AD plants had improved energy balance and economic performance compared to dry AD plants due to the following findings (Angelonidi and Smith, 2015): a) Dry AD plants had more complex pretreatment and post- treatment steps than wet AD plants. b) Wet AD plants produced higher biogas yields per tonne of waste treated compared to dry AD plants. c) Wet AD plants had lower specific capital cost per tonne of waste treated in comparison to most dry AD plant, and d) Wet AD plants had a lower specific capital cost per m^3 of biogas produced than dry AD plants.

1.2. Expected characteristics of the feedstock

Production Process
The good-practice management of residues in restaurants separates kitchen from other wastes, so organic waste is separated on-site. In restaurants, an inspection of the kitchen waste is usual to avoid loss of some restaurant materials as knives, forks, etc. The food waste varies depending on the origin, mainly with changes in the proportions of carbohydrates and proteins. Food waste consisting of rice, pasta and vegetables is abundant in carbohydrates while food waste consisting of meat, fish and eggs contains high quantity of proteins and lipids. However, their general characteristics are: moisture content of 74–90%, high volatile solids fraction around 85 ± 5%, and a mean acidic pH of 5.1 ± 0.7. Typical food waste is mainly composed of degradable carbohydrates (41–62%), proteins (15–25%) and lipids (13–30%) (Braguglia *et al.*, 2018).

Generally, FW has varying proportions of nutrients and micronutrients and low presence of heavy metals, but the variability is very high. FW typically has a relatively low C/N ratio, varying between 13.2 and 24.50, below the optimal range of 25–35 assuring efficient digestion conditions.

Feedstock conditioning and pretreatment (If applicable)
In the case of wet anaerobic process, the waste should be conditioned to reach the appropriate TS content (10-25%) by adding water as required (usually municipal wastewater). Grinding or refining of source-separated household waste and date-exceeded packaged food products may be converted to a clean pulp, favoring a high methane yield for biogas production can be applied.

Potential for co-digestion
Co-digestion with other feedstock may be advantageous (fed as a slurry). Sewage sludge may be recommended to increase biogas production at the treatment facility.

1.3. Examples of Mexican plants in operation

Examples of anaerobic plant/pilots currently in operation:
Pilot UAM. Location: Mexico City, Universidad Autonoma Metropolitana – Iztapalapa. Capacity: 0.6 tonne/day; Technology: Slurry OFUSW /UASB.
Organic residues treatment. Centro de Acopio Nopal-Verdura en Milpa Alta. Location: Mexico City. Owner: Sustentabilidad en Energía y Medio Ambiente (Suema)/ Secretaría de Ciencia, Tecnología e Innovación (Seciti) Mexico City.

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus), review from scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (representative values: 25 and 90%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results

Table 16. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	5	Expert judgment
Feedstock handling (as solid or as liquid)	Solid/Semisolid	Expert judgment
Recommended anaerobic technology if treated alone	Wet digester (CSTR or batch process)	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Grinding or pulping	Expert judgment
Current use of the feedstock	Marginal	Xu *et al*. (2018), Braguglia *et al*. (2018)
Relative use of the feedstock for other purposes	low(compost, animal feed, biogas)	Expert judgment
Expected cost	Low	Zhang *et al*. (2014), Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/inhabitant/year	0.17	Expert judgment
Dry matter	TS (%)	18.1 – 30.9	Zhang *et al*. (2014), Braguglia *et al*. (2018), Xu *et al*. (2018), Zhang *et al*. (2007)
Volatile Solids fraction	VS/TS	0.85 – 0.94	Zhang *et al*. (2014), Braguglia *et al*. (2018),
Density	kg/m³	514 - 1090	WRAP (2016), Santiago (2018)
C/N relation **(Total N)**	C/N kg N/tonne TS	11 – 24 (N: 15)	Zhang *et al*. (2014), Braguglia *et al*. (2018), Xu *et al*. (2018), Zhang *et al*. (2007); Forster-Carneiro *et al*. (2008)
Fats content	%	4- 23	Zhang *et al*. (2014), Braguglia *et al* (2018), Xu *et al*. (2018), Zhang *et al*. (2007)
Typical methane content in biogas	%	48 - 65	Zhang *et al*. (2014), Braguglia *et al* (2018), Xu *et al*. (2018), Zhang *et al*. (2007)
Typical sulfur content in biogas	%	< 0.050	Quijano *et al*. (2018)
Methane potential (yield)	N-m³CH₄/ tonne VS N-m³CH₄/ tonne fresh biomass GJ/tonne VS	310 – 530 (400) 69.8 – 119.2 (90) 11.1- 19.0 (14.4)	Zhang *et al*. (2014), Xu *et al*. (2018), Li *et al*. (2018), Braguglia *et al*. (2018), Curry *et al*. (2012), Zhang *et al*. (2007)

5. References

Aguilar, G. (2016) Food waste in Mexico: a zero-sum game? Genaro Aguilar – Consultant, World Bank. International Workshop on food loss and Food waste. 7-9/11/2016.

Angelonidi, E., Smith, S.R. (2015). A comparison of wet and dry anaerobic digestion processes for the treatment of municipal solid waste and food waste. *Water and Environment Journal* 29, 549–557.

Armijo de Vega, C., Taboada-González, P., Aguilar-Virgen, Q., Ojeda-Benítez, S. (2010). Solid Waste Generation and Composition in Mexico: A Comparison between Rural and Urban Communities. *Journal of Environmental Science and Engineering* 4 (11), 71-78.

Braguglia, C.M., Gallipoli, A., Gianico, A., Pagliaccia, P. (2018) Anaerobic bioconversion of food waste into energy: A critical review. *Bioresource Technology* 248, 37–56.

Curry, N., Pillay, P. (2012) Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy* 41, 200-209.

Forster-Carneiro, T., Pérez, M., Romero, L.I. (2008) Influence of total solid and inoculum contents on performance of anaerobic reactors treating food waste, Bioresource Technology, 99, 15, 6994-7002

INEGI (2015). Encuesta Intercensal (EIC) 2015. https://www.inegi.org.mx/temas/estructura/

Li, L., Peng, X., Wang, X., Wu, D. (2018). Anaerobic digestion of food waste: A review focusing on process stability. *Bioresource Technology* 248, 20–28. Nov. 2010, Volume 4, No.11 (Serial No.36)

Quijano, G., Figueroa-González I., Moreno G., Moreno-Andrade I. (2018). Estimating H_2S concentration in biogas produced by anaerobic sludge from sulfur-rich wastewaters. I2SM Chiapas, Mexico 2018.

Santiago, S.G., Moreno-Andrade I. (2015). Two step anaerobic process for hydrogen and methane production from organic solid waste of a restaurant. AD14 IWA World Congress on Anaerobic Digestion, Viña del Mar, Chile, 15-18/11/2015.

Wrap. (2010). Waste & Resources Action Programme, UK. Material change for environment. Summary report. Material Bulk densities. Project code: ROT039. January 2010

Xu, F., Li, Y., Ge, X., Yang, L., Li, Y. (2018) Anaerobic digestion of food waste – Challenges and opportunities. *Bioresource Technology* 247, 1047–1058.

Zhang, R., El-Mashad, H.M., Hartman, K., Wang, F., Liu, G., Choate, C., Gamble, P. (2007). Characterization of food waste as feedstock for anaerobic digestion. *Bioresource Technology* 98 , 929–935.

Zhang, C., Su, H., Baeyens, J., Tan, T. (2014). Reviewing the anaerobic digestion of food waste for biogas production. *Renewable and Sustainable Energy Reviews* 38, 383–392.

COMMERCIAL WASTES
Market wastes

Feedstock Database for biogas in Mexico 2018

1. Background

1.1 Selection criteria for the feedstock

Generation potential

Market waste has been shown as part of the "Food waste" class, with commercial, industrial and household origins; it is important to remark that organic waste characteristics depend mainly on the country of origin and the generation characteristics (Leung & Wang, 2016). Market waste, organic fraction of municipal solid waste (mixed organic wastes) and food waste (organic waste from commercial food processing establishments) should be considered different feedstocks because the properties are different among them. The market wastes are all the food chunks (non-eatable) and edible food losses that are produced in the commercial establishments of food supply (wholesale markets, town markets (neighborhoods), distribution centers, supply centers, supermarkets, flea markets, etc).

There are 90 wholesale markets; 65 supply centers and 25 wholesale markets in Mexico (Cámara Nacional De Centrales De Abastos, 2018); therefore, the total amount is 180 establishments.

According to the last official diagnosis of Mexican waste management, the information on the waste sector is scarce (Inecc & Semarnat, 2012). According to Fierro Ochoa *et al*. (2010), the markets generate up to 9% of the total municipal solid waste in several Mexican cities, from which up to 65% is an organic waste. A recent Mexican study determined 85% of Market waste is organic (Morgan-Sagastume, 2013).

In Mexico City (2016), 10.56% of the municipal solid waste generation (12 920 tonnes/day) proceeded from markets (1 364 tonnes/day) according to SEDEMA (2017). The single wholesale market (Central de Abastos) generated 585 tonnes/day (4.53% of total produced, 43% of market waste).

No information about market waste generation was found in the existing 17 published official Waste Management programs from the 32 Mexican states (Baja California Sur, Baja California, Durango, Querétaro, Michoacán, Yucatán, Guerrero, Estado de México, Veracruz, Guanajuato, Coahuila, Ciudad de México, Chihuahua, Chiapas, Jalisco, San Luis Potosi & Hidalgo). Moreover, the information about waste generation is not aggregated by industry or economic activity, but by organic matter type (bananas, potatoes, apples, etc).

Despite the lack of data, market waste generation in Mexico may be estimated as follows: from the total amount of annual municipal solid waste from 2015 [53.1 million tonnes according to SEMARNAT (2016)], at least 4.78 million tonnes (9%) were generated in markets (Buenrostro *et al*., 1999)], from which 4.06 million tonnes were organic waste [85% of Organic Fraction as found by Morgan-Sagastume (2013)]. That accounts for 11.1 thousand tonnes of organic market waste generated each day in Mexico.

