Urban Waste for Biomethane Grid Injection and Transport in Urban Areas

Project No: IEE/10/251

www.urbanbiogas.eu

Biogas & Biomethane Production in City of Zagreb

WP 4 – Task 4.3 / D 4.3

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The Biogas & Biomethane Production Concept for the City of Zagreb emerged as a joint effort between experts from the Energy Institute of Hrvoje Požar (EIHP) and members of the Biogas & Biomethane Production task force. EIHP would like to thank very much to the all members of the Biogas & Biomethane Production task force for the City of Zagreb for their active participation in development of this Concept for the City of Zagreb.

The members of the Biogas & Biomethane Production task force are (alphabetically):

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11. M. Božičević Vrhovčak - NGO DOOR
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13. M. Bartolec - Zagreb Holding - Section for Corporative Development
14. N. Kusaković - Zagreb Holding - coordinator for projects co-financed by EU Funds

During several brainstorming sessions, all the experts from the task force came to the solutions on the national and local hurdles existing at the time of developing the Concept upon the given template by Fraunhofer.

The final content and directions of this Study came up at 2nd Biomethane Use task force meeting. EIHP experts take the opportunity to thank again to the members of this task force, too.

The members of the Biomethane Use task force for the City of Zagreb, apart to the EIHP members are, (alphabetically):

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Abbreviations

AD	anaerobic digestion
BGP	biogas plant
BGUP	biogas upgrading plant
BMW	biodegradable municipal waste
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
CWM	centre for waste management
DM	dry matter content
L_{org}	organic load [$kg_{oDM}/m^3{}_R*d$]
MSW	municipal solid waste
oDM	organic dry matter content
RES	renewable energy sources
t_R	retention time [d]
Y_{gas}	specific biogas yield [$m^3{}_N/kg_{oDM}$]
Y_{CH4}	specific methane yield [$m^3{}_N/kg_{oDM}$]
WEO	waste edible oil
WWTP	waste water treatment plant
... ...	

1 Introduction

At the time of writing UrbanBiogas proposal in mid 2010, the existing landfilling site Prudinec was about to be closed and Waste Management Plan for the City of Zagreb by 2015 was about to be adopted. However, until today the only concrete action was that the life span of the existing landfilling site has been extended by 2015 while the Draft Waste management plan was developed by the end of 2012 but still pending for adoption. The fact that national waste management legislation has been harmonising with the *acquis* adds weight to the overall situation. The umbrella document - the Law on Sustainable Waste Management - has been discussed until June 2013 and has been adopted on 16th July 2013.

Even without having an official paper that defines waste management framework, it was possible but challenging difficult to provide rough biogas/biomethane concept for the largest city in Croatia. Based on worldwide experiences as well the knowledge gained during the work on this Project. EIHP jointly with the Task Forces, investigated how "waste-to-biomethane" concept could apply on the separately collected biowaste from the City of Zagreb. Namely, Republic of Croatia, as well as other EU countries has to divert 65% of biodegradable municipal waste of the total amount (by weight) of biodegradable municipal waste produced in 1997 from landfills by 31 December 2020 (Council of European Union, 2011). "Waste-to-biomethane" concept could, if conditions are set right, be a good possibility for the implementation of the targets set.

This document has intention to inspire how to produce renewable energy from, so far, untapped biomass resource in the City of Zagreb and overall Croatia .

The development of biogas and biomethane concept for the City of Zagreb faced too many unknowns to provide one final, single concept for the City. However, the material in this concept provides a starting point for the decision-makers and stakeholders when deciding about the sustainable waste management concept taking into account also waste-to-biomethane concept.

This document links the waste management concept and its obligations with the biogas production concept. It develops four different scenarios on biogas production based on waste management performances. It also delivers an overview of available technologies, methodology how to evaluate biogas & biomethane production locations from the technical point of view, general economic aspects etc. It presents strategy for successful biomethane production from biodegradable fraction of the municipal solid waste suitable for anaerobic digestion.

One of the advantages of the overall implementation of IEE UrbanBiogas project in Croatia has been the support of all stakeholders necessary for development of waste-to-biomethane concept for the City of Zagreb.

Additional advantage for the waste-to-biomethane concept is that both starting (waste management) and ending (biomethane use) are in the hands of branches of Zagreb Holding. One could notice that all the pieces of the waste-to-biomethane concept puzzle for the City of Zagreb exist but they are still not brought together.

The hope of EIHP is that this document will provide expertise for decision making process of all involved stakeholders - from the Mayor to the citizens - when fine-tuning the waste-to-biomethane concept for the City of Zagreb.

1.1 The City of Zagreb and its sustainable development profile

The City of Zagreb is one of the leading examples of Croatian local authorities having a vision in sustainable development. The Mayor of the City of Zagreb, Mr Milan Bandić has opened the 4th Zagreb Energy Week (May 2013) with the following welcoming speech:

"Dear citizens and guests of the City of Zagreb,

Global warming and climate changes present an unavoidable and global problem as well as a dangerous threat to a great number of aspects concerning life and development on Earth.

The actual situation requires fast and effective responses on local and national levels, as well as intensive cooperation and synergy on the international plan.

The City of Zagreb Administration is determined to actively and continuously implement the planned measures and processes of sustainable energy development for the realization of the vision of the City of Zagreb as a city of sustainable development, in cooperation with all of the relevant local and foreign subjects.

The organization of our 4. Zagreb Energy Week shows a high level of mutual understanding and cooperation of all participants in an effort to present the actual problems to our citizens as well as the solutions and possibilities that will ensure a better future for our children.

The City of Zagreb, as the capital city of the Republic of Croatia and signatory of the Covenant of Mayors as well as supporting structure of the European Commission-Directorate General for Energy has an obligation and responsibility to provide maximum support for and to undertake the appropriate measures in order to realize energy savings, the implementation of energy efficiency measures, use of renewable energy sources and environmentally friendly fuels as well as to provide professional support and help to all local and regional associations that show interest in the said topics.

Through our example and in cooperation with our distinguished partners, we want to show the citizens of the City of Zagreb, the Republic of Croatia and wider region the real possibilities for energy and financial savings, reduction of greenhouse gas emissions and the reduction of the harmful impact on the environment.

We want to implement a proactive energy policy and raise the ecological awareness of the Administration employees as well as the citizens of Zagreb in general concerning the actual energy issues, the need of climate and environment protection as well as the need for rational energy and natural resources use.

The ambitious goal of reducing the greenhouse gas emissions by more than 21% in comparison with the reference year 2008 is only possible through an active inclusion and cooperation of the city and state employees, numerous interest groups, economic subjects, educational and scientific institutions, non-governmental organizations and the citizens of ecologically conscious European cities.

The Zagreb Energy Week has an important role in reaching the said targets and is one of the important factors in the process of the City of Zagreb sustainable development."

The efforts of implementing the above stated vision and goals for the City of Zagreb are channelized through the City Office for Energy, Environment Protection and Sustainable Development. The efforts have been recognised even among the civil sector which has awarded Mr Marijan Maras, the head of the City Office for Energy, Environment Protection and Sustainable Development with *"η"* award - a public recognition for personal activation in fostering public dialogue in sustainable energy utilisation (for more, please visit www.door.hr).

The City of Zagreb is the largest city in Croatia and its actions towards renewable energy and, especially, waste management would significantly influence viability of fulfilling the national commitments as stated in the Accession Treaty (Council of European Union, 2011).

National Energy Strategy (Narodne novine, 130/09)(Narodne novine, 130/09) envisages meeting the 10% share of renewable energy sources (RES) in transport by 2020 or 9 PJ with biofuels from own sources, dominantly 1st generation biofuels (biodiesel and bioethanol from food competing feedstock). Later, Law on Biofuels for transport (Narodne novine 65/09, 145/10, 26/11) and National Action Plan as well as National Goal for Placing Biofuels for Transport on Market (Ministry of Economy, 2010) understands that relying on 1st generation on biofuels is not the way to go due to the, a novelty at that time, sustainability criteria (European Commission, 2009). With 2nd generation biofuels technologies that focus on residues and lignocelluloses as a primary under development and limited national efforts in this area, biogas gains an important role in achieving the national biofuels target.

Although biogas is recognised as one of possible alternative fuels for transport by Law on Biofuels, its production is not incentivised as it is the case with other alternative fuels e.g. for biodiesel and bioethanol. It can be expected that in the near future, by adoption of Ordinance on Incentivising Biogas in Transport incentivising biogas production as a biofuel – including compressed biomethane or CBM - would become feasible in Croatia.

The City of Zagreb, as a large city, has to deliver a Programme for Promotion of Biofuels Production and Use. As highly urban area, City of Zagreb cannot consider bioethanol and/or biodiesel production to support its vehicle fleet. However, there is possibility to use different type of waste as raw material for biofuels production - waste edible oil, biodegradable part of municipal waste, waste sludge from waste water treatment plant and landfill gas.

Implementation of waste-to-biomethane concept in the City of Zagreb would fit well in its path towards sustainable development vision as it could contribute to fulfilment of Landfill directive, biofuels consumption, GHG emission mitigation, adaptation to the climate changes and development of sustainable urban transport.

