Urban Climate Change Mitigation in Mexico City: Innovative Solutions in Municipal Wastewater Treatment Plants

K. Peña Muñoz

Abstract Mexico City's Metropolitan Area (ZMCM) is the third largest mega city in the world (INEGI 2010). Mexico City is also a signatory of the Global Cities Covenant on Climate and the Carbon Cities Climate Registry, suggesting that Mexico City and its ZMCM must consider national mitigation and adaptation strategies (SMADF 2008). A good opportunity is located in Wastewater Treatment Plants (WWTPs). Until 2009, only 9 % of the Wastewater produced at ZMCM was treated at (WWTPs) while the rest was discharged into surface waters (SEMARNAT 2009). A WWTP is an essential public service that simultaneously consumes a large amount of energy and produces a significant amount of by-product such as sewage sludge. In ZMCM, sludge is disposed in landfill, contributing to the green house gas emission of the area. However, there is an excellent conservation potential in WWTP which includes anaerobic digestion of sludge for biogas production as a renewable source of green energy. Additional optimization of different processes and services at WWTPs could be reached by implementing a pre-treatment of sludge and a two-stage anaerobic digestion, which could increase the total yield of bio-methane-hydrogen. Moreover, hydrogen has the highest energy content per unit weight of any known fuel (Das 2009). This is particularly interesting, as there are additional socio-economic benefits of using bio-hydrogen as a source of green energy. This chapter explores the benefits of implementing pretreatments and anaerobic digestion of sewage sludge in WWTP in ZMCM and highlights the environmental framework for wastewater treatment and green energy production.

Keywords Anaerobic digestion · Climate change · Green energy · Mega-city · WWTP

K. Peña Muñoz (✉)
Waste Water Technology (AWT), Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA), University of Stuttgart, Stuttgart, Germany
e-mail: kristy.pena.munoz@googlemail.com

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1 Introduction

Mexico City has 8,851,080 habitants, but Mexico City's Metropolitan Area (ZMCM) has a population of over 20 million, making it the third largest Megacity in the world, just behind Tokyo and Seoul (INEGI 2010). This Megacity includes the 16 boroughs (*delegaciones*) of Mexico City, 40 municipalities of the State of Mexico and one conurbation municipality of the State of Hidalgo (INEGI 2010). Moreover, the ZMCM is located in a geographical sensitive area where earthquakes, floods and thermal inversion are significant natural conditions that increase the vulnerability of its population. This Megacity provides shelter to approximately 22 % of the Mexican population (INEGI 2010). Therefore, it is important that the scientific community, investors, relevant stakeholders, urban planners and policy makers are brought together in a way that the interaction between them improves the understanding of the environmental problems that this megacity faces.

Indeed, Mexico has been favoured with the North American Free Trade Agreement (NAFTA) through several USAID's environmental programs. These programs focus on improving the management of natural resources for a better understanding and implementation of key environmental commitments towards Climate Change mitigation.

Mexico City itself is a signatory of the Global Cities Covenant on Climate (Mexico City Pact), a voluntary initiative of mayors and local authority representatives that aims to advance climate actions. By signing the Pact, signatories commit to 10 action points, including the reduction of emissions, adaptation to the impacts of climate change and fostering city-to-city cooperation (WMCCC 2010). In response to these initiatives, in 2007, the Green Plan was launched in order to address several environmental challenges and to ensure that Mexico City's government promotes environmental policies. It has seven pillars: soil conservation, housing and public space, water supply, mobility, air pollution, climate change and energy, and waste management (SMADF 2008).

Further, the Environmental Ministry of Mexico City has established the Climate Change Effect Action Plan (2008–2012), which considers five main topics: Transport, Water & Waste, Adaptation-Communication, Energy and Environmental Education (SMADF 2008). Parallel to these actions, the government of the State of Mexico has given high priority to municipalities that belong to the ZMCM. To this affect, the Environmental Ministry of the State of Mexico has implemented the Climate Change Program, Air Quality Control Program and Waste Management (SMADF 2008).

In sum, these are only a few examples reflecting that any type of action becomes significantly more effective when the federal, state government, municipalities and different sectors participate in a transversal policy strategy.