The last report from the World Bank about food loss in Mexico (World Bank, 2017) shown that every year the Mexican food loss is near 20.4 million tonnes a year, which represents 34% of the total food production of the country. This number includes only the edible losses through the agriculture, post-harvest, processing, distribution and consumption losses, not the food chunks that are also part of the market waste class. The market waste is only related to the distribution link of the Food Supply Chain, which accounts for up to 59% of the total fruits and vegetables worldwide (Kummu *et al*., 2012).

Cost of the residue

At present, there is no Mexican public policy for biogas generation from food waste and the same applies to any other organic residue. Market waste is collected as a mix and later composted or landfilled as municipal solid waste (SEMARNAT, 2016). As stated by Aguilar Vázquez (2012) the market waste may be used as food for backyard animal husbandry. There is no data about the amount of market waste, nor the cost of the feedstock in the market (Ramírez *et. al*., 2017). Further studies are required for evaluating the market of the waste feed for animal husbandry.

Current use

It is known that a fraction of the organic waste may be edible, thus scavenged by low-income people as food in the final disposal sites (Cervantes & Palacios, 2012). It is known that any kind of organic waste may be utilized as animal feed, after processing by different methods (Río, *et. al*.., 1994). It a common practice to feed animals, especially pigs, with organic waste in Mexico and Latin America without any treatment. However, there is no specific information about the amount of market waste that is utilized for animal husbandry. It is not recommended to feed animals with market waste not properly treated (Organización Panamericana de La Salud, 1999).

Donations of market waste between 11.95 to 39.18 % and landfilling from 21.44 to 49.75% were reported publicly in 2012 from Walmart de Mexico, the main supermarket company in the country. There is no generalized (or reported) use for composting, animal feeding or anaerobic digestion; the market waste is mostly landfilled as mixed market waste. (SEMARNAT, 2015).

Biogas potential

Wet digestion of biodegradable solid waste from food-processing industries, agro-industry, and agriculture is the most feasible way to recover the energy of the organic waste, notwithstanding the low efficiency achieved (Abbasi *et. al.*, 2012). However, at present, it is not feasible to cover the reactor's capital cost when high solids anaerobic digestion technology is selected (Abbasi *et. al.*, 2012)

Regarding the potential of biogas production, market waste is particularly suited for anaerobic digestion and biogas production (Bouallagui *et al*., 2005). In addition, market waste digestate is an excellent soil conditioner after minor treatments. Dilution (water addition) may be needed to decrease the concentration of organic matter and then to operate the reactors with optimal organic loading rate (Zhang *et al.*, 2008).

It has been shown that the biogas potential of market waste has lesser biogas yield and volatile solid destruction than food waste alone: biogas was generated (daily average) at laboratory scale of 290 L/day and 130 L/day. The same author expresses that in batch or semi-continuous mode, total methane yield can be enhanced with co-digestion with cattle manure as presented in section 1.2 (Das & Mondal, 2016)

1.2 Expected characteristics of the feedstock

Production Process

Market waste is the solid or semi-solid fruit & vegetable chunks that may represent up to 65% w/w of the total waste generated in a wholesale market (Prado-Salazar *et al*., 2016). In Mexico, it is common to find miscellaneous commercial establishments in wholesale markets (*centrales de abastos*). Therefore, market waste is discarded fruits, vegetables, and other food products or residues mix with other wastes from diverse establishments. As required by Mexican regulations (LGPGIR, 2018), market waste has to be separated in the generation site. However, according to Góngora Pérez (2014), the total separated volume was less than 10.9 % of the market waste generated in 2010.

Feedstock conditioning and pretreatment

Bouallagui (2005) y Zhang *et al.* (2008) recommend to grind food wastes into small particles and then homogenize the material in order to facilitate digestion before feeding the digester. Production of a pulp slurry may be particularly advantageous for this kind of waste. Dilution should be considered in order to decrease the concentration of organic matter for an optimal organic loading rate. In this sense, it is recommended not to exceed 10% of dry matter in the case of wet digestion technologies (Buenrostro et al., 2000).

Potential for co-digestion

Co-digestion has been recommended with manure in a 2:1 ratio (market waste - manure (cattle or swine)), with an optimal C/N ratio of 15.8. In such a situation, methane yield is 388 Nm^3/ tonne were produced in batch and methane yield is 317 Nm^3/tonne in semi-continuous regime (Das & Mondal, 2016).

1.3 Examples of Mexican plants in operation

The Biogas Plant “Bio-Energia Abastos Irapuato" of the Irapuato’s wholesale market is operating since 2015 with covered anaerobic ponds, biogas is used for power generation but there is no public information available about the installed capacity, nor the electric generation.

2. Research methods

The information for the market waste feedstock relies upon the expert judgment in general and upon scientific and technical publications for specific quantitative information.

3. Memory of calculations

When applicable, all the gas-related properties were normalized to 1 atmosphere and 273 K. The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (representative values: 25 and 90%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results for each column of the database

Table 1. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	4	Expert judgment
Feedstock handling (as solid or as a liquid)	Solid	Expert judgment
Recommended anaerobic technology if treated alone	Wet digester	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Grinding, homogenization, and water addition (up to 10% TS).	Expert judgment
Current use of the feedstock	Donation and landfilling	SEMARNAT (2015) and Expert judgment
Relative use of the feedstock for other purposes	Low.	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonne/year	4.06 million	Estimated from SEMARNAT (2016), Buenrostro *et al.* (1999) and World Bank (2017)
Dry matter	TS (%)	18 – 31	Campuzano & González-Martínez, (2016), Han & Shin, (2002), D. Zhang *et al.*, (2008), L. Zhang, Lee, & Jahng, (2011)
Volatile Solids fraction	VS/TS	0.85 - 0.95	Leung & Wang, (2016), Han & Shin, (2002), D. Zhang *et al.*, (2008), L. Zhang *et al.*, (2011)
Density	tonne/m^3	0.51 -0.75	Han & Shin, (2002),
C/N relation (N total)	C/N kg/tonne TS	20 - 36.4 (N: 110)	Buenrostro *et al.* (1999)
Fats content	%	17.5	Campuzano & González-Martínez, (2016)
Typical methane content in biogas	%	55-65	Leung & Wang, (2016)
Typical sulfur content in biogas	%	0-1%, H_2S	Leung & Wang, (2016)
Methane potential	N-m^3CH_4/ tonne VS	367	Leung & Wang, (2016), Curry & Pillay, (2012)
	N-m^3CH_4/ tonne fresh biomass	82.5	Leung & Wang, (2016), Curry & Pillay, (2012)
	GJ/tonne VS	13.2	Leung & Wang, (2016), Curry & Pillay, (2012)

5. References

Aguilar Vázquez, A. (2011). Desempeño, desarrollo corporal y evaluación sanguínea de lechones de traspatio alimentados con desperdicio de comedor y cocina. (Unpublished thesis). Universidad Autónoma Agraria Antonio Narro, Coahuila, México.

Abbasi, T., Tauseef, S. M., & Abbasi, S. A. (2012). Biogas Energy. *Biogas Energy* (Pp. 1–169). Https://Doi.Org/10.1007/978-1-4614-1040-9

Bouallagui, T. & Cheikh Hamdia (2005). Bioreactor Performance In Anaerobic Digestion Of Fruit And Vegetable Wastes. UR-Procédés Microbiologiques Et Alimentaires, Institut National Des Sciences Appliquées Et De Technologie (INSAT), B.P. 676, 1080 Tunis, Tunisia

Buenrostro, Cram, Bernache, Bocco (2000). La Digestión Anaerobia Como Alternativa De Tratamiento A Los Residuos Sólidos Orgánicos Generados En Los Mercados Municipales. *Revista Internacional De Contaminación Ambiental*, Vol. 16, Núm. 1, 2000, Pp. 19-26, Universidad Nacional Autónoma De México, Distrito Federal, México.

Buenrostro, O., Bernache, G., Silke, C., & Bocco, G. (1999). Análisis De La Generación De Residuos Sólidos En Los Mercados Municipales De Morelia, México. *Revista Internacional De Contaminación Ambiental*, 15(1), 27–32.

Campuzano, R., & González-Martínez, S. (2016). Characteristics Of The Organic Fraction Of Municipal Solid Waste And Methane Production: A Review. *Waste Management*, 54, 3–12. Https://Doi.Org/10.1016/J.Wasman.2016.05.016

Cervantes, J. J., & Palacios, L. (2012). El Trabajo En La Pepena Informal En México : Nuevas Realidades , Nuevas Desigualdades, *27*(1), 95–117. Https://Doi.Org/10.2307/41759672

Cámara Nacional De Centrales De Abastos (2018) "Directorio Nacional" Retrieved from Http://Www.Conacca.Mx/Index.Php/Styles/Centrales-De-Abasto

Curry, N., & Pillay, P. (2012). Biogas Prediction And Design Of A Food Waste To Energy System For The Urban Environment. *Renewable Energy*, 41, 200–209. Https://Doi.Org/10.1016/J.Renene.2011.10.019

Das, A., & Mondal, C. (2016). Biogas Production From Co-Digestion Of Substrates : A Review. *International Research Journal Of Environment Sciences*, *5*(1), 49–57.

Fierro Ochoa, Armijo De Vega, Buenrostro Y Valdéz (2010). Análisis De La Generación De Residuos Sólidos En Supermercado De La Ciudad De Mexicali, México. *Revista Internacional De Contaminación Ambiental*. 26 (4) 291-297, 2010.

Góngora Pérez, J. P. (2014). El Reciclaje En México. *Comercio Exterior*, *64*(3), 4. Retrieved From Http://Revistas.Bancomext.Gob.Mx/Rce/Magazines/757/2/Reciclaje_Mexico.Pdf

Han, S.-K., & Shin, H.-S. (2002). Enhanced Acidogenic Fermentation Of Food Waste In A Continuous-Flow Reactor. *Waste Management & Research*, 20(2), 110–118. Https://Doi.Org/10.1177/0734242X0202000202

Inecc & Semarnat. (2012). Diagnóstico Básico Para La Gestión Integral De Los Residuos, 201. Retrieved From Http://Www.Semarnat.Gob.Mx/Temas/Residuos-Solidos-Urbanos

Kummu, M., De Moel, H., Porkka, M., Siebert, S., Varis, O., & Ward, P. J. (2012). Lost Food, Wasted Resources: Global Food Supply Chain Losses And Their Impacts On Freshwater, Cropland, And Fertiliser Use. *Science Of The Total Environment*, *438*(September 2012), 477–489. Https://Doi.Org/10.1016/J.Scitotenv.2012.08.092

Leung, D. Y. C., & Wang, J. (2016). An Overview On Biogas Generation From Anaerobic Digestion Of Food Waste. *International Journal Of Green Energy*, 13(2), 119–131. Https://Doi.Org/10.1080/15435075.2014.909355

LGPGIR. (2018). Ley General Para La Prevención Y Gestión Integral De Los Residuos. *Diario Oficial De La Federación*, 52. Https://Doi.Org/10.1017/CBO9781107415324.004

Morgan-Sagastume, J. M.. (2013). *Proyecto De Aprovechamiento De Residuos Orgánicos*. II-UNAM-Instituto de Ingeniería-Universidad Nacional Autónoma de México. Informe interno, sin publicar.