Figure 1-1 Buses on CNG in City of Zagreb public transport - future biomethane fleet

2 Survey of available feedstock

There are different possibility and technologies for use of waste materials. Having in mind Project requests, herewith the focus is gaining energy (biomethane) from waste using anaerobic digestion (further – AD). Biodegradable fraction of MSW suitable for AD is waste originated from preparation and consummation of food (food waste, edible oil, grease, expired food, foodstuff not suitable for human/animal consumption etc.) plus green waste from landscaping, excluding branches and woody material. Availability of feedstock suitable for AD will greatly depend on the future actions in respect to the waste management and efforts to fulfil several goals stipulated as national obligations particularly related to reduction of biodegradable part of MSW. Namely, although the obligation mandates reduction of up to 65% of biodegradable waste based on 1997, this would reflects only ~20% of today's (actually existing) quantities, Landfill Directive and Renewables Directive being the foremost, by 2020. In any case, as the capital is also the largest city in Croatia, the City of Zagreb carries significant contribution in achieving overall national goals.

Diverting biodegradable part of MSW from landfills is an overall EU task were each member country has its mandates. For most of the member states, percentage of biodegradable municipal waste (BMW) landfilled in each European country with derogation periods for fulfilling the BMW diversion targets of the EU Landfill Directive, are compared with the amount generated in 1995. The general derogation is a four year period implying that the countries have to fulfil the targets by 2010, 2013 and 2020 instead of by 2006, 2009 and 2016. Some countries have diverting derogations periods: Ireland: derogation only for the 2006 and 2009 targets, to be met 2010 and 2013. Portugal: derogation only for the 2009 and 2016 targets, to be met in 2013 and 2020. Slovenia: derogation only for the 2016 target, to be met by 2020. Croatia must meet the targets by 2013, 2016 and 2020 based on the year 1997 (Waste and material resources, 2013).

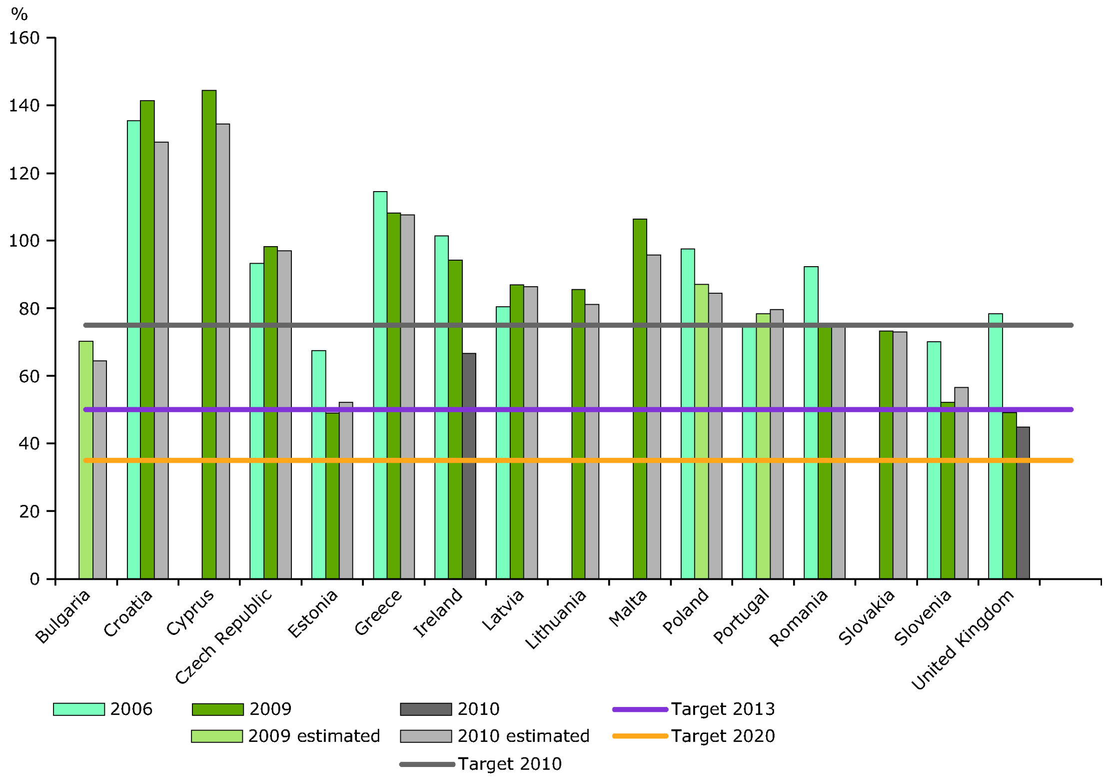


Figure 2-1 Targets for diverting BMW for the EU member states according to the Landfill Directive

As the past efforts in waste management in general are implementing at slower pace than expected and legal framework for overall national waste management has just been adopted (July 2013), it was rather difficult to estimate clear future in respect to the available feedstock for any place in Croatia, let alone the City of Zagreb. According to the Sustainable Waste Management Law, article 19, the implementation of national waste obligations is transferred to the local and regional self-government. In that sense, the City of Zagreb will have to implement waste management that will divert biodegradable waste going on landfills in dynamic as foreseen in the Accession Treaty (Council of European Union, 2011).

As the national interpretation of Article 5 "reduction of biodegradable waste going to landfills" (Council Directive 1991/31/EC of April 1999 on the landfill of waste) varies, the reliability of estimations for quantities of biodegradable waste suitable for AD for the City of Zagreb by 2020 decreases further. Namely, explanation of the article 21 that defines ways of implementation of foreseen dynamic of biodegradable part of municipal waste and its landfilling, says, among others:

"(...) Minister is authorised to decide on quantities of biodegradable waste landfilled on each landfill and on quantities of waste that is landfilled on non-synchronised landfill as well on delivering instructions on a way how to calculate share of biodegradable waste (...)".

For the purpose of this Study, the base quantity of calculating the share of biodegradable fraction of municipal waste would be the quantity of waste landfilled on Prudinec - landfilling site of the City of Zagreb in 1997 which is about 209,000 t (Croatian Environment Agency, 2006) Although it is true that the City's waste management company has collected 184,502 t of waste in that year, here it is assumed that all waste that was landfilled at the City's landfill falls under the Landfill Directive mandate.

2.1 Municipal solid waste, organic in the City of Zagreb and vicinity

For the above given reasons, this material considers four possible scenarios for quantities of biodegradable part of municipal waste that is suitable for AD for the City of Zagreb.

1. Scenario: Total estimated quantities of biowaste in the City of Zagreb

This scenario continues on the Waste Management Concept delivered by Zagreb holding - branch Čistoća. It presents total estimated quantities of biowaste which might be collected in Zagreb and directed toward biogas production by 2020. Details on this calculations can be found at the project site www.UrbanBiogas.eu, deliverable D.3.3 Municipal waste management in the City of Zagreb/Croatia (Ribić, B., D. Sinčić, M. Kruhek, 2012). This document will continue on highlights of this material which are:

- composition of the collectable biodegradable waste in the City of Zagreb (Figure 2-2)
- dynamic of its implementation by 2020 (Figure 2-3).

Table 5. Total estimated quantities of biowaste in the City of Zagreb

Input	Dry matter,%	Amount, t/year
Biowaste from shopping centers and households	20	5.000
Biowaste from kitchens and restaurants	20	10.000
Market biowaste	20	3.000
Industrial biodegradable waste (brewery, diary, food processing)	20	1.500
Expired milk & eggs	17	500
Total		20.000

Figure 10. Estimate of the increase of separately collected biowaste (2014-2020)

Figure 2-2 Collectable biodegradable waste in the City of Zagreb

Figure 2-3 Estimate of the increase of separately collected biowaste (2014-2020)

2. Scenario: Meeting the IEE UrbanBiogas longterm goal by 2020

IEE UrbanBiogas has ambitious expected long-term impact in 2020: "to use 70% of the currently untapped organic fraction of urban waste (MSW, FW) in the target cities. Thereby 70% shall be converted into biomethane for grid injection or for its use as transport fuel." (IEE Grant Agreement, Annex I: Description of the Action, 2010).

This scenario assumes fulfilment of this goal as a linear function from 2014 to 2020, taking the base year value from Scenario 1.

3. Scenario: Meeting the targets set by the Accession Treaty, considering Landfill Directive, for the City of Zagreb

Accession Treaty, in parts relating to the Landfill Directive, defines quantities and dynamics of diverting biodegradable part of municipal waste going to landfills. The projections are made assuming the same of kitchen waste share in total municipal waste of the City of Zagreb (Ribić, B., D. Sinčić, M. Kruhek, 2012), quantity of municipal waste in 1997 (base year for calculating the targets upon Landfill Directive) and respective shares and years of diverting biowaste from landfilling (reduction to 75%, 50% and 35% of the total amount of biodegradable municipal waste produced in 1997, respectively).

This scenario assumes fulfilment of this goal as a linear function from 2014 to 2020, taking the base year value from Scenario 1.

4. **Scenario: Separation of biodegradable fraction suitable for AD at the Centre for waste management (CWM)**

As experiences from practice indicate and in the line of Scenario 1, a "worst-case-scenario" is developed which assumes that separate collection of biodegradable waste will not be implemented for the City of Zagreb but biodegradable fraction in the mixed municipal waste will be separated prior landfilling at the Centre for Waste Management (CWM).