The ZMCM is also ready to face the "green energy revolution." A good opportunity has been pinpointed at Municipal Wastewater Treatment Plants (WWTPs) located in ZMCM. In general, a WWTP is an essential public service that consumes a large amount of energy. It is mandatory that each Municipality in Mexico has several WWTPs to guarantee the protection of surface water. Nevertheless, the cost involved in the operation and maintenance of any WWTP is very high. The main operation costs include: (a) the "electricity" for the operation of the site; and (b) the "disposal of by-products" (e.g. Sludge). This situation directly impacts the annual budget of many Municipalities, causing the stoppage of the WWTP operations, with a difficult decision of when to restart it. However, WWTPs offer an excellent conservation potential through the use of biogas in situ for generating heat and electricity. This electricity could potentially be introduced into existing operations or into the electrical network. On one hand, each cubic meter of biogas contains a calorific value equivalent to 5–7.5 kWh, if the biogas produced has a composition of methane between 50 and 75 % (BELV 2010). Biogas refers exclusively to the use of methane as sole source of fuel. Additionally, methane is related to Green House Gases (GHG) emission when it is incinerated rather than used in cogeneration systems. On the other hand, bio-hydrogen has been gaining more importance, since it has the highest energy content per unit weight of any known fuel, which corresponds to 120.21 MJ/kg; while the energy content of methane is only 50.2 MJ/kg (Das 2009). This is of particular interest since there are additional technical, socio-economic and environmental benefits to using bio-hydrogen. For example, it is easily transported for domestic/industrial consumption through conventional means, it is safer to handle than domestic natural gas, it is universally accepted as an environmentally safe and renewable energy resource, it is an ideal substitute for fossil fuels, and it does not contribute to the GHG emissions (Das 2009).

Some up-to-date applications of hydrogen are in the use of hydrogen fuel cells in combination with internal combustion engines, or in stationary back-up systems when operated with reformers for on-board conversion of other fuels. These can save energy and reduce air pollution, especially in congested urban traffic (European Commission 2003). In addition, fuel cells provide efficient and clean electricity generation from a range of fuels. Some benefits of hydrogen in fuel-cell systems are very low to zero carbon emissions and no emissions of harmful ambient air substances like nitrogen oxides, sulphur dioxide or carbon monoxide (European Commission 2003).

It is a reality that alternative fuels have to take over the market and new technologies need to be developed. However, developing a standard for the sustainability of bio-fuels has become a hindering factor for world free trade (WEC 2010). In addition, an incorrect or incomplete technology transfer could impact the social acceptance of technology and process that could contribute to the reduction of climate change impacts such as the Clean Development Mechanism. Therefore, any technology transfer must consider the socio-economic and political background of the city and the country.

This chapter gives the status quo in Mexico City and its ZMCM, including:

1. An overview of the environmental framework in Mexico;

2. Innovative ideas for the production and use of biogas and bio-hydrogen as a green energy source in situ in WWTPs;
3. Suggestions on how to improve the interaction between the scientific community (scientists researching on biogas/bio-hydrogen), the urban planners, policy makers and other relevant stakeholders for integrating hydrogen and methane in the national renewable energy market.

2 Mexico: Environmental Status Quo

Environmental protection is playing a very important role in the Mexican economy of the 21st Century. The beginning of this trend could already be observed in the early 1970s. At that time, the first environmental law, focusing on restoration of the environmental equilibrium in the Mexican territory, was adopted. Moreover, during this last 40 years, several institutions and a strong Ministry structure have been created with a special focus on environmental protection in Mexico City (Torres Landa Rulfo and Yañez Vega 2011). In comparison to other Latin–American countries, Mexico has some of the most developed environmental legislation. The following sections show the environmental background of this country and the status quos of two areas: wastewater and energy.

2.1 Institutional Framework

In Mexico the environmental policy is determined every 6 years by the National Development Plan (NDP) where the environmental sustainability is one of the main points (Galindo 2010). The Ministry of Environment and Natural Resources of Mexico (SEMARNAT) is the Federal Government's agency in charge of impelling the protection, restoration and conservation of the ecosystems, natural resources and environmental services of Mexico, with the purpose of propitiating their use and sustainable development. It coordinates the environmental policy under the federal level with its federal delegations and local coordination offices. To fulfill this command, SEMARNAT has three secretariats and diverse agencies that are part of the Environmental Federal Sector. Their work is based on four high-priority aspects (SEMARNAT 2010):

- Conservation and sustainable use of the ecosystems and their biodiversity
- Prevention and control of pollution
- Integral management of the water resources
- Climate change mitigation.

SEMARNAT is divided into three secretariats: Planning and Environmental Policy, Management for Environmental Protection and Environmental Regulation. The secretariats support the following decentralized bodies: Federal Delegations, National Water Commission (CONAGUA), National Ecology Institute (INE), Federal Environmental Protection Agency (PROFEPA) and the Natural Protected Areas National Commission (CONANP). Additionally, there are two decentralized bodies: the Mexican Institute of Water Technology (IMTA) and the National Forestry Commission (SEMARNAT 2010).