Organización Panamericana de La Salud. (1999). *GUÍA PARA EL MANEJO DE RESIDUOS SÓLIDOS EN CIUDADES PEQUEÑAS Y ZONAS RURALES*. Retrieved From Http://Www.Fao.Org/Livestock/Agap/Frg/APH134/Cap13.Htm

Prado-Salazar, M. R., Mejía-Estrella, I. A., & Ávalos Sánchez, T. (2016). Valorización De Residuos Orgánicos Del Mercado De Abastos De Guadalajara. *Marzo*, *2*(2), 55–63. Retrieved From Http://Www.Ecorfan.Org/Bolivia/Researchjournals/Desarrollo_Urbano_Y_Sustentable/Vol2num2/Revista_Del_Desarrollo_Urbano_Y_Sustentable_V2_N2_7.Pdf

Ramírez N., V. M., Peñuela S., L. M., & Pérez R., M. D. R. (2017). Los Residuos Orgánicos Como Alternativa Para La Alimentación En Porcinos. *Revista De Ciencias Agrícolas*, *34*(2), 107–124. Https://Doi.Org/10.22267/Rcia.173402.76

Río, J. Del, Pineda, A., Chao, R., Leal, M., & Pérez., A. A. (1994). Capítulo 13 Experiencia Cubana Sobre Procesamiento Industrial De Residuos, Desechos Y Subproductos Alimenticios Como Piensos Líquidos.

SEDEMA. (2017). Inventario De Residuos Sólidos 2016. Secretaría De Medio Ambiente, Ciudad de México.

SEMARNAT (2015). Informe De La Situación Del Medio Ambiente En México, Cap 7.

SEMARNAT. (2016). *INFORME DE LA SITUACIÓN DEL MEDIO AMBIENTE EN MÉXICO. COMPENDIO DE ESTADÍSTICAS AMBIENTALES. INDICADORES CLAVE, DE DESEMPEÑO AMBIENTAL Y DE CRECIMIENTO VERDE. EDICIÓN 2015*. Ciudad De México.

Zhang, El-Mashad, Hartman, Wang, Liu, Choate Y Gamble (2008). Characterization Of Food Waste As Feedstock For Anaerobic Digestion. Science Direct. *Bioresource Technology,* 98 (2007) 929-935

Zhang, L., Lee, Y.-W., & Jahng, D. (2011). Anaerobic Co-Digestion Of Food Waste And Piggery Wastewater: Focusing On The Role Of Trace Elements. *Bioresource Technology*, 102, 5048–5059. Https://Doi.Org/10.1016/J.Biortech.2011.01.082

World Bank (2017) *Pérdidas Y Desperdicios De Alimentos En México. Una Perspectiva Económica, Ambiental Y Social.* Unidad De Desarrollo Sostenible De América Latina Y El Caribe.

URBAN WASTES

Organic Fraction of Municipal Solid Waste

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

In Mexico (2015), the generation of municipal solid waste (MSW) reached 53.1 million tonnes (which represented an increase of 61.2% compared to 2003). If expressed per inhabitant, it reached 1.2 kilograms on average daily in the same year. The Organic Fraction of Municipal Solid Waste (OFMSW), represent the highest proportion of MSW and consists of scraps, food residues, paper and garden waste. The OFMSW can represent between 50 to 70% of the waste composition with moisture content around 70–80%.

In data recollected by SEMARNAT (2015), the composition of OFMSW represent 52.4% of the total MSW. However, this percentage is related to the economically development of each regions of Mexico, i.e., the higher contribution to the economy, the higher MSW production. This residue shows a high availability in all the Mexican territory. According to the Secretaría de Desarrollo Social de Mexico, in 2012 the Central region concentrated 51% of the MSW generation, followed by the Northern Border region with 16.4% and the metropolitan area of Mexico City with 11.8%. If the different states are classified by the volume of MSW produced, five of them concentrated 45.7% of the total MSW: the Estado de Mexico (6.7 million t, 16.1% of the national total), Mexico City (4.9 million t, 11.8 %), Jalisco (3.1 million t, 7.2%), Veracruz (2.3 million t, 5.5%) and Nuevo León (2.2 million t, 5.1%).

The estimated average generation rate of OFMSW in the main cities of Mexico range from 0.356 to 0.659 kg/inhabitant/day. As example in Guadalajara was 0.508 kg/inhabitant/day, while in the state of Mexico the value is 0.54 kg/inhabitant/day (Bernache-Pérez *et al*. 2001, Redondo 2014).

Current use

The main current final disposal of this feedstock is landfilling. Some minor uses include composting in combination with garden residues. Few demonstrative biogas production plants have been recently built.

Cost of residue

There is no market for this feedstock at present. However, an opportunity may arise if separation is done either at the source or in transfer stations, and a biogas production facility is associated.

Biogas potential

A OFMSW characterization and methane production in Mexico City (Campuzano *et al*. 2015) determined the following: moisture 70.3 %, TS 29.7%, VS 22.3 %, VS/TS 75.1 %, N- Kjeldahl 5.4 g/kg. In the same study, a methane production of 0.545 N-m^3 CH_4/kgVS was found in a semi-continuous reactor (wet digestion at mesophilic conditions).

1.2. Expected characteristics of the feedstock

Production Process

The separation or organic fraction of municipal solid waste has some differences, depending on the local regulation (compulsory or voluntary household separation). In markets, usually the OFMSW is separated. Some landfills sites (e.g., landfills operated by concession as Proactiva, Veolia, etc.) have separation facilities on premises. However, their capacity usually does not reach the 100% of the total received solid waste. New projects (as in Queretaro City, 2018) include separation plants for recovery of recyclable materials but also the separation of organic solid waste will be considered.

The inherent variability of this material requires specific characterization and tailor-made engineering for its valorization in a biogas producing facility- As an example, the major components of municipal solid waste from Guadalajara's OFMSW were food waste (40.7%) and yard trimmings (12.2%), which together constituted 52.9% of the total. Similar values were reported for putrescible waste in other Mexican Cities: Mexico City, 53.4%; Hermosillo, 41.32%; Mexicali, 46.9%; and Culiacán, 54.6% (Bernache-Pérez, 2001). The percentage contribution of putrescible wastes from household in large urban areas in Mexico has not changed significantly over the last decades.

Feedstock conditioning and pretreatment (If applicable)

Milling followed by pulping (water addition) is recommended for increasing methane production potential.

Potential for co-digestion

Co-digestion with other feedstock may be advantageous (fed as a slurry). Sewage sludge may be recommended to increase biogas production at the treatment facility

1.3. Examples of Mexican plants in operation

Examples of anaerobic plant/pilots currently in operation:

Pilot FQ-UNAM. Location: Cuautitlán, Edo de Mexico, Universidad Nacional Autónoma de Mexico. Capacity: 1.0 tonne/day. Technology: Solid dry anaerobic digestion / anaerobic digester (complete mixed reactor)

Pilot Central de Abastos de Irapuato. Location: Irapuato, Guanajuato. Technology: Anaerobic digester

2. Research methods

Literature was reviewed searching in specialized data bases (Scopus), review from scientific papers, technical publications and thesis were identified and revised.

3. Memory of calculations

Estimation of yearly feedstock generation per population or area unit was made taking into account the value given by the reports presented in by SEMARNAT (2018).

The conversion of N-m^3/kg VS to N-m^3/kg fresh biomass was done using the dry and volatile content of fresh biomass, as reported in Table 2 (representative values: 30 and 75%, respectively). The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4

4. Results

Table 17. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation speed	5	Expert judgment
Feedstock handling (as solid or as liquid)	Solid/Semisolid	Expert judgment
Recommended anaerobic technology if treated alone	Wet digester (Complete mixed)	Expert judgment
Pretreatment required before anaerobic technology (if applicable)	Milling / pulping	Expert judgment
Current use of the feedstock	Marginal	Expert judgment
Relative use of the feedstock for other purposes	low	Expert judgment
Expected cost	Low	Expert judgment

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes/inhabitant/year	0.33	Campuzano *et al*. (2016), SEMARNAT 2018
Dry matter	TS (%)	16.0 – 46.3	Campuzano *et al*. (2016), Davidsson *et al*. (2007)
Volatile Solids fraction	VS/TS	0.61 – 0.94	Campuzano *et al*. (2016), Davidsson *et al*. (2007)
Density	tonne/m^3	328 - 1052	Wrap 2010, Campuzano *et al*. (2016), Forster-Carneiro *et al*. (2008b)
C/N relation (Total N)	C/N kg/tonne TS	11 – 27 (N: 5.4)	Campuzano *et al*. (2016), Davidsson *et al*. (2007)
Fats content	%	6.1 – 35.0	Campuzano *et al*. (2016),
Typical methane content in biogas	%	58 - 69	Davidsson *et al*. (2007), Bolzonella *et al*. (2003) Rintala *et al*. (1994),
Typical sulfur content in biogas	ppb	< 0.1	Expert judgment
Methane potential	N-m^3CH_4/ tonne VS N-m^3CH_4/ tonne fresh biomass GJ/tonne VS	255 – 579 (400) 57.4 – 130.3 (90) 9.15 – 20.8 (14.4)	Curry *et al*. (2012), Alibardi *et al*. (2015), Fitamo *et al*. (2016), Angelidaki *et al*. (2006), Davidsson *et al*. (2007), Bolzonella *et al*. (2003)

5. References

Alibardi, L., Cossu, R. (2015). Composition variability of the organic fraction of municipal solid waste and effects on hydrogen and methane production potentials. Waste Management 36, 147–155.