Here, the base for calculation is not the Landfill Directive but actual quantity of collected waste. Namely, Landfill Directive objectives in Croatian background uses 1997 as a base year for calculating the share of biodegradable waste and could provide estimations on availability of biowaste for biogas production. However, period 2007 - 2011 demonstrates larger quantities of municipal waste than in 1997. In average, the collected quantities were 32% higher than those in 1997. Looking at several official sources (Waste balances by Department for Statistics, the City of Zagreb; chapter: 20. Quality and Protection of Nature and Environment, The City of Zagreb Annual Report 2012 by Department for Statistics, the City of Zagreb; Reports on Waste by Croatian Environment Agency; Waste Management concept by Zagreb holding - branch Čistoća.) that report on waste collected and/or landfilled in the City of Zagreb, one could spot the differences in the reported quantities Figure 2-4.

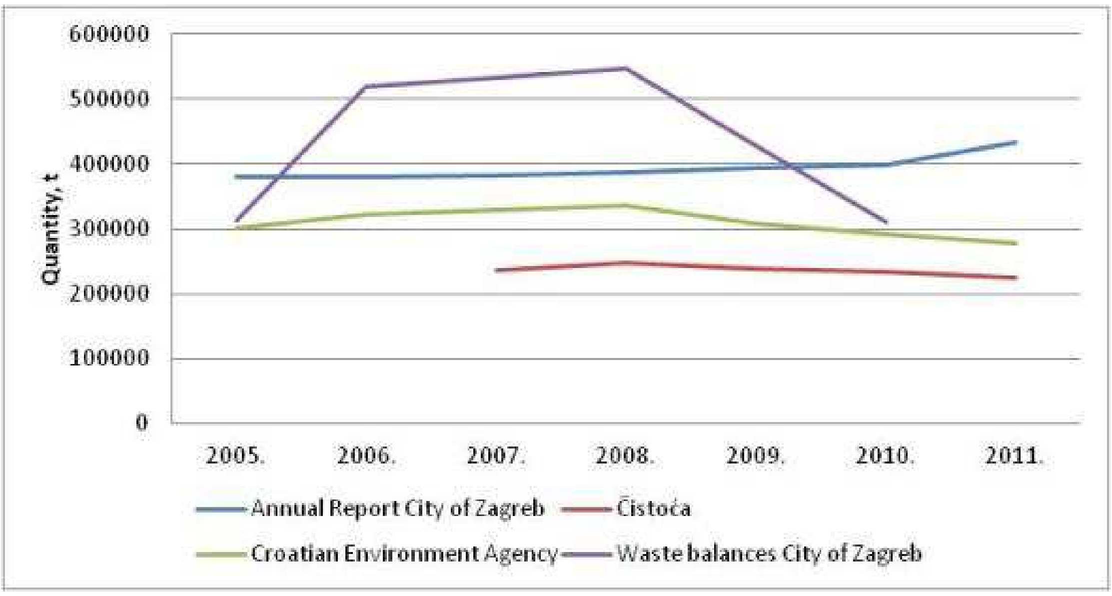


Figure 2-4 Quantities of landfilled municipal waste for the City of Zagreb, according to different official sources (2005-2011)

As Croatian Environment Agency is an independent public institution established by a decision of the government of the Republic of Croatia collect, integrate, and process environmental data, this report will use its numbers to create the Scenario 4. In addition, in it reports, Agency differs from total waste collected and waste landfilled plus it covers all quantities of municipal waste of certain administrative area, regardless on the waste management company.

Scenario 4 will assume steadiness in produced quantities of waste as in 2011 and the same kitchen waste share in total municipal waste of the City of Zagreb (Ribić, B., D. Sinčić, M. Kruhek, 2012). While it is reasonable to assume that this way of waste management might provide additional material such as grass, leaves etc., here a conservative approach will be assumed and focus will be placed on kitchen waste.

This scenario assumes operation of CWM in 2015 with the base year value from Scenario 1.

The following four tables represent four different scenarios in quantities of availability of biodegradable fraction of municipal waste of the City of Zagreb suitable for AD by 2020:

Table 2-1: Scenario 1: Total estimated quantities of biowaste in the City of Zagreb (in 000 t)

Type of waste	2011	2015	2017	2020
Biowaste from shopping centres and households	1.5	2.6	3.8	5.0
Biowaste from kitchens and restaurants	0	3.4	6.7	10.0
Market biowaste	0	1. 0	2.0	3.0
Industrial biodegradable waste (brewery, dairy, food processing)	0	0.5	1.0	1.5
Expired milk & eggs	0	0.2	0.3	0.5
Total	**1.5**	**7.7**	**13.8**	**20.0**

Table 2-2: Scenario 2: Meeting the IEE UrbanBiogas longterm goal by 2020 (in 000 t)

Type of waste	2011	2015	2017	2020
Biowaste suitable for AD, collected at source	1.5	14.9	28.6	38.7
Industrial biodegradable waste (brewery, dairy, food processing)*	0	20.6	21.1	21.6
Total	**1.5**	**35.5**	**49.7**	**60.3**

*elaborated in later text

Table 2-3: Scenario 3: Meeting the targets set by the Accession Treaty, considering Landfill Directive, for the City of Zagreb (in 000 t)

Type of waste	2011	2013	2015	2017	2020
Biowaste suitable for AD, collected at source	1.5	19.4	27.7	31.5	35.9
Industrial biodegradable waste (brewery, dairy, food processing)*	0	20.1	20.6	21.1	21.6
Total	**1.5**	**39.5**	**48.3**	**52.6**	**57.5**

*elaborated in later text

Table 2-4: Scenario 4: Separation of biodegradable fraction suitable for AD at the CWM (in 000 t)

Type of waste	2011	2015	2017	2020
Biowaste suitable for AD, separated at CWM	1.5	37.0	73.9	73.9
Industrial biodegradable waste (brewery, dairy, food processing)*	0	20.6	21.1	21.6
Total	**1.5**	**57.6**	**95.0**	**95.5**

*elaborated in later text

Industrial biodegradable waste presented in the Scenario 2, 3, and 4 represents additional asset for biogas production in the City of Zagreb. This type of waste and its quantities are elaborated later in this chapter, following the given template of this Study.

Seasonal variations

Annual variations of waste quantities are usual for continental part (migration of domicile inhabitants over summer) but are partially compensated with tourists whose arrivals peak in summer season. In summer months, tourist make about 10% of domicile inhabitants. The average stay of tourists in the City of Zagreb is 1.7 days. Arrivals are increasing by 5% per year with almost equal number of tourist arrivals and inhabitants in 2012.

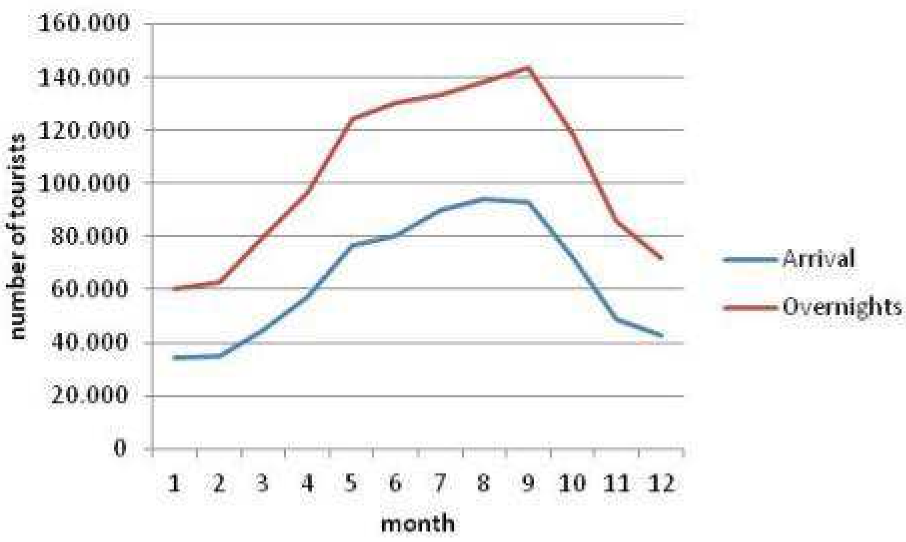


Figure 2-5 Arrivals and overnights of tourists to the City of Zagreb over year (2012)

Source: Department for Statistics, the City of Zagreb (Mjesečno priopćenje-Turizam, 14/02/2013)

Current form of disposal

Current form of disposal is landfilling while separate collected biowaste (both from maintenance of urban green areas and separately collected kitchen waste) is used in composting facilities. The share of biowaste going on composting in the total collected waste was 3.4% in 2011. In the same year, the waste going on landfills made 92.6% of the total collected municipal waste.

Current and future costs of disposal

Current costs of unsorted municipal waste disposal are 322.36 HRK/t (VAT excl.) or 42.98 €/t of landfilled waste (Zagrebački holding d.o.o.- Podružnica ZGOS, 2012). Zagreb holding - branch Čistoća pays annually about 68 mil. HRK or 9 mil € /year (VAT excl.) for landfilling plus 31.74 HRK or 4.23 € for each weight measuring (in/out).

The currently separate collected biowaste is not landfilled but disposed at the existing composting site (property of sister company Zagreb holding - branch Zrinjevac) at 200 HRK/t (VAT excl.) or 26.67 €/t (ZAGREB CH, 2013).

Future costs of disposal are not available as the current cost calculations of Zagreb holding - branch Zrinjevac are not elaborated (ZAGREB CH, 2013).