2.2 Environmental Framework

The first environmental legislation in Mexico appeared in 1971. This legislation was the base for the Federal Law on Environmental Protection of 1982. Furthermore, two important amendments on the Mexican Federal Constitution were done: (a) article 27 which now includes the preservation and restoration of the ecological equilibrium; and (b) article 73 section XXIX-G which gives the Federal Congress the power for creating and applying federal, state and local environmental laws (SEMARNAT 2010).

In January 1988 the General Law for the Ecological Equilibrium and Environmental Protection (LGEEPA) was approved. The LGEEPA addresses ecological policy at a federal, state and municipal level. The three main areas under federal level are: air quality control, hazardous waste, water and wastewater (SEMARNAT 2010). This law marked the first step forward for Mexico and Latin America on environmental legislation and inclusion into international negotiations.

Finally, the states and municipalities were given jurisdiction over their respective territories to handle and implement environmental decisions that fall within their scope of authority and are not otherwise reserved for the federal agencies and branches of government (Torres Landa Rulfo and Yañez Vega 2011).

2.3 Climate Change

A megacity is a metropolitan area with specific characteristics: it is the seat of government power, it has a strong economic activity, the population size is larger than planned and therefore the environmental issues are complex. This is exactly the case of ZMCM, which is the major contributor to the environmental problems of Mexico. In addition, the city's vulnerability to the effects of climate change has become a national security issue. As a result, whatever this megacity does to reduce GHG emissions and to decrease the vulnerability through actions that mitigate climate change impacts is highly significant for Mexico City's inhabitants and the country. For instance, around 88 % of all GHG emissions in the ZMCM are attributed to energy consumption in the form of fossil fuels and electricity used in transportation, industry, trade, housing, or services (SMADF 2008). Nevertheless, it is possible for citizens to live and for the economy to function with a lower output of GHGs if the following steps are taken: grow and improve the public transportation; transform vehicle technology; increase the efficient use of energy in buildings, industrial facilities, public lighting systems, water pumping systems, and homes; exploit new renewable energy sources, like bio-hydrogen; optimize the use of water; reduce waste generation; and promote adequate wastewater and waste management.

Likewise, the outcomes of the Climate Change Conference (COP16) in Cancún include an agreement adopted by the states' parties that called for a large "Green Climate Fund" and a "Climate Technology Centre" towards a second commitment period for the Kyoto Protocol. The conference established the Cancun Adaptation Framework and the Adaptation Committee. It invited Parties to strengthen and, where necessary, establish regional adaptation centers and networks. Concerning mitigation, developed countries should submit annual GHG inventories and biennial reports on their progress, as well as take nationally appropriate mitigation actions in the context of sustainable development, supported and enabled by technology, financing and capacity-building, aimed at achieving a deviation in emissions relative to "business as usual" emissions in 2020 (UNEP 2010).

The Climate Change Effect Action Plan for Mexico City (2008–2012) has set in place public policies and programs designed to improve the quality of life for city residents with the aim to mitigate the GHG emissions and to attain the target for Mexico under the international climate change framework. One of the specific targets on climate change defined for Mexico includes the adoption of renewable energy as well as improving energy efficiency. Both topics are indirectly related to wastewater management as it can reduce the amount of sewage sludge disposed at landfills and also reduce the operating cost of WWTPs through cogeneration of heat and power. This program also proposes new initiatives and actions that are viable for citizens, communities, businesses and government (SMADF 2008). Additionally, a total of 26 GHG mitigation actions have been proposed in the Climate Change Effect Action Plan. If implemented, these will reduce the carbon dioxide equivalent emissions by 4.4 million tons a year, which represents 12 % of the annual GHG emissions in Mexico City. The budget for the implementation of these actions during that term was $56,152 million pesos (SMADF 2008).

2.4 Wastewater

The National Water Commission (CONAGUA) manages the national waters and wastewater through the National Water Law (LNA). This law sets the discharge limits, the conditions for obtaining a discharge permit and develops the infrastructure for the water protection. In addition, the LNA classifies the surface and ground waters in three main groups depending on the water use (SEMARNAT 2010). Furthermore, there are four Mexican norms, which regulate the wastewater discharge and final disposal of bio-solids. Likewise, the Renewable Energy Law was approved in 2008, opening a new chapter on producing green energy in WWTPs, like bio-methane and bio-hydrogen (SEMARNAT 2010; SENER 2010).

The Ministry of Environment and Natural Resources of Mexico (SEMARNAT) reported in 2008 a total of 1833 WWTPs with an installed capacity of 113,024 liters per second (lps). This figure represents 40.2 % of the total volume wastewater generated in Mexico. By the year 2009, this volume increased to 43.5 % (SEMARNAT 2009). In addition, the annual production of bio-solids in 2009 was reported as 640 millions of tons; 64 % of it was sent to landfills and open pits, contributing with GHG emissions (SEMARNAT 2009). One can clearly see two good opportunities for innovative ideas on waste and wastewater management.