Angelidaki, I., Chen, X., Cui, J., Kaparaju, P., Ellegaard, L. (2006). Thermophilic anaerobic digestion of source-sorted organic fraction of household municipal solid waste: start-up procedure for continuously stirred tank reactor. *Water Research.* 40 (14), 2621–2628.

Bolzonella, D., Innocenti, L., Pavan, P., Traverso, P., Cecchi, F. (2003). Semi-dry thermophilic anaerobic digestion of the organic fraction of municipal solid waste: focusing on the start-up phase. *Bioresource Technology* 86 (2), 123–129.

Campuzano, R., González-Martínez, S. (2016). Characteristics of the organic fraction of municipal solid waste and methane production: A review. *Waste Management* 54, 3–12.

Campuzano, R., González-Martínez, S. (2015). Extraction of soluble substances from organic solid municipal waste to increase methane production. *Bioresourse Technology.* 178, 247–253.

Curry, N., Pillay, P. (2012) Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy* 41, 200-209.

Davidsson, A., Gruvberger, C., Christensen, T.H., Hansen, T.L., Jansen, J. (2007). Methane yield in source-sorted organic fraction of municipal solid waste. *Waste Management* 27, 406–414.

Fitamo, T., Boldrin, A., Boe, K., Angelidaki, I., Scheutz, C. (2016). Co-digestion of food and garden waste with mixed sludge from wastewater treatment in continuously stirred tank reactors. *Bioresourse Technology*. 206, 245–254.

Forster-Carneiro, T., Pérez, M., Romero, L.I. (2008). Thermophilic anaerobic digestion of source-sorted organic fraction of municipal solid waste. *Bioresourse Technology* 99 (15), 6763–6770.

INEGI (2015). Instituto Nacional de Estadistica y Geografía. http://www.beta.inegi.org.mx/temas/estructura/

Redondo, F. (2014). Producción de biogáss a partir de residuos sólidos orgánicos provenientes de diferentes fuentes generadoras (Thesis). Universidad Nacional Autónoma de México, UNAM.

SEMARNAT (2018) Informe de la Situación del Medio Ambiental en México. Compendio de Estadísticas Ambientales. Indicadores Clave, de Desempeño Ambiental y de Crecimiento Verde. Edición 2015, Dirección General de Estadística e Información Ambiental SEMARNAT.

SMAGEM (Secretaría de Medio Ambiente del Estado de México). http://portal2.edomex.gob.mx/sma/acerca_secretaria/directorio/index.htm

Rintala, J., Ahrin, B. (1994). Thermophilic anaerobic digestion of source- sorted household solid waste: the effects of enzyme additions. *Applied Microbiology and Biotechnology* 40 (6), 916–919.

Wrap. (2010). Waste & Resourcees Action Programme, UK. Material change for environment. Summary report. Material Bulk densities. Project code: ROT039. January 2010.

URBAN WASTES
Landfill leachates

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

Mexico produces 112 500 tonnes of municipal solid waste (MSW) per day and up to 23% is not disposed of properly (INEGI, 2013). The leachate or percolated liquid production in a landfill depends on the following factors: rainfall in the area of the landfill, surface runoff and/or underground infiltration, evapotranspiration, natural humidity of the MSW, compaction degree, field capacity (soil and MSW capacity to retain moisture); however, the volume of leachate is mainly a function of rainfall. Due to the different conditions of operation and location of each landfill, the expected leachate production rates may vary; hence, they must be calculated for each particular case. In general, daily generation rates are 0.23 liters/kg MSW/day in rainy season and 0.15 liters/kg MSW/day in dry season (Orta *et al*., 2003). Municipal leachate is generated during the decomposition of municipal solid waste (MSW) in landfills. The composition and concentration of contaminants in landfill leachates may vary according to the following conditions: (a) the composition of the MSW disposed in the landfill, (b) the biochemical reaction processes that take place, (c) the handling conditions of the leachate, (d) the environmental conditions, and (d) the age of the landfill. This last factor is highly important for the chemical composition of leachates because they tend to stabilize over the years, observing a decrease in the concentration of their components (Renou *et al*., 2008). The leachate of young (new) and old landfills are characterized by typical values of total nitrogen 0.8 (old) – 3 g/L (young); phosphorus 0.01 (old) – 0.15 g/L (young); chemical oxygen demand (COD) of 0.5 (old) – 18.0 g/L (young), and suspended solids (SS) of 0.4 (old) –0.5 g/L (new); limited biodegradability (0.4 – 0.1 g BOD/g COD), C/N ratios of 10 – 30, as well as a significant amount of inorganic salts, toxic pollutants, and heavy metals may hinder the application of biological treatments (Renou *et al*., 2008; Mukherjee *et al.,* 2015). However, these typical concentration ranges may vary a lot, depending on the factors previously mentioned.

Current use

Landfill leachate is not reclaimed or used in any applications. There are certain drawbacks associated with the land application of leachate directly in crops, the most important being high nitrogen and salinity loadings (Jones *et al.,* 2006) but also the presence of heavy metals.

Cost of the residue

Leachate landfill is not reclaimed, so there is no demand for it. The management of leachate may represent an important cost to the operator of the landfill site, depending on many factors (site conditions, technology applied, discharge regulations) (Torretta *et al.,* 2016).

Biogas potential

Collection and treatment of leachate are two of the most important problems associated with operation of landfills (Li, 2010). The biodegradability of leachates tends to decrease as the age of the landfill increases, according to the BOD/COD ratio, so that biological treatments tend to be less effective in old leachates (Montesinos *et al*., 2007). Leachate may be recirculated to the landfill, where biogas production take place. However, in many cases leachates are treated separately, anaerobic digestion being a suitable alternative mainly for young and mature leachates. For old leachates (after the decommissioning of the landfill site), physicochemical treatment may be required. Methane production of mixture of leachate landfill and food waste took place after 70 days, with both 30% and 20% of leachate. Bioreactors had a production of 87 and 99 L-CH_4/kg VS calculated from only the leachate, respectively. Under the 30% regime, a stronger leachate was produced and consequently a higher methane production rate (Hernández-Berriel *et al*., 2014). Methane yields between 181 and 239 N-m^3 CH_4/tonne VS were obtained after 10 and 28 days of co-digestion of fresh leachate and domestic wastewater, respectively, with an average methane content of 70% (Moujannı *et al.,* 2019). Addition of alkalinity had a favorable effect on the methane yield. Considering its high biodegradability (82.6%) and methane production potential, anaerobic digestion of leachate in bioreactor landfills or anaerobic digesters with a preferred control of alkalinity and salinity can be considered as a sustainable solution to the present emergent problem (Lee *et al*., 2009).

1.2. Expected characteristics of the feedstock

Production process

Landfill leachate is defined as any liquid effluent percolating through deposited waste and emitted within a landfill or dump site. Often, its route of exposure and toxicity remains unknown and a matter of prediction due to extremely complicated geochemical processes in the landfill and the underlying soil layers (Koshi *et al*., 2007). Leachate presents high values of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total suspended solid (TSS), total dissolved solid (TDS), recalcitrant organic pollutants, ammonium compounds, sulfur compounds and dissolved organic matter (DOM) bound heavy metals which eventually escape into the environment, mainly soil and groundwater, thereby posing serious environmental problems (Gajski *et al*., 2012). Around two hundred hazardous compounds have already been identified in the heterogeneous landfill leachate, such as aromatic compounds, halogenated compounds, phenols, pesticides, heavy metals and ammonium (Jensen *et al*., 1999). All of these pollutants have accumulative, threatening and detrimental effect on the survival of aquatic life forms, ecology and food chains leading to enormous problems in public health including carcinogenic effects, acute toxicity and genotoxicity (Moraes & Bertazzoli, 2005). A leachate is characterized by two principle factors, its composition and the volume generated, both of which are influenced by a variety of parameters, such as type of waste, climatic conditions and mode of operation. The most important factor influencing landfill leachate composition is the age of the landfill (Kulikowska & Klimiuk, 2008).

There are three broad and overlapping phases of waste decomposition, in which chemical and biological processes give rise to both landfill gas and leachate during and beyond the active life of the site (Robinson, 1996): (a) phase 1, oxygen present in the wastes is rapidly consumed by aerobic decomposition. This phase typically lasts less than one month and is normally relatively unimportant in terms of leachate quality, it is exothermic and high temperatures may be produced. This speeds up the later phases if some of this heat is retained; (b) phase 2, anaerobic and facultative microorganisms hydrolyze cellulose and other putrescible materials which are converted during acetogenesis to acetic acid, carbon dioxide and hydrogen. Leachate from this acidic phase typically contains a high concentration of free fatty acids. The resulting low pH (between 5 to 6) favors the solubilization of some components of the wastes, such as the alkaline earths and heavy metals, which can be mobilized in the leachate; and (c) phase 3, full anaerobic conditions convert the volatile acids to methane and carbon dioxide, mineralizing the organic matter in a stabilized form and producing biogas. The carbon dioxide tends to dissolve producing the very high bicarbonate concentrations typical of phase 3 leachates. The rate at which this phase becomes established is controlled by a number of factors, including the content of readily putrescible waste (Christensen *et al*., 1994).

Feedstock conditioning and pretreatment (if applicable)
The treatment of leachates may be complex due to the diverse characteristics and the evolution during time: A number of combined physical, chemical, and biological processes should be arranged for an effective leachate treatment (Wei *et al*., 2012). In many cases, physicochemical techniques, such as air stripping, adsorption, coagulation–flocculation may be needed for pretreating leachate, depending on the specific characteristics, which are related to the age of the landfill. The benefits of this pretreatment operations are counteracted by remarkable shortcomings such as higher energy consumption and operational costs.