The possibility of having mid to long term contract

Waste management service traditionally belonged to the public service. As for now, Zagreb holding - branch Čistoća is considered as a main municipal waste management provider for the City of Zagreb. However, the Law on Sustainable Waste Management Law considers allowing private companies to provide waste management services.

Zagreb holding - branch Čistoća gradually creates systematic increase in collection of biowaste from all possible sources but it finds unsuitable to commit itself to long term agreements until building the biogas plant remains uncertain (ZAGREB CH, 2013). It finds that numerous details will be possible once when Waste Management Plan for the City of Zagreb will be adopted. After that, it should be possible to have mid to long term contract for biowaste delivery.

The Law on Sustainable Waste Management (2013) encourages agreements and collaboration among several local authorities in terms of waste management.

Potential sources of biodegradable municipal waste suitable for biogas production could be four satellite towns: Dugo Selo (East), Velika Gorica (South-East), Samobor (West) and Zaprešić (North-West) from Zagreb.

Figure 2-6 Satellite towns of City of Zagreb

Town of Samobor and Municipality of Sv. Nedjelja already deliver a part of their waste to Zagreb's landfill Prudinec. Zagrebačka County represents a ring around the City of Zagreb and generates ~51,000 t/year of municipal waste. This would represent a potential of additional ~13,500 t/year of biowaste suitable for AD, assuming the same share of kitchen waste as in the City of Zagreb.

Table 2-5 Additional potential for biowaste from satellite towns of City of Zagreb

Town	Population	Distance from Zagreb	Biowaste
		km	000 t/yr
Samobor	37,663	28	3.7
Velika Gorica	31,553	17	3.1
Dugo Selo	17,466	21	1.7
Zaprešić	25,223	19	2.4
	total		**10.9**

The Table 2-5 shows that the quantities of biowaste in vicinity of the City of Zagreb currently do not justify the effort of having the mid to long term contract for delivery of biowaste to the biogas plant. Even more, practice shows that smaller places with family houses and gardens have less share of biodegradable waste suitable for AD than in urban areas.

It seems that the greatest challenge in producing biogas from biowaste lies in directing the biowaste towards the biogas plant.

2.2 Industrial organic residues in the City of Zagreb and vicinity

Industrial organic residues in the City of Zagreb that are landfilled are presented in Figure 2-2 as 1,500 t of industrial waste (brewery, dairy, food processing) and 500 t of expired milk and eggs for the year 2020.

In addition to that, there are organic residues from brewery: beer cake, waste yeast and waste water treatment sludge (Table 2-6).

Table 2-6 Industrial organic residues in City of Zagreb

Substrate	Quantity (t)	DM (%)	Current form of use
beer cake	17 000	25	fodder
waste yeast	300	16	fodder
waste water treatment sludge	100	24	agriculture

Annual variation are not expected except in waste water treatment sludge that is collected/cleaned annually.

In the interview with the brewery, they don't see any objections if the beer cake is used for biogas production as long as they are not at loss.

2.3 Agricultural energy crops in the City of Zagreb and vicinity

As the City of Zagreb is the most urbanised area in Croatia whose "agriculture" is mostly consisted of gardening for private purposes, agricultural energy crops are not considered in this Study as possible input for biogas production.

3 Product biomethane

3.1 Calculation of prospective biogas and biomethane yield

Based on the four Scenarios developed in the previous section, calculations of prospective biogas and biomethane yield are calculated. All scenarios but 1st are evaluated following the same logic:

- calculation of biogas and biomethane yield out of available biowaste suitable for AD
- calculation of biogas and biomethane yield out of industrial waste suitable for AD and adding it to the biowaste total (industrial biodegradable waste - IBW)

Biogas yield from biowaste will vary significantly according to the income group, diet, eating preferences as well as on season. In Croatia, tourism will play important role in seasonal variations of biogas yield. For the purpose of this Study, average annual values are used and it is recommendable to execute measurements of biogas yield over the year of biowaste collected at certain type of waste management to come up with more realistic numbers.

Given the lack of data on specific biogas yield for separately collected biowaste from City of Zagreb (ZAGREB CH B. R., 2013), the average values for biogas from biowaste in Germany are applied (FNR, 2004) as shown in Table 3-1.

In addition, there are also other substrates considered for biogas production and their parameters are also shown in the same table.

Table 3-1 Average values for biogas and biomethane yield from biowaste in Germany

Type of biowaste	DM %	VS % of DM	Biogas yield Nm^3/t VS	Methane content %
catering waste, average fat content (Speisereste mittelfet)	16	87	680	60
Biowaste (Bioabfall)	40	50	615	60
exipred milk and eggs* (Vollmilch Kuh. frisch)	14	95	899	63
brewery cake (Biertreber siliert)	26	95	552	59
yeast (Bierhefe abgepreßt. gekocht)	25	92	662	62
sludge from beer production* (Biertreber frisch)	24	96	533	59

*estimation

Having troubles of finding specific values for category "expired milk and eggs" that occur in Scenario 1, the parameters of best alternative (whole fat milk) were applied. The same applies for substrate "sludge from beer production".

For calculation of biogas yield, the parameters from Table 3-1 were used except for Scenario Zagreb holding - branch Čistoća where dry matter content is taken from original table shown in Figure 2-2.

Dry matter content is estimated for each of the substrate mixture (results in Table 3-2) and it suggests that additional liquid might be needed, selection of dry AD technology might be considered or substrate manipulation equipment should be adjusted to the dry matter content.

Table 3-2 Dry matter content (%) for each substrate mixture

	Biowaste only*				Including IBW			
Scenario	**2011 - base year**	**2015**	**2017**	**2020**	**2011 - base year**	**2015**	**2017**	**2020**
1	16	25	21	21				
2	16	16	16	16	16	22	20	20
3	16	16	16	16	16	26	20	20
4	16	40	40	40	16	36	37	37

*composition of Scenario 1 is considered as in Figure 2-2

Calculations of prospective biogas and biomethane yields are made for 2011, 2015, 2017 and 2020 in order to have milestones what needs to be done in terms of waste management and substrate supply to the AD plant from current position. The results are shown in the following tables.

Table 3-3 Biogas and biomethane production - Scenario 1 (mil.Nm^3/yr)

Parameter	2011	2015	2017	2020
Biogas production	0.19	1.07	1.41	2.04
Methane production	0.09	0.60	0.77	1.11

Table 3-4 Biogas and biomethane production - Scenario 2 (mil.Nm^3/yr)

Parameter	2011-base year	2015	2017	2020
Biogas production	0.19	1.41	2.72	3.68
Methane production	0.09	0.85	1.63	2.21
Including IBW				
Biogas production	0.19	3.85	5.22	6.24
Methane production	0.09	2.29	3.11	3.72

Table 3-5 Biogas and biomethane production - Scenario 3 (mil.Nm^3/yr)

Parameter	2011-base year	2013	2015	2017	2020
Biogas production	0.19	1.84	2.63	2.99	3.41
Methane production	0.09	1.10	1.58	1.80	2.05
Including IBW					
Biogas production	0.19	1.84	5.07	5.50	5.98
Methane production	0.09	1.10	3.02	3.28	3.57

Table 3-6 Biogas and biomethane production - Scenario 4 (mil.Nm^3/yr)

Parameter	2011-base year	2015	2017	2020
Biogas production	0.19	4.56	9.12	9.12
Methane production	0.09	2.73	5.47	5.47
Including IBW				
Biogas production	0.19	7.00	11.62	11.62
Methane production	0.09	4.18	6.95	6.95

In the following tables, possible hourly production of biogas/biomethane is estimated, based on 7,690 working hours of the upgrading plant.

Table 3-7 Hourly biogas and biomethane production - Scenario 1 (Nm^3/h)

Parameter	2011	2015	2017	2020
Biogas production	25	139	183	265
Methane production	11	79	100	145

Table 3-8 Hourly biogas and biomethane production - Scenario 2 (Nm^3/h)

Parameter	2011-base year	2015	2017	2020
Biogas production	19	184	354	478
Methane production	11	110	212	287
Including IBW				
Biogas production	19	501	679	811
Methane production	11	298	405	484

Table 3-9 Hourly biogas and biomethane production - Scenario 3 (Nm^3/h)

Parameter	2011-base year	2013	2015	2017	2020
Biogas production	19	239	342	389	444
Methane production	11	143	205	234	266
Including IBW					
Biogas production	19	239	659	715	777
Methane production	11	143	393	426	464

Table 3-10 Hourly biogas and biomethane production - Scenario 4 (Nm^3/h)

Parameter	2011-base year	2015	2017	2020
Biogas production	19	593	1,186	1,186
Methane production	11	356	711	711
Including IBW				
Biogas production	19	910	1,511	1,519
Methane production	11	543	904	909

From the point of hourly biogas and biomethane production estimation, it seems that it would be worthy to include other substrates than biowaste in biogas production, especially if that biogas will be considered for upgrading. Namely, both Scenario 1, 2 and 3 are either far from or barely reach production of 500 Nm3/h of raw gas by 2020 if industrial biodegradable waste is not considered. In the Scenario 4, it is a question of technology that will be able to retrieve all the organic substance to reach the estimated potential.

In the next section, Biogas Production and Upgrading Plant, there are two locations suggested for biogas production and upgrading plant due to the existing biogas production facilities that do not benefit from the existing FiT system:

- location Prudinec: there could be additional biogas supply from an existing landfill gas power plant of ~ 600 Nm3/h from landfill gas, average methane content 50%.
- location Resnik: there could be additional biogas supply from an existing WWTP power plant of ~ 500 Nm3/h from sewage sludge gas, average methane content 60%.