One of the most important actions on these topics is reflected in the Sustainable Water Program for Mexico City (PROAGUA) which presents different programs and policies for improving the wastewater management of the city. For instance, the latest report (2007) states that there are 28 active WWTPs; 90 % of these have biological wastewater treatment (conventional) with a maximum installed capacity of 6.65 m^3/s; of which, only 3.65 m^3/s is in use. Few of the WWTPs have tertiary treatment, which represent an extra opportunity for other projects (SMADF 2007). Furthermore, the Municipalities from the State of Mexico, which belong to the ZMCM, have 70 WWTPs with an installed capacity of 1.38 m^3/s; of which, only 1.24 m^3/s is in use. To sum up, there are the 98 WWTP located in ZMCM which treat a total volume of 4.36 m^3/s wastewater. Nonetheless, considering the average water consumption in the ZMCM, which is 150 liters per inhabitant per day (SMADF 2007) the total amount of wastewater is 40 m^3/s (SEMARNAT 2009).

One can clearly see that less than 11 % of the wastewater generated in the ZMCM is treated and the rest of the volume is sent to the Valley of Tula, located 60 km North from ZMCM. This situation had brought a positive mass balance and excess water for its aquifer. The Valley of Tula has been receiving a steady flow of wastewater (WW) from the ZMCM, carrying a considerable amount of suspended inorganic and organic matter, including phosphorus and nitrogen. This has brought some benefit for the Valley of Tula, like becoming a highly productive agricultural district. However, on the other hand, this practice has impacted the water quality of the local aquifer (CONAGUA 2008). Therefore, in 2008 the Mayors of Mexico City, the State of Hidalgo and the State of Mexico signed an agreement on wastewater management which included the construction of the first Mega-WWTP of the country. The Mega WWTP is located in Atotonilco (Hidalgo). The Atotonilco Mega WWTP will start operation at the end of 2012 and will treat 23 m^3/s of wastewater, which represents 57.5 % of the total amount of wastewater produced in ZMCM.

The next challenge for the National Water Commission (CONAGUA) is to find a suitable solution for the 31.6 % (or 12.58 m^3/s) of wastewater that needs treatment. This situation is without considering the fluctuating population and population growth at the city (CONAGUA 2008).

2.5 Energy and Renewable Energy

There are two federal agencies in charge of developing strategies for renewable energy resources—the Ministry of Environment and Natural Resources of Mexico (SEMARNAT) which is responsible for the Environmental Policy and the preservation of renewable and non-renewable resources in Mexico and the Ministry of Energy (SENER), which defines the National Energy Policy and strategies. Some other institutions are the National Commission for Energy Savings (CONAE), which is responsible for promoting energy savings and energy efficiency, and the National Secretariat for Social Development (SEDESOL), which promotes the use of renewable energy in different sectors. These four Institutions are under the federal umbrella of the central government (SENER 2010).

The total energy consumption in Mexico is clearly dominated by an oil based economy (58 %), while less than 5 % of the produced energy is by means of renewable sources (EIA 2012). According to SENER, by the end of 2008, Mexico had an installed electricity capacity of 58 GW distributed as: 75.3 % thermal; 19 % hydro; 2.4 % nuclear (only one nuclear power plant: 1,400 MW); and 3.3 % renewable, other than hydro. In addition, the general trend in thermal generation is declining from a petroleum-based fuel and moving to natural gas and coal.

SENER needs to launch the National Strategy for Energy Transition and Sustainable Energy in order to increase the renewable energy production from 3 to 6 MW by 2012 (SENER 2010). At the moment the program does not give specific targets for the implementation of renewable energies as part of the main grid, but rather promotes the developing of networks, and invests in these technologies.

An example of local level solution is Mexico City's Green Plan which includes the Climate Change Effect Action Plan. In both cases, the Programs deal with a set of local actions that have global repercussions and a set of joint public policies that will be a reference point in both the national and international spheres. Some of the direct actions are energy saving and efficiency measures, the promotion of the use of solar energy, and the promotion of renewable energy sources. For this purpose, the Renewable Energy Law was approved in 2008, establishing a specific and more favourable framework for renewable energy sources and regulating the use of renewable energy sources and clean technologies to generate electricity. It includes the national strategy and instruments for financing the energy transition.

2.6 Summary of Programs for Mitigation and Adaptation in Mexico City's Metropolitan Area

The analysis of climate data gathered in recent decades shows that the Mexico City's Metropolitan Area (ZMCM) is vulnerable to extreme conditions, whether they involve a rise in environmental temperatures, heavy rains, or droughts. If correct measures are not taken the regional economy will suffer significant economic costs as a consequence of climate change (UNEP 2010). Thus, it is urgent to design, refine, and implement strategies to strength the ability to adapt to the effects of climate change, thereby reducing vulnerability to the most probable scenarios of adverse impacts on the population.