Co-digestion potential
Anaerobic co-digestion of leachate has recently gained interest using different substrates, effluents and technologies (Guven *et al.,* 2018). Leachates, particularly the young ones, are more and more considered as a source of energy. Due to logistic reasons, the co-digestion of food waste and landfill leachates are particularly attractive to improve anaerobic leachate treatment efficiency and energy dependence (Yoon *et al.,* 2018). For concentrated leachate, anaerobic treatment by co-digestion could be a promising environmental strategy, when considering the highly organic content and limited biodegradable characteristics of these leachates as revealed by many works (Imen *et al.,* 2009). Few data are available regarding the co-digestion of landfill leachates with sewage sludge or septage (Montusiewicz & Lebiocka, 2011). Kheradmand *et al.* (2010) showed that co-digestion of leachate with sewage sludge increased the biogas and methane yield by 13% and 16%, respectively compared to the sewage sludge alone. Recently an energetic yield increase up to 80% was achieved with landfill leachate as co-substrate of slaughterhouse wastes (Gannoun *et al.,* 2009). According to fundamental basis of methanogenises, the most suspected methanogenic inhibitors associated to co-digestion in this case are ammonia and volatile fatty acids since these compounds are particularly abundant in young leachates (Forster-Carneiro *et al.,* 2007).

1.3. Examples of Mexican plants in operation

There are no biogas generation plants by digestion or co-digestion of leachate landfill in Mexico.

2. Research methods

A variety of data sources for conducting the resource assessment, including:
- Published data by national and international organizations (e.g., INEGI datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
- The main national-level government stakeholders in Mexico include the Ministry of Environment and Natural Resources (SEMARNAT).
- Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

Calculations were made for converting methane production to 1 atm and 273 K, based on the ideal gasses relation ($P_1V_1/T_1 = P_2V_2/T_2$). *In situ* conditions were not reported in the literature of reference, so an estimation was made (0.9 atm, 25°C) representative of the leachate landfill in Mexico.
The methane yield was expressed as N-m^3CH_4/ tonne VS converting the conventional units for a liquid effluent (N-m^3 CH_4/ kg COD) taking representative values of TS (100 g/L and VS/TS fraction of 0.50), presented in Table 2, and a COD representative value of 18 g/L. The energy conversion factor applied is 35.9 MJ/N-m^3 CH_4.

4. Results for each column of the database

Table 18. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	2	De Morais & Zamora (2005)
Feedstock handling (as solid or as liquid)	Liquid	Renou *et al.* (2008)
Recommended anaerobic technology if treated alone	Anaerobic sequencing batch, UASB reactors and Anaerobic filter	Renou *et al.* (2008)
Pretreatment required before anaerobic technology	Yes	Torretta *et al.* (2016)
Current use of the feedstock	Unused	Jones *et al.* (2006)
Relative use of the feedstock for other purposes	Low use	Torretta *et al.* (2016)
Expected cost	Low	Torretta *et al.* (2016)

Table 2. Feedstock quantitative information

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	m^3/Tonne MSW/year	91.2 – 54.7	Stuart & Klinck (1998)
Dry matter	TS (%)	1.1 – 39.0	Moujannı *et al*. (2019)
Volatile Solids	VS/TS	0.23 – 0.72	Lin et al. (2000)
Density	Tonne/m^3	1.00	So *et al*. (2014)
C/N ratio (Total N)	C/N kg N/m^3	11 – 30 (N: 0.8 – 3)	Hernández-Berriel *et al*. (2014); Lee *et al*. (2009), Mukherjee *et al*., 2015
Fats content	%	0.04 – 0.62	Espinosa *et al*. (2007); Méndez-Novelo *et al*. (2004)
Typical methane content in biogas	%	52 – 85	Lin *et al*. (2000); Renou *et al*. (2008)
Typical sulfur content in biogas	%	0.2 – 0.8	Silva *et al*. (2002); Thabet *et al*. (2009)
Methane potential (yield)	N-m^3 CH_4/tonne VS N-m^3 CH_4/tonne COD N-m^3 CH_4/m^3 GJ/tonne VS	181 – 239 (210) 502 – 664 (583) 9.1 – 12.0 (11.0) 6.5 – 8.6 (7.5)	Hernández-Berriel *et al*. (2014); Lee *et al*. (2009)

5. References

Christensen, T. H., Kjeldsen, P., Albrechtsen, H.-J., Heron, G., Nielson, P. H., Bjerg, P. L., and Holm, P. E., (1994). *Attenuation of Landfill Leachate Pollutants in Aquifers*. Critical Reviews in Environmental Science and Technology, 24(2), 119-202.

De Morais, J. L., & Zamora, P. P. (2005). Use of advanced oxidation processes to improve the biodegradability of mature landfill leachates. *Journal of Hazardous Materials*, 123(1-3), 181-186.

Espinosa, M. D. C., López, M., Pellón, A., Fernández, L. A., Hernández, C., & Bataller, M. (2007). Lixiviados de vertederos de residuos sólidos urbanos. *Monografía*. CENDA. Ciudad de La Habana.
Forster-Carneiro, T., Pérez, M., Romero, L.I., Sales, D. (2007). Dry-thermophilic anaerobic digestion of organic fraction of the municipal solid waste: Focusing on the inoculum sources. *Bioresource Technology*, 98, 3195-3203.
Gajski, G., Oreščanin, V., Garaj-Vrhovac, V. (2012). Chemical composition and genotoxicity assessment of sanitary landfill leachate from Rovinj, Croatia. *Ecotoxicology and Environmental Safety*, 78, 253-259.
Gannoun, H., Bouallagui, H., Okbiv, A., Sayadi, S., Hamdi, M. (2009). Mesophilic and thermophilic anaerobic digestion of biologically pretreated abattoir wastewaters in an upflow anaerobic filter. Journal of Hazardous Materlals, 170, 263-271.
Guven H, Akca MS, Iren E, Keles F, Ozturk I, Altinbas M. (2018). Co-digestion performance of organic fraction of municipal solid waste with leachate: Preliminary studies. *Waste Management*, 71, 775-784.
Hernández-Berriel, M.D.C., Mañón-Salas, M.D.C., Buenrostro-Delgado, O., Sánchez-Yáñez, J.M., & Márquez-Benavides, L. (2014). Landfill leachate recirculation. Part I: Solid waste degradation and biogas production. *Environmental Engineering & Management Journal*, 13(10).
Imen, S., Ismail, T., Sami, S., Fathi, A., Khaled, M., Ahmed, G., & Latifa, B. (2009). Characterization and anaerobic batch reactor treatment of Jebel Chakir Landfill leachate. Desalination, 246(1-3), 417-424.INEGI, (2013), Statistical Yearbook of the United States Mexican 2012, National Institute of Statistics and Geography, (in Spanish), México, D.F., México, On line at: http://www.inegi.org.mx/prod serv/contenidos/espanol/bvinegi/productos/integracion/pais/aeeum/2012/aeeum2012.pdf.
Jensen, D. L., Ledin, A., Christensen, T. H. (1999). Speciation of heavy metals in landfill-leachate polluted groundwater. *Water Research*, 33, 2642-2650
Jones, D.L.; Williamson, K.L.; Owen, A.G. (2006). Phytoremediation of landfill leachate. *Waste Management*, 26, 825–837.
Kheradmand S, Karimi-Jashni A, Sartaj M. (2010). Treatment of municipal landfill leachate using a combined anaerobic digester and activated sludge system. *Waste Management*, 30, 1025-1031.
Koshi, L., Paris, E., Ling, S., Jones, T.and Berube, K. (2007). Bioreactivity of leachate from municipal solid waste landfills-assessment of toxicity. *Science of the Total Environment*. 384, 171-181.
Kulikowska, D. & Klimiuk, E. (2008). The effect of landfill age on municipal leachate composition. *Bioresource Technology*, 99, 5891-5895.
Lee, D. H., Behera, S. K., Kim, J. W., & Park, H. S. (2009). Methane production potential of leachate generated from Korean food waste recycling facilities: a lab-scale study. *Waste Management,* 29(2), 876-882.
Li, W., Zhou, Q., & Hua, T. (2010). Removal of organic matter from landfill leachate by advanced oxidation processes: a review. *International Journal of Chemical Engineering*, 2010, 1-10.
Lin, C. Y., Chang, F. Y., & Chang, C. H. (2000). Co-digestion of leachate with septage using a UASB reactor. *Bioresource Technology*, 73(2), 175-178.
Méndez-Novelo, R., Castillo-Borges, E., Sauri-Riancho, M.R., Quintal-Franco, C., Giacoman-Vallejos, G., & Jiménez-Mejía, B. (2004). Tratamiento fisicoquímico de los lixiviados de un relleno sanitario. *Ingeniería*, 8(2).
Montesinos, A.M.H., Santoyo, A.B., Gómez, M.G., Murcia, M.D., & Marín, V. (2007). Tecnologías de tratamientos de lixiviados de vertedero: tratamientos avanzados. *Ingeniería química*, (454), 108-116.
Montusiewicz, A., & Lebiocka, M. (2011). Co-digestion of intermediate landfill leachate and sewage sludge as a method of leachate utilization. Bioresource Technology, 102(3), 2563-2571.
Moraes, P.B. & Bertazzoli, R. (2005). Electrodegradation of landfill leachate in a flow electrochemical reactor. *Chemosphere*, 58, 41-46.
Moujannı, A. E., Qarraey, I., Ouatmane, A. (2019). Anaerobic codigestion of urban solid waste fresh leachate and domestic wastewaters: Biogas production potential and kinetic.

Mukherjee, S., Mukhopadhyay, S., Hashim, M. A., & Sen Gupta, B. (2015). Contemporary environmental issues of landfill leachate: assessment and remedies. Critical reviews in environmental science and technology, 45(5), 472-590.

Orta, M.T., Cruz-Rivera, R., Rojas-Valencia, N., Monje-Ramírez, I., & Sánchez-Gómez, J. (2003). Serial water balance method for predicting leachate generation in landfills. Waste management & research, 21(2), 127-136.

Renou, S., Givaudan, J. G., Poulain, S., Dirassouyan, F., & Moulin, P. (2008). Landfill leachate treatment: review and opportunity. Journal of hazardous materials, 150(3), 468-493.

Robinson, H. D., (1996). A review of the composition of leachates from domestic wastes in landfill sites. Department of the Environment (DoE), Wastes Technical Division, U.K. Technical Aspects of Controlled Waste Management Series, CWM-072-95.

Silva, A.J., Varesche, M.B., Foresti, E., Zaiat, M. (2002). Sulfate removal from industrial wastewater using a packed-bed anaerobic reactor, Process. Biochem. 37, 927–935.

So, M. A. B. B., Oliveira, M. B., Araújo, A. D. S. F., & de Castro, J. A. (2014). Analyze of the Density and Viscosity of Landfill Leachate in Different Temperatures. American Journal of Environmental Engineering, 4(4), 71-74.