Those two plants might consider turning to upgrading biogas instead of producing electricity and heat in CHP.

3.2 Prospective demand

Natural gas consumption in City of Zagreb in 2011 totalled 12.63 PJ (371,6 million m3), which represents 26.1 % of final energy consumption (Figure 3-1).

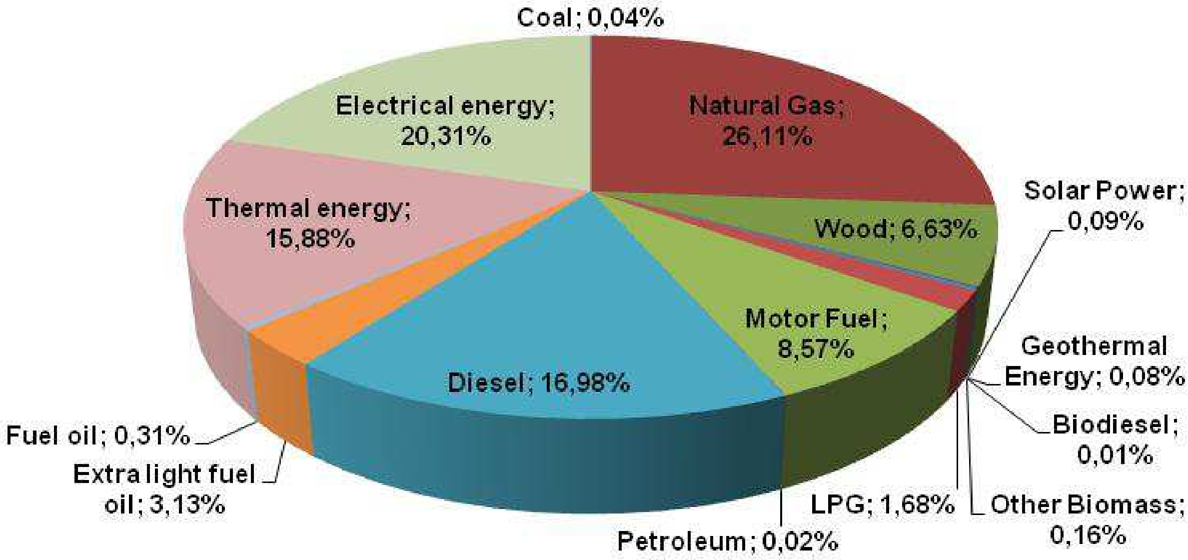


Figure 3-1 Final energy consumption in City of Zagreb in 2011 (by fuels)

Natural gas is mostly used by households (66%) followed by industry (27%) and service sector (7%) and very insignificant share of final energy consumption in transport.

Namely, final energy consumption in transport in City of Zagreb in 2011 totalled 12.01 PJ. Natural gas consumption in transport sector totalled 0.027 PJ (0.8 mil. m3), which represents only 0.22 % of total energy consumption in transport sector in City of Zagreb in 2011.

3.3 Comparison of biomethane production and demand

Currently, the City of Zagreb has 60 public transport busses powered by CNG which represents existing demand for biomethane use.

When comparing biogas/biomethane production (tables 3-3 to 3-6) through scenarios for year 2020, all scenarios meet the existing demand for the existing public transport demand. However, some scenarios meet the demand in earlier years (2015) such as Scenario 2, 3 and 4.

If combining any of the scenarios with existing biogas production at two locations within the City of Zagreb, even without including industrial biodegradable waste as a digestion substrate, sufficient biogas/biomethane production reaching close or little above 1,000 Nm3/h as soon as in year 2015 (Scenario 2, 3 and 4).

When investigating maximal biomethane production (Scenario 4, including IBW in 2020,

Table 3-6), this production will meet about 2% of final consumption of natural gas in the City of Zagreb. On the other hand, the same production will surpass the existing demand for biomethane in the transport of the City of Zagreb by eightfold.

Hourly production of biomethane is not sufficient to meet the demand as 2,700 Nm3/h is needed. The demand cannot be achieved even if combining the existing biogas production with biowaste biogas production of the City of Zagreb.

Based on this comparison, it can be concluded that there is potential to fully close waste-to-biomethane concept for the City of Zagreb where biomethane use will be aimed at injection in the natural gas grid instead of having a filling station on the production site (Robert Bošnjak et al., 2013).

4 Biogas Production and Upgrading Plant

Waste-to-energy is a large business niche with well developed technologies that companies offer either as turn-key or by specialised processing parts. Namely, waste-to-energy concept include several processing steps related to collection, sorting, waste conditioning, biogas production and biogas utilisation, in this case: biogas upgrading and utilisation of biomethane either as vehicle fuel or as substitute for natural gas (Figure 4-1). Each of these steps has accompanying technologies that are adjusted to the type of inputs (waste management).

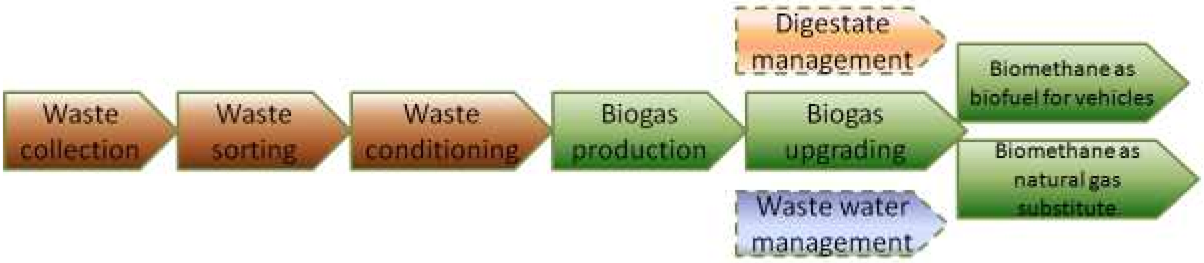


Figure 4-1 Processing chain of Waste-to-biomethane concept

Each of the steps in the processing chain has its own options: waste can be collected either mixed or source sorted or biogas production technology will depend on the dry matter content. The figure below presents a general scheme for treatment options for organic fraction of municipal waste.

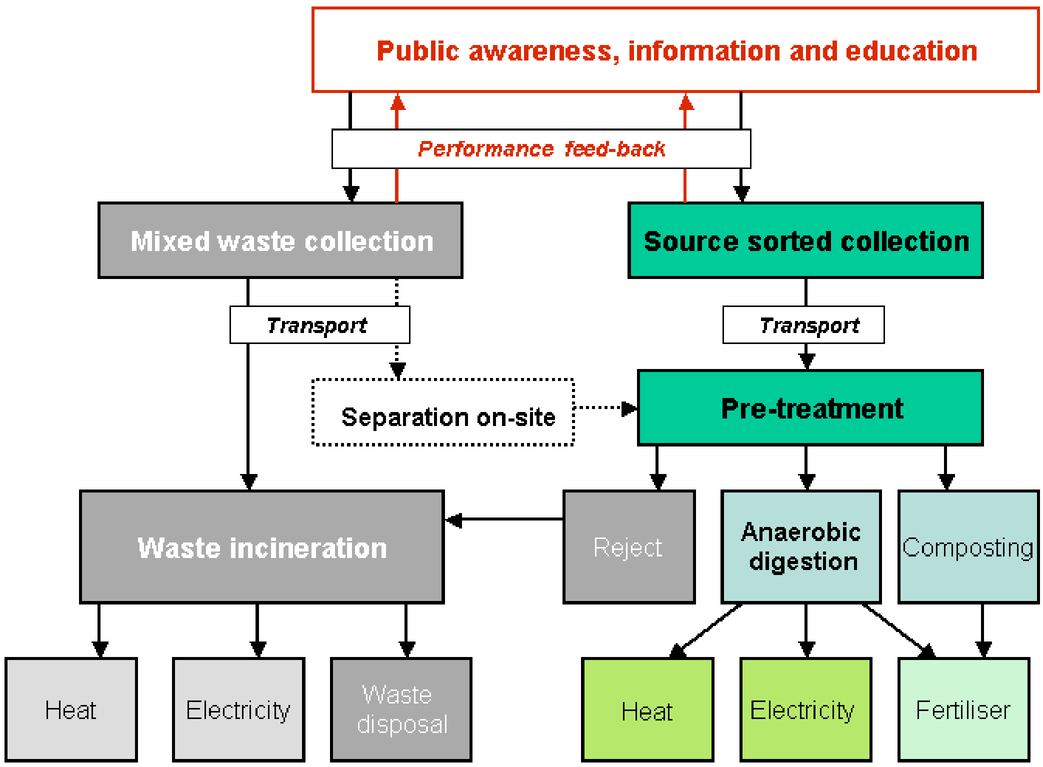


Figure 4-2 Treatment options for organic fraction of municipal waste (Baxter & Al Seadi, 2013)

In the recent period, the City of Zagreb has (been) considered in its development plans to have a waste incineration plant as a waste management facility. Removing the organic "wet" part such as kitchen waste would improve overall plant efficiency as this symbiosis has been demonstrated in several examples. Namely, having incineration plant and biogas plant close by, improves the overall efficiency of both plants. Even more, digestate could be dried and incinerated in the incineration plant.