The "Climate Action Program 2008–2012" for Mexico City intends to contribute to the reduction of GHG, reduce the vulnerability of the city to the effects of global warming, and heighten adaptation. This program needs coordinated efforts, commitment, consciousness raising, cooperation, participation, and verification (SMADF 2008). Mexico City government has already instituted different programs related to control the waste management, transportation, water, etc. and that some of the planned actions have a high impact on the reduction of GHG and adaptation to climate change. After 5-years of operation, the main outcomes could be summarized as follows:

> … of the projected 4.4 million tons annual carbon dioxide equivalent reduction, 12 % was reduced in the water sector through the seven actions; 10 % was reduced in the energy sector through five integrated actions; 35 % in the waste sector through four specific actions; and 42 % in the transportation sector through ten actions contemplated in the Program (SMADF 2008, pp 14).

Additionally, the Program of Climate Change Adaptation consists of setting of both short and long-range actions to reduce potential climate change risks on the Mexico City population and economy. Likewise, the program promotes the development of adaptation abilities aimed at reducing vulnerability and moderating, reducing possible damages, forecasting risks, and taking advantage of opportunities derived from the climate change in Mexico City and its outlying areas. The main adaptation actions are:

> …. the implementation of a Metropolitan Hydro-meteorological Monitoring and Forecasting System for the Valley of Mexico (Early Warning System) geared towards identifying risks and threats to the Mexico City population and taking immediate, medium term, and long term action; Micro-basin management of urban ravines in order to deal with the threat of heavy rains and to help reduce risks to the population inhabiting these areas; assistance to people who are vulnerable to extreme climate events conditions such as heavy rains, or intense cold waves or heat waves; epidemiological monitoring or identification of vectors presented as a result of climate change … (SMADF 2008, pp 18).

Consequently, the Ministry of Environment and Natural Resources of Mexico (SEMARNAT) together with the government of Mexico City and State of Mexico have launched the Air Quality Monitoring Program (PROAIRE) with the purpose of reducing emissions and improve the air quality in ZMCM. Moreover, SEMARNAT has a National Environmental and Natural Resources Information System that contains national environmental information and databases (SEMARNAT 2010).

Concerning wastewater management, the Environmental Agency of the State of Mexico developed an "Inventory of domestic and industrial wastewater discharges" (SMA-Edomex 2012). Additionally, this agency has implemented the Sustainable Savings Program Resources. It is an education policy that promotes the principles and practices of conservation and rational use of natural resources. This program is carried out as an environmental management system and it is designed to prevent, minimize and reduce waste generation, energy and water, and to encourage their rational use.

Some other examples of actions are those published in the Gazette No. 1 (2011) which defines the "Water and Sanitation Program (PAS), as an Action Program orientated exclusively to WWTPs". The PAS gives the opportunity to rehabilitate, build up, start up and operate WWTPs in Mexican territory. A second example is the program U031-Incentives for Operating Plants Wastewater Treatment. The objective is to incent WWTPs that are discharging with higher standards than the discharge limits set on the Mexican norms (SEMARNAT 2010).

3 Energy Saving and Green Energy Production in Municipal WWTPs

3.1 Background

Anaerobic digestion is the oldest process used for the stabilization of solids and bio-solids (sludge) for final disposal and thus green energy production. This process involves the decomposition of organic and inorganic matter (mainly sulphate) in the absence of molecular oxygen. It is a microbial process where organic material is biodegraded through a complex microbiological process leading to the production of a more suitable organic material and biogas (Tchobanoglous et al. 2003). Some important physic-chemical factors that define the process are type of inoculums, substrate, reactor type, hydraulic and solid retention time, bioavailability of nutrients, presence of inhibitory substance (toxic substances and heavy metals), temperature, alkalinity and pH (Tchobanoglous et al. 2003).

It is well know that anaerobic digestion of sludge can produce sufficient biogas to meet most of the energy needs of any Municipal WWTP. In a conventional anaerobic digestion process, methane formation takes away a significant portion of the reactants acetate and hydrogen, which is produced by "hydrogen-producing bacteria" (e.g. Clostridium, Enterobacter) and at the same time consumed by "hydrogen-consumed bacteria" (e.g. methanogens, homoacetogens) for the methanogenesis. In contrast, a two-stage anaerobic digestion process produces hydrogen in the first stage (acido/acetogenesis), and methane in the second stage (methanogenesis) (Peña Muñoz and Steinmetz 2012).