Stuart, M. E., & Klinck, B. A. (1998). A catalogue of leachate quality for selected landfills from newly industrialised countries. British Geological Survey Technical Report WC/98/49, Keyworth.

Thabet, O. B. D., Bouallagui, H., Cayol, J. L., Ollivier, B., Fardeau, M. L., & Hamdi, M. (2009). Anaerobic degradation of landfill leachate using an upflow anaerobic fixed-bed reactor with microbial sulfate reduction. Journal of Hazardous Materials, 167(1-3), 1133-1140.

Torretta, V., Ferronato, N., Katsoyiannis, I. A., Tolkou, A. K., & Airoldi, M. (2016). Novel and conventional technologies for landfill leachates treatment: A review. Sustainability, 9(1), 9.

Yoon Y, Lee S, Kim KH, Jeon T, Shin S. (2018). Study of anaerobic co-digestion on wastewater treatment sludge and food waste leachate using BMP test. J. Mater. Cycles Waste Manage. 20, 283-292.

Wei, Y., Ji, M., Li, R., Qin, F. (2012). Organic and nitrogen removal from landfill leachate in aerobic granular sludge sequencing batch reactors. Waste Manag. 32, 448–455.

URBAN WASTES

WWTP Sludge

Feedstock Database for biogas in Mexico 2018

1. Background

1.1. Selection criteria for the feedstock

Generation potential

According to the inventory made by the National Water Commission (CONAGUA), in Mexico there are 2,477 plants in operation with an installed capacity of 212.8 m^3/s. These plants process a flow of 120.9 m^3/s equivalent to 57.0% of the total water collected in the formal municipal sewerage systems (CONAGUA, 2017). The most widely used method in the country for wastewater treatment is stabilization ponds, applied in 776 plants, equivalent to 31% of the total. It is followed by activated sludge applied in 732 plants, 30% of the total. In third place is the upflow anaerobic sludge blanket reactor, known as UASB, which is used in 236 plants, equivalent to 10% of the total (CONAGUA, 2017; Noyola *et al.,* 2012). Wastewater produces excess biomass that should be removed from the process, constituting the so-called waste sludge. Depending on the process arrangement, this waste may represent between 40% (primary and secondary sludge) to 15% (secondary sludge, extended aeration) of the incoming biological oxygen demand (BOD). In the case of conventional activated sludge treatment (primary and secondary sludge) as well as in some other aerobic arrangements, the waste sludge must be treated before final disposal. In 2011, 6 700 million cubic meters wastewater were generated, and it is expected that in 20 years the volume of treated water will be 9 200 million cubic meters. This implies that the generation of residual sludge increases from 640 000 tonnes (dry weight) for 2011 to 880 000 tonnes (dry weight) for 2030 (CONAGUA, 2011) as 0.08 to 0.1 kg TS is produced per cubic meter of treated sewage.

Current use

The amount of WWTP sludge will increase and challenge the need for safe treatment and disposal. But, at the present time, proper sludge treatment and disposal are not current practices, and most of it is discharged into sewers or simply abandoned in soil, threatening health and the environment. In few cases, sludge is sent to landfills as solid waste and in others it is applied to the soil as a biosolid amendment, but there is no reliable data on this (LeBlanc *et al.,* 2009). However, in recent years the anaerobic digestion of WWTP sludge produced during WWT has been regarded an essential requirement for large-scale treatment plants, offering also the benefit that the energy generated can reduce the electricity consumption of the plant (Rios & Kaltschmitt, 2016). In Mexico, around 27 municipal treatment plants have anaerobic sludge digesters, and around 6 are recovering energy from the produced biogas (López-Hernández *et al*., 2017)

Cost of the residue

At present, in Mexico about 51% of WWTP sludge is stabilized by anaerobic digestion; however, the biogas generated during this process is not recovered, since 76% of the residual sludge, regardless of its treatment, is deposited in landfills (Jiménez & Wang, 2006). Biogas from sludge only contribute with 0.05% of the annual electricity generation (Rios & Kaltschmitt, 2016). Sludge is a problem due to the additional cost of treatment, the volumes and quantities that are generated, as well as its composition, since they are constituted mainly by organic matter and contaminants. Also, problems arise due to the gaseous compounds produced a result of their decomposition, bad odors, and the bacteria and other pathogenic microorganisms associated to this waste. National regulations indicate that waste sludge must be treated to eliminate, reduce or transform these elements and not represent a risk to health or the environment (Ghazy *et al.,* 2009).

Biogas potential

The use of biogas produced by the anaerobic digestion of WWTP sludge has economic benefits because there is a reduction in the handling and disposing of biosolids costs and a reduction in the cost of electric energy when using biogas as an energy source, representing an annual savings in electricity expenses between 40-60%. Secondary sludge's are composed predominantly of biomass; that is, microbial cells that are not readily biodegradable (Boehler & Siegrist, 2006).

1.2. Expected characteristics of the feedstock

Production process

Sludge is a water slurry byproduct of the wastewater treatment process. It contains suspended solid materials removed during treatment. Contaminants associated with sludge include natural organics and nutrients, pathogens, metals, and toxic organic compounds. Some of these contaminants present recognized health risks, while others, if controlled and monitored closely, can be beneficial. Wastewater influent volume, its characteristics, and the level of treatment all determine the nature and quantity of sludge. The higher the level of treatment, the more sludge produced (Demirbas *et al.,* 2017). The sludge contains mainly proteins, sugars, detergents, phenols, lipids. Inorganic constituents of sewage sludge are mainly nitrogen compounds (15 – 30 g/kg) and phosphorus (2.2 – 3.1 g/kg) (Tao *et al*., 2012). Both nitrogen and phosphorus in the sewage sludge have a high fertilizer value (Demirbas *et al.,* 2017). The inorganic parts of the sewage sludge are mainly the precipitated or adsorbed compounds of iron, phosphorus, calcium, aluminum, and sulfur, including traces of heavy metals (such as zinc, chromium, mercury, lead, nickel, cadmium, and copper) (Li *et al*., 2012; Tao *et al*., 2012).

Feedstock conditioning and pretreatment (if applicable)

Sludge volume should be reduced by water removal (dewatering). This may be accomplished with sludge thickener (gravity or flotation), band filters and centrifuges. These operations may be improved by chemical (floculant) additions (LeBlanc *et al.,* 2009). Applying a pre-treatment prior to anaerobic digestion is one option to increase sludge hydrolysis and degradability. A number of different pre-treatment processes have been proposed including biological, chemical, enzymatic, thermal, and mechanical (Appels *et al*., 2008). The waste secondary sludge pre-treatment offers the following advantages: (a) the bioavailable organic matter can be transformed into biogas (60 to 70% by methane volume), (b) the solids content is reduced, and (c) reduces odor problems associated with residual putrescible matter (Shehu *et al*., 2012).

Co-digestion potential

The anaerobic co-digestion of WWTP sludge with organic fraction of municipal solid waste seems to be attractive (Hamzawi *et al*., 1998) as well as for co-digestion with grease trap sludge (Davidsson *et al*., 2008) and meat-processing by-products (Luste & Luostarinen, 2010). The benefits of the co-digestion include: dilution of potential toxic compounds, improved balance of nutrients, synergistic effects of microorganisms, increased load of biodegradable organic matter and better biogas yield. Additional advantages include hygienic stabilization and increased digestion rate, when the process occurs under thermophilic conditions (Sosnowski *et al*., 2003).

1.3. Examples of Mexican plants in operation

In Mexico, there are successful experiences of WWTP sludge digestion and biogas use, mainly for cogenerate energy. Some of these plants are: WWTP Atotonilco, WWTP Agua Prieta, WWTP El Ahogado and WWTP San

Pedro Mártir I. These plants have anaerobic digestion of WWTP sludge and which can reach up to 69% of the electrical energy required, once WWTP operates at 100% capacity.

2. Research methods

A variety of data sources for conducting the resource assessment, including:

- Published data by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production datasets), specific subsector information from business and technical journals, and other documents, reports and statistics.
- The main national-level government stakeholders in Mexico include the Ministry of Environment and Natural Resources (SEMARNAT) and National Water Commission (CONAGUA).
- Literature was reviewed searching in specialized databases, scientific papers and technical publications.

3. Memory of calculations

The conversion of N-m³ CH_4/kg VS to N-m³ CH_4/m³ was done using the dry and volatile content of fresh biomass, as reported in Table 2 (an average of 4% and 70%, respectively). The energy conversion factor applied is 35.9 MJ/N-m³ CH_4.

4. Results for each column of the database

Table 19. Feedstock qualitative information

Qualitative information	Description / Value	Source
Estimated Biodegradation level	2	Reyes *et al.* (2015)
Feedstock handling (as solid or as liquid)	Liquid	Demirbas *et al.* (2017)
Recommended anaerobic technology if treated alone	Mixed and heated digesters	López-Hernández *et al.* (2017)
Pretreatment required before anaerobic technology (if applicable)	Yes	Appels *et al.* (2008)
Current use of the feedstock	Sent to landfills or applied to the soil	LeBlanc *et al.* (2009)
Relative use of the feedstock for other purposes (low use→ high availability / high use→ low availability)	Low	Moreno *et al.* (2002)
Expected cost (high or low)	Low	Moreno *et al.* (2002)

Table 2. Feedstock quantitative information for primary (PS) and secondary sludge (SS)

Quantitative information	Units	Description / Value	Source
Yearly feedstock generation per population or area unit	Tonnes TS/year	640,000	Rojas & Mendoza (2013)
Dry matter	TS (%)	5 – 9 (PS) 0.8 – 1.2 (SS)	Limón, J. (2013)
Volatile Solids fraction	VS/TS	0.60 – 0. 80 (PS) 0.59 – 0.80 (SS)	Limón, J. (2013)
Density	Tonne/m^3	1.02 (PS) 1.05 (SS)	Limón, J. (2013)
C/N ratio **(Total N)**	C/N kg/tonne TS	20 – 30 (N: 20)	Arthur & Brew-Hammond (2010); (Tao *et al.*, 2012)
Fats content	%	1.0 – 2.8	Rojas & Mendoza (2013)
Typical methane content in biogas	%	60 – 65	Rojas & Mendoza (2013)
Typical sulfur content in biogas	%	0 – 1.0	Demirbas *et al.* (2017)
Methane potential (yield)	N-m^3 CH_4/tonne VS N-m^3 CH_4/m^3 GJ/tonne VS	230 – 430 (400) 6.4 - 12.0 (11.2) 8.3 – 15.4 (14.4)	Reyes *et al.* (2015)

Note: PS (primary sludge), SS (secondary sludge)

5. References

Appels, L., Baeyens, J., Degrève, J., & Dewil, R. (2008). Principles and potential of the anaerobic digestion of waste-activated sludge. *Progress in energy and combustion science*, 34(6), 755-781.