Comparing to the current way of biowaste management - composting, the emissions to the air are significantly lower and easier to control in anaerobic digestion (AD) process than from composting as AD is conducted in closed reactors. Generally speaking, every tonne of biowaste sent to biological treatment can deliver between 100-200 m3 of biogas. Due to the energy recovery potential from biogas coupled with the soil improvement potential of residues (especially when treating separately collected biowaste), biogas production from biowaste may often represent the environmentally and economically most beneficial treatment technique (Commission of the European Communities, 2008).

There are more than 200 plants running on biowaste in the EU by 2010 (Mattheeuws, 2012) with an average size of 30,000 t/yr. Main drivers are Landfill Directive, increased bioenergy and production of biofuels while the main restrictions are animal by-product regulation and restrictive utilisation of digestate as fertiliser (depending on the national legislation). As 30,000 t/yr of biowaste provides biogas just at the turn for upgrading economy, biogas production from biowaste is often combined with other substrates such as sludge from WWTP, industrial biowaste, fats or agricultural substrates.

The first step in selecting the technology for biogas production from biowaste will depend on the way how the waste is collected. Since overall waste management in Croatia is still to be defined according to the new umbrella law, this text does not presume any type of waste management. The previous chapter provides four different scenarios where scenarios 1-3 are assuming source sorted collection and scenario 4 assumes mixed waste collection. The following text will provide overall view of AD methods and AD systems that are used in turning biowaste to biogas with few examples of AD plant concepts. The main source for this overview is material from IEA Bioenergy Task 37.

Table 4-1 Examples of relation between available feedstock and AD systems (Baxter & Al Seadi, 2013)

Feedstock: biowaste		**AD systems**	
• **Source separated, separately collected** o source separation and collection by door-to-door method ▪ Bin collection system • single compartment bins • two compartment bins or double ▪ Bag collection system • paper bags • plastic bags • biodegradable plastic bags o Source separation and separate collection in road containers o Underground containers o Optical sorting of household waste • **Bulk collected, centrally separated**	**Pre-processing**	• Wet or dry • Batch or continuous • Single stage or multi-stage • Co-digestion or mono-digestion	**Post-treatment of digestate**

Biogas upgrading plant will, again, depend on the hourly production of biogas and the desired quality of biomethane. Given the results on the hourly production of biogas in the previous chapter and characteristics of natural gas prerequisites in Croatia, two technologies are most likely to be selected for biogas upgrading: water scrubbing and PSA.

In the following text, production of biogas via AD of biowaste and composting of remained digestate will be investigated for the City of Zagreb.

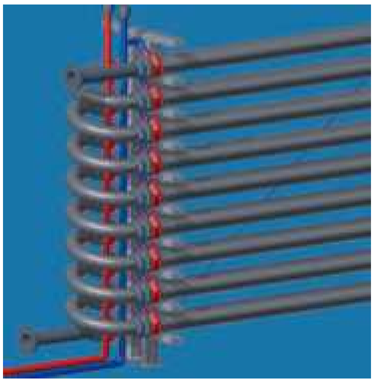
4.1 Technology

National Ordinance of Handling Animal By-Products Not Intended for Human Consumption (Pravilnik o nusproizvodima životinjskog porijekla koji nisu za prehranu ljudi, (OG 87/09)) specifies how to handle catering waste (Category 3 waste) in order to be used in biogas or composting plants (Annex VI). From this Ordinance, few biowaste pre-treatment steps are predefined, regardless on the biowaste collection option. Namely, a biogas plant using Category 3 substrates, needs to have a pasteurisation/sanitation unit that will meet the minimum standards of:

a. maximal particle size prior entering the unit: 12 mm
b. minimal temperature of the overall material in the unit: 70 ºC
c. minimal continuous retention time in the unit: 60 minutes.

The same Ordinance describes microbiological standards that digestate must meet.

Figures below provide an example of pasteurisation/sanitation unit for biowaste that could be also used as feeding tube for the digesters and external heating of the digesters.



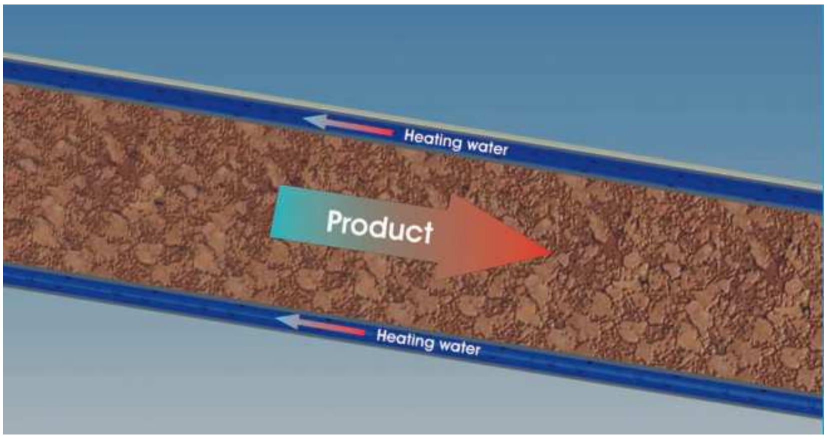


Figure 4-3 Example of pasteurisation/sanitation unit (source: Finsterwalder Umwelttechnick, www.fitec.com)

Conditions set by the Ordinance assume shredding/liquefying the biowaste and heating the material. Having that in mind, dry AD will occur only if plenty of additional material with high dry matter will be used (i.e. grass cuttings from public landscaping). In general AD method will depend on the dry matter content in the biowaste or the substrate(s) available.

Biowaste is very likely to come with some impurities (egg shells, bones, stones, plastics) or with/in packaging or, even more, together with overall municipal waste which also assumes separation step prior to the AD. This is done usually by high pressure presses of which examples are shown below:

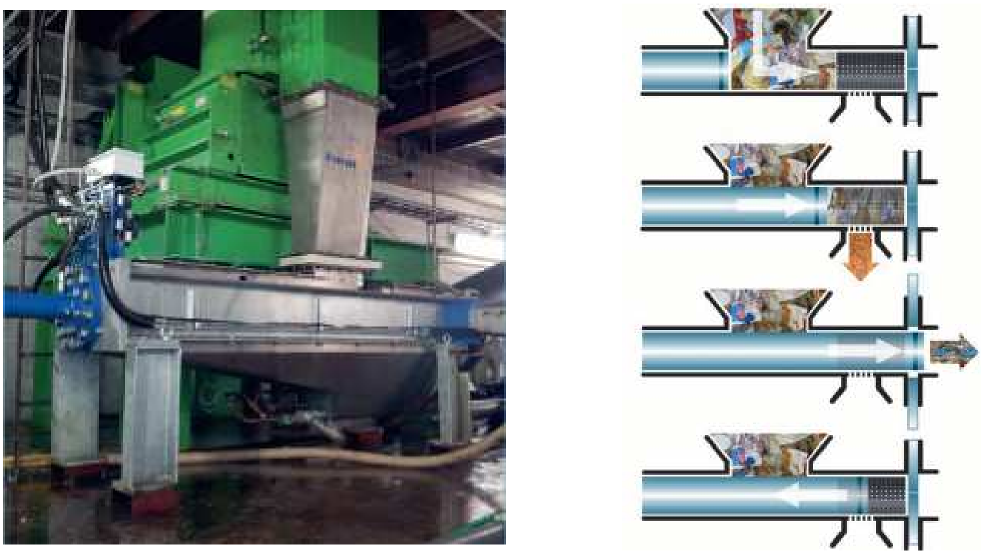


Figure 4-4 Example of separation press for smaller capacities (3 m^3/h) of biowaste (source: Finsterwalder Umwelttechnik, www.fitec.com)

Above are figures for separation press for smaller capacities (up to 3 m3/h) where the level of waste impurities treated could be food packaging. There is also technology for larger capacities and less "clean" biowaste. One of the producer is VMpress Technologies GmbH with three biogas plants (Germany, Italy and Latvia) using its separation system. They claim that the press is the "heart of the waste-to-biomethane concept" as the key is to separate desirable part (biowaste) from the undesirable part of the municipal waste. For that reason, they have developed VMpress - a waste pressurizing machine designed to physically separate waste into two fundamental fractions, an organic wet fraction with hardly any non-organics and a solid dry fraction with almost total absence of organic substances. The separation process consists of a chamber with a very strong mesh, in which waste is compressed using high pressure from 300 to 1,000 Bar. This results in changing the structure of the organic material into a fluid plasma, allowing it to be pressed through the mesh. This wet organic fraction can be treated in AD plants to generate biogas. The dry non-organic fraction contains mainly RDF, but also some minerals and metals. After the dry fraction has undergone an additional separation process by sorting out these materials, only RDF and recyclables remain. The VMpress can process from 3 up to 35 tons of waste per hour (Figure 4-5).

Figure 4-5 Example of press for mixed municipal waste (source: VMpress Technologies GmbH, http://www.vmpresstechnologies.com/)

Just the two examples of separation units indicate two possible ways how biogas production could go: the above technology (Finsterwalder Umwelttechnik) provides shredding at particle size suitable for sanitation and no additional water is necessary as separation of to 25% of TS is possible. This would lead to choose dry AD for biogas production. The other technology (VMpress Technologies) will also not require additional water but it liquefies the organic matter in its process which assumes wet AD.