Recent works suggest the combination of two processes for enhancing the biomethane-hydrogen production: a two-stage anaerobic digestion and a pre-treatment of the sludge (Peña Muñoz and Steinmetz 2012). According to Hallenbeck and Ghosh (2010) the inoculum (sludge seed) needs a specific pre-treatment in order to theoretically enhance the yield of 4 mol H2/mol substrate. Therefore a pre-treatment should selectively inhibit methanogenesis to increase the efficiency of acetate reduction by mixed cultures and thus increase the production of bio-hydrogen. Several researchers have identified three main pre-treatment groups, divided as follows: chemical addition or specific methanogen inhibitors; heat-shock such as thermal hydrolysis; and a combination of the two previous methods. In general, a simple heat shock applied to the inoculum removes any hydrogen consuming non-spore forming bacteria presented in the sludge (Li and Fang 2007).

According to Das and Veziroglu (2001) there are 4 main sources from which to produce hydrogen: from fossil fuels; from biomass; from water; and from microorganism, which includes fermentative bacteria and anaerobic digestion. In addition, bio-hydrogen production has been put forward as one of the cleanest hydrogen production technologies. The relevance of this process lays in the fact that bio-hydrogen and fuel cells together represent one of the most promising ways to produce green energy (European Commission 2003; Reed and Gutman 2011). In addition, the combination of a pre-treatment with a two-stage process reduces the amount of sludge for final disposal. One of the major bottlenecks in commercialization of the bio-hydrogen production processes is the use of efficient microbial strains which can use different carbonaceous organic materials as feedstock and the low rate of hydrogen production after the complete process (Das and Veziroglu 2001).

3.2 Feasible Solution for Municipal WWTPs

As previously mentioned, the operation and maintenance costs of Municipal WWTPs are high, and among other reasons, the main issue that hinders their operation. According to SEMARNAT (2009), many Municipal WWTPs located in ZMCM need to:

- reduce energy consumption,
- reduce the amount of sludge for final disposal,
- increase the quality of effluent, and
- become auto-sustainable.

These four concerns could be addressed by optimizing the process in WWTPs and integrating specific technologies, such as pre-treatment of sludge for enhancing bio-methane-hydrogen production in anaerobic digesters and producing green energy. Some studies have shown that pre-treatment can enhance the Bio-methane production of an anaerobic digester up to 80 %, while reducing the amount of bio-solids to final disposal up to 50 %. Furthermore, the size of the reactor can be significantly reduced or the efficiency of the existed digester could be increased 2–3 times its capacity (CAMBI 2011).

According to the Norwegian company CAMBI, some advantages of a thermal hydrolysis (pre-treatment) of sludge includes:

- the increasing of sludge bio-degradability and therefore increase in biogas production;
- significant sludge cake volume reduction;
- higher digestion rate;
- two to three times digestion capacity increase;
- stable and reliable digester operations;
- highly energy-efficient process;
- elimination of foaming problems caused by filamentous bacteria; and
- sludge dewaterability improves up to 40 % dry solids.

In terms of accomplishing Mexican norms, this pre-treatment guarantees pathogen kill and production of bio-product/bio-solids class A with no re-growth or reactivation of bacteria, 30–100 % more biogas production than conventional technology, 50 % mass reduction after dewatering, 2–3 times enhancing digester capacity and all steam produced is recycled (CAMBI 2011). Figure 1 shows the suggested treatment flow. In short, the energy produced by means of anaerobic digestion and pre-treatment is enough to cover the energy requirement of the WWTP, the pre-treatment of sludge and the anaerobic digestion itself, if a correct operation is planned.

One concrete action from the government of Mexico City, the State of Mexico and the State of Hidalgo is the sanitation of at least 50 % of the WW produced in the ZMCM. This has been nearly accomplished through the Atotonilco Mega-WWTP. This plant is design to treat a domestic wastewater flow of 23 m^3/s

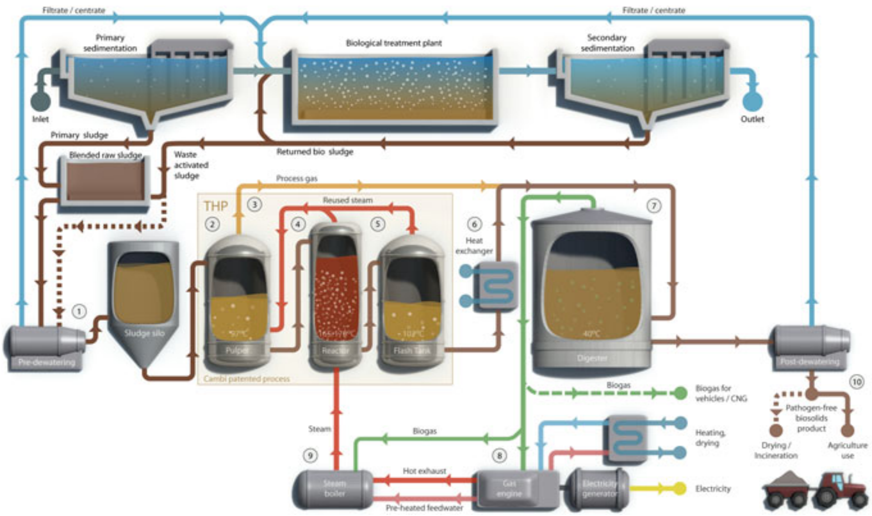

Fig. 1 WWTP with a thermal hydrolysis pre-treatment (CAMBI 2011)