Arthur, R., & Brew-Hammond, A. (2010). Potential biogas production from sewage sludge: A case study of the sewage treatment plant at Kwame Nkrumah University of science and technology, Ghana. *International Journal of Energy & Environment*, 6, 1009-1015.

Boehler, M., & Siegrist, H. (2006). Potential of activated sludge disintegration. *Water Science and technology*, 53(12), 207-216.

COMISIÓN NACIONAL DEL AGUA (CONAGUA) (2011). Agenda del agua 2030, Coyoacán, CDMX, México. http://gia.imta.mx/geoportal/docs/Agenda_Agua_2030.pdf

COMISIÓN NACIONAL DEL AGUA (CONAGUA) (2017). Estadísticas del agua en México 2016, Coyoacán, CDMX, México. http://www.conagua.gob.mx/CONAGUA07/Publicaciones/Publicaciones/EAM.pdf.

Davidsson, Å., Lövstedt, C., la Cour Jansen, J., Gruvberger, C., & Aspegren, H. (2008). Co-digestion of grease trap sludge and sewage sludge. *Waste Management*, 28(6), 986-992.

Demirbas, A., Edris, G., & Alalayah, W. M. (2017). Sludge production from municipal wastewater treatment in sewage treatment plant. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 39(10), 999-1006.

Ghazy, M., Dockhorn, T., & Dichtl, N. (2009). Sewage sludge management in Egypt: Current status and perspectives towards a sustainable agricultural use. *World academy of science, engineering and technology*, 57, 492-500.

Hamzawi, N., Hamzawi, K.J., Kennedy, D.D., Mc Lean. (1998). Technical feasibility of anaerobic co-digestion of sewage sludge and municipal solid waste. *Environmental Technology*, 19, 993-1003.

Jiménez, B. & Wang, L. (2006). Sludge Treatment and Magament. En: Municipal Waste Water Management in Developing Countries. *Principles and Engineering*. London, UK: IWA Publishing, 237-292.

LeBlanc, R. J., Matthews, P., & Richard, R. P. (Eds.). (2009). Global atlas of excreta, wastewater sludge, and biosolids management: moving forward the sustainable and welcome uses of a global resource. *Un-habitat.*

Li, L., Xu, Z. R., Zhang, C., Bao, J., and Dai, X. (2012). Quantitative evaluation of heavy metals in solid residues from sub- and super-critical water gasification of sewage sludge. *Bioresource Technology*, 121:169–175.

Limón, J. (2013). Los lodos de las plantas de tratamiento de aguas residuales ¿Problema o recurso? Guadalajara, Jalisco.

Luste, S. & Luostarinen, S. (2010). Anaerobic co-digestion of meat-processing by-products and sewage sludge—effect of hygienization and organic loading rate. *Bioresource Technology*. 101(8), 2657-2664.

López-Hernández J.E., Ramírez-Higareda B.L., Gomes-Cabral C.B., Morgan-Sagastume J.M. (2017). Guía Técnica para el Manejo y Aprovechamiento de Biogás en Plantas de Tratamiento de Aguas Residuales. GIZ, SENER, SEMARNAT, CONAGUA, ANEAS, México, 236 pp. www.gob.mx/sener/documentos/guia-tecnica-para-el-manejo-y-aprovechamiento-de-biogas-en-plantas-de-tratamiento-de-aguas-residuales

Moreno, J., Colín, A., Balcázar, M., & Tavera, L. (2002). Feasibility analysis of a sewage sludge treatment by an irradiation plant in Mexico. *Revista internacional de contaminación ambiental*, 18(4).

Noyola, A., Padilla-Rivera, A., Morgan-Sagastume, J. M., Güereca, L. P., & Hernández-Padilla, F. (2012). Typology of municipal wastewater treatment technologies in Latin America. *Clean–Soil, Air, Water*, 40(9), 926-932.

Reyes, I.P., Díaz, J.P., & Horváth, I.S. (2015). Anaerobic Biodegradation of Solid Substrates from Agroindustrial Activities—Slaughterhouse Wastes and Agrowastes. *In Biodegradation and Bioremediation of Polluted Systems-New Advances and Technologies*. InTech.

Rios, M., & Kaltschmitt, M. (2016). Electricity generation potential from biogas produced from organic waste in Mexico. *Renewable and Sustainable Energy Reviews*, 54, 384-395.

Rojas, R. & Mendoza, L.G. (2013). Utilización de biosólidos para la recuperación energética en México. Producción+ Limpia, 7(2).

Shehu, M.S., Abdul Manan, Z., Wan Alwi, S.R. (2012). Optimization of thermo-alkaline disintegration of sewage sludge for enhanced biogas yield. *Bioresource Technology*, 114, 69–74.

Sosnowski, P., Wieczorek, A., & Ledakowicz, S. (2003). Anaerobic co-digestion of sewage sludge and organic fraction of municipal solid wastes. *Advances in Environmental Research*, 7(3), 609-616.

Tao J., Wu S., Sun L., Tan X., Yu S., Zhang Z. (2012) Composition of waste sludge from municipal wastewater treatment plant, *Procedia Environmental Sciences*, 12, 964 – 971

FEEDSTOCK DATABASE QUALITATIVE INFORMATION

Feedstock Database Qualitative Information (Part 1)

CLASIFICATION	Agricultural Wastes			Livestock Wastes			
Waste / QUALITATIVE INFORMATION	Nopal Residues	Water Hyacinth	Cofffee pulp	Cow manure	Dairy slurry	Poultry manure	Pig manure
Estimated Biodegradation level	4	3	2	3	2	1 (pollinaza) 3 (gallinaza)	3
Feedstock handling (as solid or as liquid)	Slurry (or juice and mesh)	Solid	Solid	Solid	Liquid (slurry)	Solid/slurry	Semisolid, slurry
Recommended anaerobic technology if treated alone	Completely Stirred Tank Reactor	Anaerobic filters and CSTR reactors	Dry digester	Covered anaerobic ponds	UASB reactors and ponds	Wet digestion/dry digestion	Covered ponds. Pre-treated manure: CSTR and UASB reactors,
Pretreatment required before anaerobic technology (if applicable)	Grinding and sieving	Grinding	Coarse grinding	Yes	Yes	Yes	Solid separation for UASB reactor. (CSTR at lower extent)
Current use of the feedstock	Less than 1% is used to generate biogas	Without use	Marginal (biogas, compost, animal feed)	Soil amendment	Crop irrigation, soil disposal	*Gallinaza* (soil amendment). *Pollinaza*:forage amendment	Applied on cropland
Relative use of the feedstock for other purposes	Low	Low	Low	Medium	Low	High	Low
Expected cost	Low	Low	Low	$300 - 1,000 MXN/tonne	Low	High	Low

Feedstock Database Qualitative Information (Part 2)

CLASIFICATION	Industrial Wastes					
QUALITATIVE INFORMATION / Waste	Alcohol Vinasse (sugarcane)	Cheese whey	Fishery waste	Nejayote (corn nixtamalization wastewater)	Slaughterhouse (green stream)	Slaughterhouse (red stream)
Estimated Biodegradation level	3	3	4	5	2	3
Feedstock handling (as solid or as liquid)	Liquid	Liquid	Semisolid	liquid	Slurry/Semisolid	Liquid
Recommended anaerobic technology if treated alone	UASB or EGSB	Downflow fixed-film, and UASB	Leach bed reactor followed by UASB, anaerobic filter	Wet digester (UASB)	Sieve and digester (UASB). Grinding and CSTR	UASB with pretreatment. CSTR
Pretreatment required before anaerobic technology (if applicable)	Cooling, pH adjustment	pH control	No		Sieving or grinding	Sieving, grease trap for UASB
Current use of the feedstock	Fertirrigation	Dairy and nutritional supplements	Food and oil production	No current	Marginal (agricultural compost, animal feed)	Marginal (compost, animal feed, biogas)
Relative use of the feedstock for other purposes	Low	Low	High	Low	Low	Low
Expected cost	Low	Low	High	Low	Low	Low

Feedstock Database Qualitative Information (Part 3)

CLASIFICATION	Commercial Wastes				Urban Wastes		
Waste / QUALITATIVE INFORMATION	Spent earths from edible oil industry	Fats, Oils and Grease (FOG)	Food waste (restaurant)	Market wastes	Organic Fraction of Municipal Solid Waste	Landfill Leachates	WWTP Sludge
E.Biodegradation level	3	4	5	4	5	2	2
Feedstock handling (as solid or liquid)	Solid	Liquid/Semisolid	Solid/Semisolid	Solid	Solid/Semisolid	Liquid	Liquid
Recommended anaerobic technology if treated alone	Completely Stirred Tank Reactor (co-digestion)	Wet digester (CSTR) in co-digestion	Wet digester (CSTR or batch process)	Wet digester	Wet digester (Complete mixed)	Anaerobic sequencing batch, UASB reactors and Anaerobic filter	Mixed and heated digesters
Pretreatment required before anaerobic technology (if applicable)	None	None (should be co-digested)	Grinding or pulping	Grinding, homogenization, and water addition (up to 10% TS).	Milling / pulping	Yes	Yes
Current use of the feedstock	Waste	Marginal (animal feed, biogas, soap production, typically landfill)	Marginal	Donation and landfilling	Marginal	Unused	Sent to landfills or applied to the soil
Relative use of the feedstock for other purposes	Low	Low	Low (compost, animal feed, biogas)	Low.	Low	Low	Low
Expected cost	Low	Low	Low	Low	Low	Low	Low

FEEDSTOCK DATABASE QUANTITATIVE INFORMATION

Feedstock Database Quantitative Information (Part 1)