Table 4-2 Types of AD methods used for biowaste(Baxter & Al Seadi, 2013)

AD method	Process type	Dry matter, %
Mono-digestion (only biowaste)	Dry	20-30
	Wet	2
Co-digestion (with animal slurry, other wastes, crops....)	Wet	8-15
Integrated	Dry	20-30

The following text will present best practice plants in the field of production of biogas from biowaste. The preferred option will be defined by finding the real composition of biowaste, the way of (bio)waste management for the City of Zagreb and the plant location which will either allow or not allow combination of other substrates or upgrading biogas. The main source for biowaste AD technology overview is material from IEA Bioenergy Task 37 and Master of Science thesis by S. Verma (Verma, 2002).

Single stage wet system is also called singe stage low solids process. Examples of this AD process can be found in Wassa, Finland; EcoTec, Germany; SOLCON at the Disney Resort Complex, Florida, USA. The pre-treatment involves removing of coarse particles and heavy contaminants.

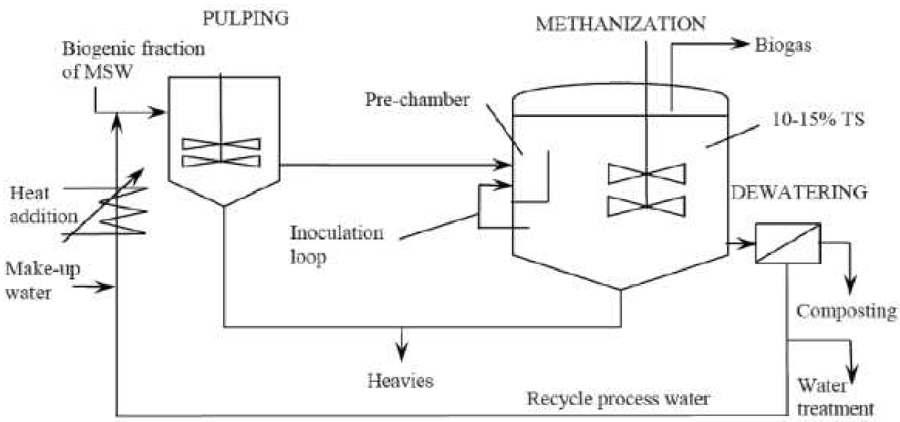


Figure 4-6 Process flow of single stage wet system AD

Advantages:

- operational simplicity
- mature technology
- low cost equipment for handling slurries

Disadvantages:

- pre-treatment steps cause a loss of 15 - 25 % VS, with corresponding decrease in biogas yield
- formation of a layer of heavier fractions at the bottom of the fermenter and floating scum at the top
- additional equipment or actions are needed for periodical removal of both scum and sediments which results either in lower biogas yield or additional investment
- shorter retention time than the average retention time of the total feed. This lowers the biogas yield and impairs sanitation of the waste
- if higher of dry solids in the feedstock occur, additional water (liquid) is needed to dilute the substrate which implies for larger volume of the fermenter and more heat for heating the fermenter plus more investment in dehydrating the digestate
- sanitation is not included which is mandated by Croatian law

Another example is wet AD of biowaste at KOMPTECH biogas plant at Markgrafneusiedl, Austria with 360 kW_{el} under full capacity of 15,000 t of biowaste. The plant covers all waste-to-biomethane process steps including:

a) pre-treatment of waste: pre-shredding, liquefaction using wet screen, screw press, sand separation, sanitation
b) AD in two digesters
c) treatment of digestate - where direct use in agriculture is not possible, waste water treatment needs to be applied prior discharging the digestate into the sewer.

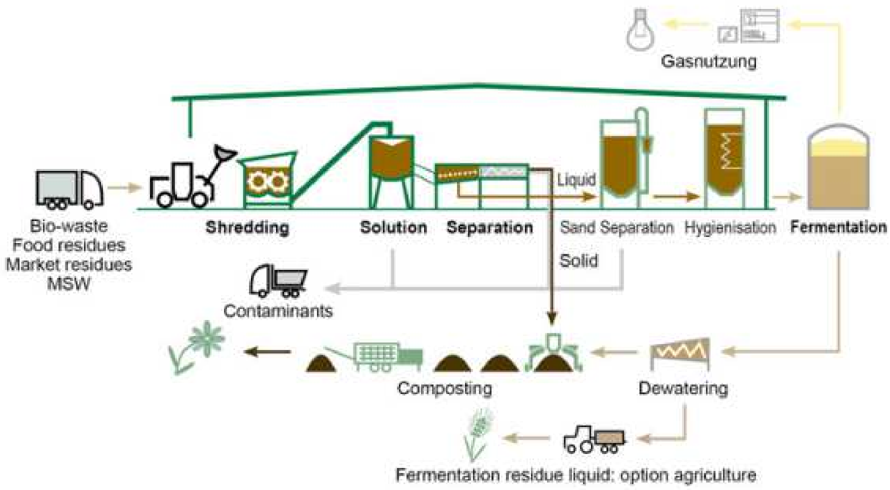


Figure 4-7 Process flow of wet AD of biowaste (KOMTECH http://www.komptech.com)

The first stage in treating contaminated organic waste is pre-shredding to open packaging. The waste can then be diluted (liquefied) in a pulper unit or pressed in a screw press to separate the liquid substrate components. Obtained biogas is used in CHP where electricity is feed into the grid and heat for sanitation process and heating of digesters.

Advantages:

- the liquefaction process is suitable for most types of bio-waste, including heavily contaminated bio-waste.
- the screw press process well suited to the treatment of separately collected organic household waste, but is not suitable for expired food because the associated packaging material cannot be treated properly.
- sanitation is included which is mandated by Croatian law
- sanitation tank is used as buffer storage to maintain consistent feed of the substrate
- compact turnkey solution

Disadvantages:

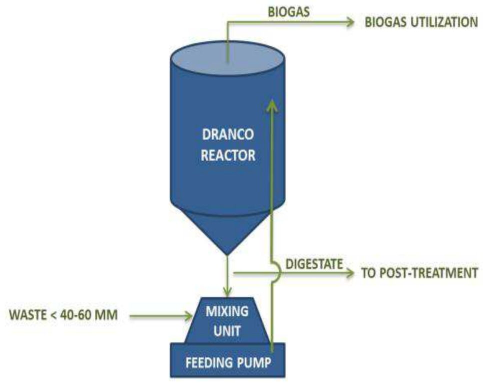
- additional water (liquid) is needed to dilute the substrate which implies for larger volume of the fermenter and more heat for heating the fermenter plus more investment in dehydrating the digestate
- shorter retention time than the average retention time of the total feed. This lowers the biogas yield.

Single stage dry systems or high solids plug flow digesters are appropriate for biowaste with higher dry matter content than 15%. The main companies using this technology are Dranco, Belgium; Kompogas, Switzerland and Valorga, France.

The patented Kompogas process (http://www.axpo.com/axpo/kompogas/en/axpo-kompogas/kompogassystem.html) is based on the continuous dry fermentation of organic waste using a plug-flow digester. The fermentation process is both thermophilic and anaerobic. In this kind of dry fermentation, the temperature in the digester is maintained at 55°Celsius. The average substrate moisture is aroun d 75% and the retention time is approximately 14 days. The Kompogas process ensures that the organic waste is degraded properly and freed of undesired spores, germs and micro-organisms.

The continuous-feed, horizontal plug-flow digester facilitates a high gas yield and offers high operating reliability thanks to the simple and efficient control systems. A low-speed agitator ensures the optimum formation of methane. The special design and arrangement of the agitator paddles also prevents sedimentation of dense media materials in the fermentation substrate.

Fermentation involves various upstream and downstream processes. Via a feed unit, the organic waste is fed into the fermenter for treatment. Subsequently, the substrate is automatically conveyed to the fermenter. A discharge pump withdraws the hard substrate. Around one-third of this substrate is pumped back for inoculation. The remaining quantity is either pushed out of the fermenter or mixed with green waste using the partial flow process.



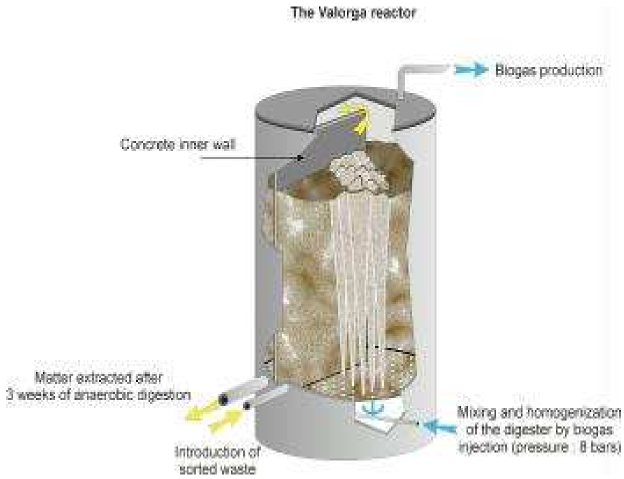


Figure 4-8 Examples of process flows for different single stage dry systems (left: Dranco http://www.ows.be/wp-content/uploads/2013/02/DRANCO-2013.jpg, right: Valorga http://www.valorgainternational.fr/en/

Both Valorga and Dranco are among the top companies in using dry AD in waste-to-energy concept. Valorga International (http://www.valorgainternational.fr/en/) has worldwide references in 19 methanization treatment plants today representing treatment capacities in a range from 10,000 to 300,000 tons per year. Until 2007, about 2 million tons of waste have been treated in Valorga plants. DRANCO (DRy ANaerobic COmposting) (http://www.ows.be/biogas-plants/) technology has emerged from "dry" digestion that occurs spontaneously at the landfills. Due to its origin, the DRANCO digestion technology has often been applied for the treatment of mixed or residual household waste, which were commonly landfilled. These plants operate at a dry matter content in the digester of up to 40 %. However, DRANCO is a widely applicable technology that can treat different kinds of waste streams. In other DRANCO plants, source separated organics and yard / food waste is being treated at a dry matter content of 20 to 35%. It has references in 25 European and 3 Asian biogas plants where some of them run also on agricultural feedstock.