(BOD5: 250 mg/L and TSS: 250 mg/L). The Mega WWTP was design to accomplish the Mexican Norm NOM-003 SEMARNAT-1997 (BOD5:30 mg/L and TSS: 40 mg/L). The treatment consists of a primary treatment for removal of solids, then a secondary treatment (activated sludge), tertiary treatment (coloration) and anaerobic digestion of sludge. The Mega-WWTP is expected to produce 1,134 ton DS/d of sludge. In addition, through a cogeneration 9,729 m^3 biogas/h will be produced, with a content of 70 % of methane. The usable energy has been calculated as 0.49 MW-h/d, which will reduce 507,276 tons of carbon dioxide emissions per year (CONAGUA 2008). Figure 2 shows the flow diagram of the Mega WWTP.

The operation and maintenance cost of the Mega-WWTP are calculated as MXN$632 million pesos per year, while the benefit from the green energy sold will be MXN$75 million pesos per year and the benefit from the carbon credits will be MXN$137 million pesos per year (CONAGUA 2008). The cost of treated water at the Atotonilco WWTP is calculated as MXN$2.06 pesos/$m^3$ without considering the benefits out of carbon credits, otherwise the cost of treated water could be reduced up to MXN$0.49 pesos/$m^3$ (CONAGUA 2008).

One existing opportunity at the Atotonilco WWTP is the integration of pre-treatment for sewage sludge for enhancing bio-methane-hydrogen production and increase the energy production at the site.

Other wastewater management opportunities in ZMCM are available, for example: select and implement the best available technologies; private companies could collaborate with Municipalities for technology transfer and apply to Clean

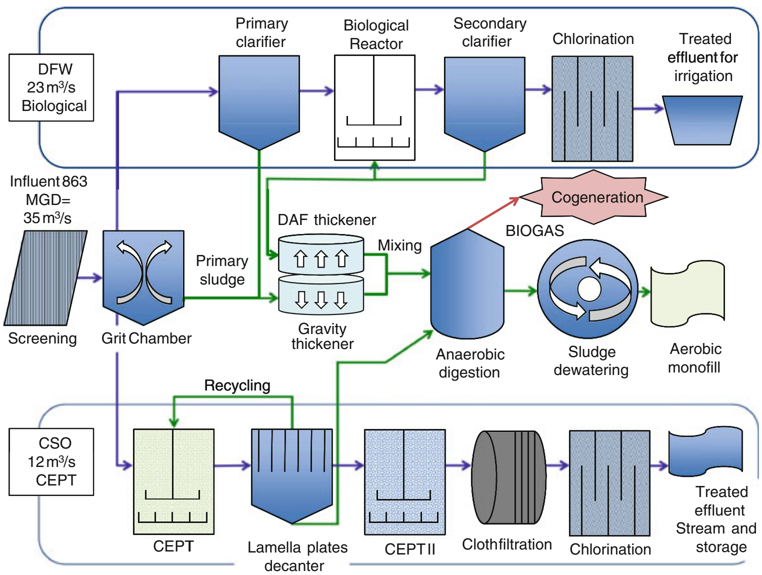

Fig. 2 Flow diagram of Atotonilco Mega-WWTP (CONAGUA 2008)

Development Mechanism (CDM). Although CDM projects do not have an explicit technology transfer mandate, it may contribute to technology transfer by financing emission reduction projects using technologies currently not available in the host countries. For instance, Mexico has been referring to American wastewater standards and environmental legal frameworks for over 30 years. Some advantages of this position is an easy way to transfer technology from U.S.A. to Mexico and a faster integration of the process into Mexican WWTPs. Nevertheless, a technology transfer from Europe into Mexico needs to take into consideration the environmental framework and background of each partner.

It is important to clarify that, by technology transfer one should understand "a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions" (Seres and Haites 2008). Indeed, the policy makers, federal institutions and private companies working on wastewater management need to come closer for building together the technology transfer, which will allow a "green energy revolution" in Mexico.