QUANTITATIVE INFORMATION	CLASIFICATION / Waste / Units	Agricultural Wastes: Nopal Mash	Agricultural Wastes: Water Hyacinth	Agricultural Wastes: Cofffee pulp	Livestock Wastes: Cow manure	Livestock Wastes: Dairy slurry
Yearly feedstock generation	Tonnes/unit/year	30 Tonnes/ha/year	300 (wet basis) 36 (dry basis)	Not Found	a. 1.46 b. 2.92 c. 3.65 d. 5.475 Tonnes/cow/year *(Note 1)*	34 Tonnes/cow/year
Dry matter	TS (%)	5.7-6.5	18	22.2 – 23.3	4-15	8.0-12.0
Volatile Solids fraction	VS/TS	0.91	0.86	0.92 – 0.97	0.74 – 0.80	0.85
Density	Tonne/m^3	1.02 kg/m^3	1	270 - 300 kg/m^3	0.9 – 1.05	0.97
C/N relation (N total)	C/N kg/tonne TS	48 (N:22)	25 (N: 15)	25-31 (N: 17.6)	6.2 – 10.6 (N: 10.1)	6-20 (N:90)
Fats content	%	<1	4.1	2 – 2.5	Not siginificant	3.23
CH4 content in biogas	%	60-65	50 – 75	48 - 60	50 - 58	55
H2S content in biogas	%	0.01	< 0.1	< 0.01	0.14 -0.25	0.4
Methane potential (yield) recommended	N-m^3CH_4/tonne VS or tonne COD (*)	410-517 (460)	340	350 – 670 (450)	210 – 330 (270)	124 – 216 (136) 165 – 288 (181)*
	m^3 CH_4/tonne biomass	22.4-28.2 (25.1)	52.6	76 - 146 (100)	16.2 – 25.4 (20.8)	10.5 – 18.4 (15.4)
	GJ/tonne VS	14.7-18.6 (16.5)	1.9	12.6 – 24.1 (16.2)	7.5 - 11.8 (9.7)	4.5 – 7.8 (4.9)

Notes:
1) Animal age a. < 1 year; b. 1 to 2 years; c. > 2 years to 3 years; d. > 3 years

Feedstock Database Quantitative Information (Part 2)

QUANTITATIVE INFORMATION	CLASIFICATION / Waste / Units	Livestock Wastes: Poultry manure	Livestock Wastes: Pig Manure	Industrial Wastes: Alcohol Vinasse (sugarcane)	Industrial Wastes: Cheese whey	Industrial Wastes: Fishery waste
Yearly feedstock generation	Tonnes/unit/year	a) 0.0075 b) 0.0062-0.009	1.64	10 – 15 Tonnes/unit/year L/L ethanol	4.0-11.3 Tonnes CW/Tonnes Cheese	0.6 Tonne fishery waste/Tonne fish
Dry matter	TS (%)	a) 80.6 b) 29.9	10-20	7.8 (2.1-14.0)	5.9	38.5
Volatile Solids fraction	VS/TS	a) 0.607 b) 0.653	0.64 - 0.80	0.75	0.7	0.94
Density	Tonne/m³	0.35	1.13	1.0 – 1.1	1.04	1.05
C/N relation (N total)	C/N kg/tonne TS	9.5 (N: 16)	10 (N: 70)	10 – 25 (N: 0.6)	8.7 (N:2.2)	4.1 (N: 115)
Fats content	%	Not significant	0	< 0.01	0.85	4.0 – 8.0
CH4 content in biogas	%	65 – 70	47.0 – 68.0	65 (58-68)	58	50 – 75
H2S content in biogas	%	0.35	1	2.5	0.06	< 1.0
Methane potential (yield) recommended	N-m³CH₄/tonne VS or ton COD (*)	a) 159 b) 170-181 (175)	244 – 343 (300)	200 200*	109-383 (246) 280-340 (310)*	280 – 390 (335)
	m³ CH₄/tonne biomass	a) 77.6 b) 33.2 – 35.3 (35.3)	25.6 – 36.0 (31.5)	14	4.5-15.8 (10.2)	101.3 – 147.1 (121.2)
	GJ/tonne VS	a) 5.8 b) 6.1 – 6.5 (6.3)	8.8 – 12.3 (10.8)	7.18	3.9 – 13.7 (8.7)	10.0 – 14.0 (12.0)

Feedstock Database Quantitative Information (Part 3)

	CLASIFICATION	Industrial Wastes		
QUANTITATIVE INFORMATION	Units / Waste	Nejayote (corn nixtamalization wastewater)	Slaughterhouse (green stream)	Slaughterhouse (Red stream)
Yearly feedstock generation	Tonnes/unit/year	3 – 5 m^3/tonne maize 14.4 Millons m^3/year	7-7.5 M tonne tonne/year 7 (swine) kg/animal *(Note 2)* 17 (cow) kg/animal *(Note 2)*	3- 3.5 M tonne tonne/year 8 (swine) kg/animal 23 (cow) kg/animal
Dry matter	TS (%)	2.2 – 2.3	10.0- 50.7	1% (TSS: 270-6400 mg/L) (COD: 29 – 131 g/L)
Volatile Solids fraction	VS/TS	0.8	0.87 – 0.95	0.45 - 0.66
Density	Tonne/m^3	1.00 – 1.05	1.2	1.2 *(Note 5)*
C/N relation (N total)	C/N kg/tonne TS	13.9 (N: 0.3)	6.2-35.9 (N: 60) *(Note 3)*	5.3 - 6.2 (N: 0.25)
Fats content	%	0.008 ± 0.002	8.5 - 28.9	5 -
CH4 content in biogas	%	58-79	55-74%	50 - 60
H2S content in biogas	%	<0.01	<0.5%	< 0.1
Methane potential (yield) recommended	N-m^3CH_4/tonne VS or ton COD (*)	370 260*	250 – 1076 *(Note 4)*	300 – 900 *(Note 6)* 0.15 – 0.45* *(Note 6)*
	m^3 CH_4/tonne biomass	6.5	45- 193 *(Note 4)*	12 – 36 *(Note 6)*
	GJ/tonne VS	13.3	9.0 - 38.6 *(Note 4)*	10.8- 32.3 *(Note 6)*

Notes:
2) Taking into account an average of the animal weight of 100 kg for swine and 250 Kg for cow.
3) A C/N ratio for fat (371) was obtained by Pitk et al. (2012), but not was considered for the reported range.
4) Highest BMP can be obtained from digestive tract content (1076 N-m^3CH4/ tonne VS), Intestine residue (848 N-m^3CH4/ tonne VS) and blood (799 N-m^3CH4/ tonne VS) with a substrate/Inoculum ratio of 0.10. In this case (high BMP) the data is also related to the high mass of fat matter that is included in this value. The corresponding yields are also presented.
5) Taking into account an average of the animal weight of 100 kg for swine and 250 kg for cow.
6) Higher methane potential is taking into account the fat content in the stream

Feedstock Database Quantitative Information (Part 4)

QUANTITATIVE INFORMATION	CLASIFICATION / Waste / Units	Industrial Wastes: Spent earths (vegetable oil industry)	Commercial Wastes: Fats, oils and grease (FOG)	Commercial Wastes: Food waste	Commercial Wastes: Market wastes
Yearly feedstock generation	Tonnes/unit/year	0.01 – 0.015 Tonne spent earth / ton oil	0.003 Tonnes/inhabitant/year	0.17 Tonnes/inhabitant/year	4.06 million Tonneyear
Dry matter	TS (%)	84.16 (alone) 17.4 (mix)	1.3 -22	18.1 – 30.9	18 – 31
Volatile Solids fraction	VS/TS	0.355 0.973	0.86 - 0.98	0.85 – 0.94	0.85 - 0.95
Density	Tonne/m³	1.8	0.907	514 - 1090	0.51 -0.75
C/N relation (N total)	C/N kg/tonne TS	256 (N: 0.8)	22.1-39 (N: 33)	11 – 24 (N: 15)	20 - 36.4 (N: 110)
Fats content	%	13.2 - 40	75.4 - 99.5	4-23	17.5
CH4 content in biogas	%	65 -67	50 - 69	48 - 65	55-65
H2S content in biogas	%	<0.1	< 0.1	< 0.050	0-1
Methane yield recommended	N-m³CH₄/tonne VS or COD	310	400-1100 (600)	310 – 530 (400)	367
	m³ CH₄/tonne biomass	52.5	36 – 100 (54)	69.8 – 119.2 (90)	82.5
	GJ/tonne VS	11.1	14.4 – 39.5 (21.5)	11.1- 19.0 (14.4)	13.2

Feedstock Database Quantitative Information (Part 5)

QUANTITATIVE INFORMATION	CLASIFICATION / Waste / Units	Urban Wastes: Organic Fraction of Municipal Solid Waste	Urban Wastes: Landfill Leachates	Urban Wastes: WWTP Sludge
Yearly feedstock generation	Tonnes/unit/year	0.33 Tonnes/inhabitant/year	54.7 - 91.2 m³/Tonne MSW/year	0.1 Tonnes/m³/year
Dry matter	TS (%)	16.0 – 46.3	1.1 – 39.0	5 – 9 (PS) 0.8 – 1.2 (SS)
Volatile Solids fraction	VS/TS	0.61 – 0.94	0.23 – 0.72	0.60 – 0. 80 (PS) 0.59 – 0.80 (SS)
Density	Tonne/m³	328 - 1052	1	1.02 (PS) 1.05 (SS)
C/N relation (N total)	C/N kg/tonne TS	11 - 27 (N: 5.4)	11 – 30 (N: 0.8 – 3)	20 – 30 (N: 20)
Fats content	%	6.1 – 35.0	0.04 – 0.62	1.0 – 2.8
CH4 content in biogas	%	58 - 69	52 – 85	60 – 65
H2S content in biogas	%	< 0.1	0.2 – 0.8	0 – 1
Methane potential (yield) recommended	N-m³CH₄/tonne VS or tonne COD(*)	255 – 579 (400)	181 – 239 (210) 502 – 664 (583)*	230 – 430 (400)
	m³ CH₄/tonne biomass	57.4 – 130.3 (90)	9.1 – 12.0 (11.0)	6.4 - 12.0 (11.2)
	GJ/tonne VS	9.15 – 20.8 (14.4)	6.5 – 8.6 (7.5)	8.3 – 15.4 (14.4)