An example of this type of interaction is the company Ingeniería y Equipos Ambientales, S.A. de C.V. (IEASA), which has approached some Municipalities in ZMCM and Mexico. IEASA has proposed some innovative technologies for enhancing the biogas production in WWTP. It has optimized the actual process at the site. This company has suggested the construction of some WWTPs which include specific pre-treatments. The first studies have shown that "energy neutrality" at the WWTP is possible, when implementing a pre-treatment, integrated with anaerobic digestion in two-steps. Optimizing the actual treatment has to be done parallel to the integration of these units for accomplishing energy neutrality. This term basically refers to the matter that the energy required for operating the new units will be covered my means of the energy produced by the anaerobic digestion. In addition, there will be a "left over of energy" for operating the rest of the units at the site and possibly, for incorporating into the electrical network. As a consequence, the operation costs of the WWTP will be considerably reduced.

4 Conclusions and Recommendations

A careful review of the environmental framework is suggested, in order to identify weaknesses and "black holes" that have been the main reasons for the misconception of regulations, especially in the energy and wastewater sector. Additionally, policymakers need a better advisement team, so it will be easier to implement and generate new laws that manage the transition to a low-carbon growth path, the markets for low-carbon and high-efficiency goods and services. Mexico needs to actively participate in an effective international agreement that considers the economic costs of adaptation. In fact, the cost of taking actions to reduce the impacts of climate change is less, than the cost of inaction.

Certainly, a WWTP is a high energy demanding public service, but selecting the best available technology for the conditions of operations facilitates the treatment and guarantees the protection of the environment. Therefore, enterprises that design and construct WWTPs should be given an opportunity to approach policy makers, stakeholders and federal government spheres, to suggest, present and develop projects related with technology transfer to Mexico. More incentives should be proposed for companies, private holders and municipalities that produce green energy. Once WWTPs are looked at as sites where three goods are produced (treated WW, sanitized bio-solid and green energy), municipalities will be more willing to invest in these sites. The production of bio-methane-hydrogen in WWTPs offers many opportunities for reducing GHG by directly reducing the amount of sludge sent to landfills and using these green fuels for cogenerating heat and power. These actions will show that climate change issues have an important position in the Municipality's agenda and will contribute to the adaptation and mitigation targets under international agreements such as the Kyoto Protocol.

Just like the main challenges for the use of hydrogen and fuel cells, bio-hydrogen production must also consider the infrastructure that is required for hydrogen production, storage and distribution.

The selection of pre-treatment for enhancing bio-methane-hydrogen production in a two-stage anaerobic digester has to consider the type of wastewater that produces the sludge, the geographical location of the site, the options for technology transfer and the available technology in the country. The technology transfer must consider the Mexican and partner's context for a successful implementation.

The governments from Mexico City, the State of Mexico and the State of Hidalgo, should keep working together with private companies to suggest the most suitable and feasible solution to treat the remaining 31.6 % of wastewater in ZMCM. Optimization of WWTPs located in ZMCM, together with the implementation of the suggested pre-treatment for enhancing the bio-methane-hydrogen production, is required. This megacity could be an example for other cities in the country towards improving their wastewater management.

Indeed, Mexico is ready for facing the "green energy revolution."

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Glossary of Terms

AD Anaerobic digestion

GHG Green house gases

mg/l Milligrams per liter

m^3/s Cubic meters per second

WWTPs Waste water treatment plants

ZMCM Mexico City's metropolitan area

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Author Biography

Kristy Peña Muñoz is a PhD student in the Wastewater Technology Department (AWT) at ISWA, University of Stuttgart. Her current research focuses on *enhancing bio-hydrogen production in a two-stage anaerobic digestion as renewable energy source in WWTPs*. This project has been funded by the Alexander von Humboldt Foundation (AvH), the Instituto de Ciencia y Tecnología of Mexico City (ICYT-DF) and the company Ingeniería y Equipos Ambientales S.A. de C.V. (IEASA). At the moment Kristy is collaborating with IEASA to build a Benchmark WWTP in Mexico which includes a pre-treatment for enhancing bio-methane-hydrogen production. Prior to arriving at ISWA, she worked as an Environmental Engineer for an automotive company in Germany and Mexico. In 2008 this company built a benchmark plant in Mexico, where Kristy implemented an environmental system, based on guidelines that apply to any of its production sites. She has a M.Sc., in Air Quality Control, Solid Waste and Wastewater Process Engineering from the University of Stuttgart (Germany) and a Bachelor of Environmental Engineering from UPIBI-IPN (Mexico). Kristy's background includes several years of industrial experience in occupational health, risk assessment, wastewater management and wastewater technology. More specifically she is interested in technology transfer for reducing climate change, the impact of climate change/environmental regulation/policies on technology transfer/implementation, strategic development from climate change regulation and initiatives, corporate social responsibility and renewable energy technologies for developing countries.