Advantages:

- no need for additional water (liquid)
- higher biogas yield than at wet single stage AD

Disadvantages:

- more robust and expensive handling equipment (screws, pumps, conveyor belts)
- less liquid (waste water) to be treated for discharge

Multi-stage AD process

The introduction of multi-stage AD processes was intended to improve digestion by having separate reactors for the different stages of AD, thus providing flexibility to optimize each of these reactions. Typically, two reactors are used, the first for hydrolysis/liquefaction-acetogenesis and the second for methanogenesis.

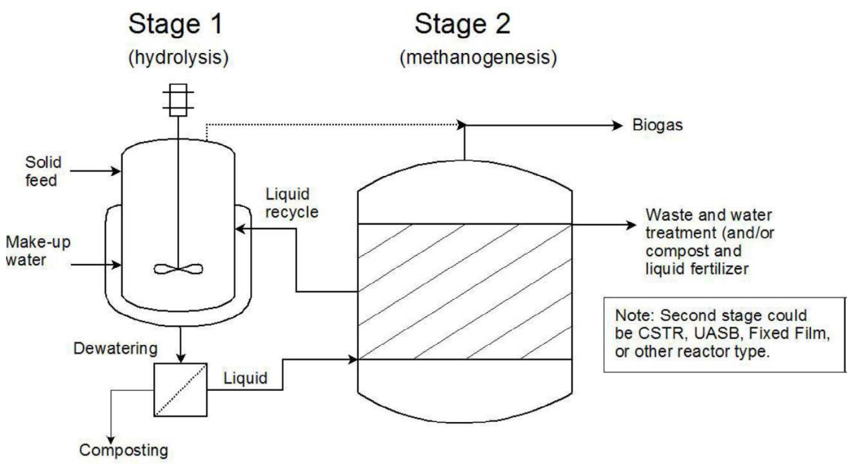


Figure 4-9 Process flow for multi-stage AD process

There are also dry (high solids) and wet (low solids) multi-stage AD processes.

Examples of **wet multi-stage AD processes** are Pacques (Netherlands) and the BTA Process (Germany, Canada). They both maintain the level of dry matter at 10%.

Pacques technology comes from waste water treatment and it plays both roles at the bioenergy market: biogas technology supplier and biogas producer. Namely, it offers a wide range of equipment that is used in waste-to-energy concept, a part of AD: desulphurisation unit; nitrogen removal unit, different filters and membranes, settling systems etc. (http://en.paques.nl/pageid=68/BIOPAQ%C2%AE.html). Over 800 Paques' BIOPAQ® installations produce biogas that meet the natural gas requirements of 1.7 million European households.

BTA Process (http://www.bta-international.de/en/der-bta-prozess/der-bta-prozess0.html) is the original of hydromechanical waste treatment. It comprises two central steps: (1) the hydromechanical pre-treatment and (2) the subsequent biological step towards AD (Figure 4-10). It has 19 references where they specially highlight four MBT plants (two in the UK and two in Portugal), four biowaste methanisation plants (Spain, Belgium, Germany and Canada) and three biowaste co-digestion plants (Germany, Luxemburg and Italy).

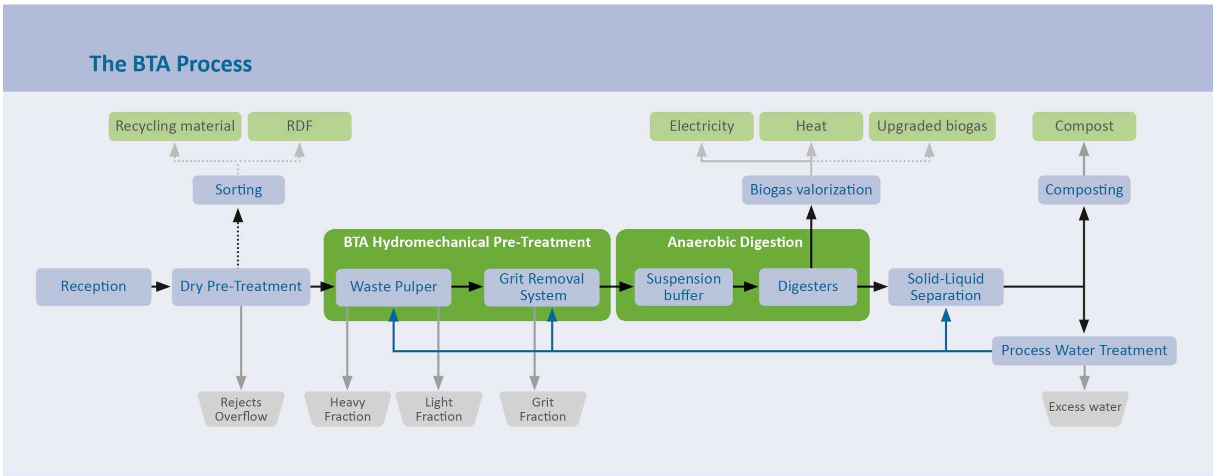


Figure 4-10 BTA Process scheme (source: BTA International, http://www.bta-international.de/en/der-bta-prozess/der-bta-prozess0.html)

Example of **dry multi-stage AD processes** is Biopercolat (Germany) and the BTA Process (Germany, Canada). They both maintain the level of dry matter at 10%.

Biopercolat Plant is managed by WEHRLE Umwelt GmbH and WEHRLE-WERK AG consortium (http://www.wehrle-umwelt.com/dynasite.cfm?dsmid=7702&dspaid=36407) and is designed to operate on 100,000 t/yr of municipal waste (so called ZAK process).

The biological processing plays a key role in the ZAK-concept mechanical biological waste treatment. Firstly the conversion of biogenic waste creates energy in the form of biogas and process heat. Secondly, the waste volume is reduced through degradation and dewatering. The result of this is that through the BIOPERCOLAT®-process the waste is optimised for subsequent biological drying. In addition to the percolation of water through the waste, the BIOPERCOLAT®-process also treats the wastewater through fermentation and aerobic processes.

Multi-stage AD processes have the same advantages and disadvantages as the single stage AD processes where sometimes higher capital costs are not justified by higher biogas yields.

Advantages:

- higher biogas (energy) yield per tonne of biowaste
- sophisticated process
- allows resistance to high ammonium concentrations in the biowaste

Disadvantages:

- short-circuits
- foaming
- formation of layers of different densities
- specific pre-treatment
- higher capital investment

Batch digesters

Batch digesters are usually used with material with high solids content. They are loaded with feedstock (truck loaders or automatic feeders), subjected to reaction (AD), and then are discharged and loaded with a new batch. The batch systems seem like controlled landfills but with much higher biogas yields due to the controlled conditions for AD: (1) continuous recirculation of the percolate liquid (leachate) that maintains inoculation and (2) reaction occurs at higher temperatures than landfills.

In general, there are three types of batch systems:

- Single stage batch digester (e.g. Biocel process in Lelystad in the Netherlands, http://www.ncbi.nlm.nih.gov/pubmed/11382005)
- Sequential batch digester (e.g. Sequential Batch Anaerobic Composting - SEBAC, http://www.docstoc.com/docs/22545000/Sequential-Batch-Anaerobic-Composting-of-Municipal-and-Space)
- Hybrid batch or Upflow Anaerobic Sludge Blanket (UASB) reactor which is similar to multi-stage AD process.

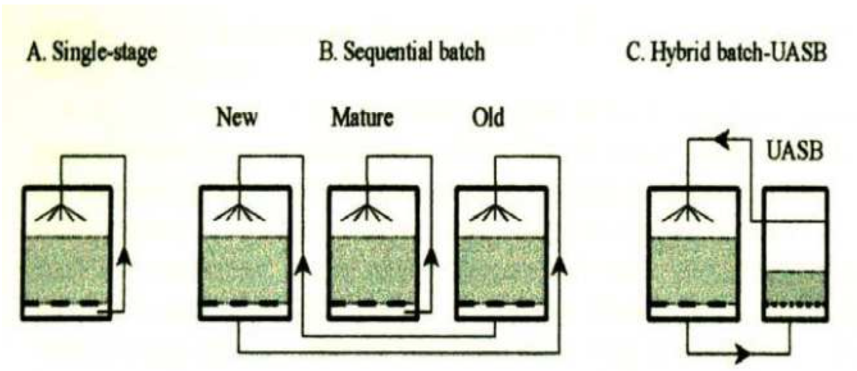


Figure 4-11 Types of batch digesters

One of the leading companies in batch system is Bekon, Germany (http://www.bekon.eu/) with references of 24 biogas plants over Europe. It has its origins in MSW management and waste-to-energy concepts but it spreads its business to dry AD of energy crops as well.

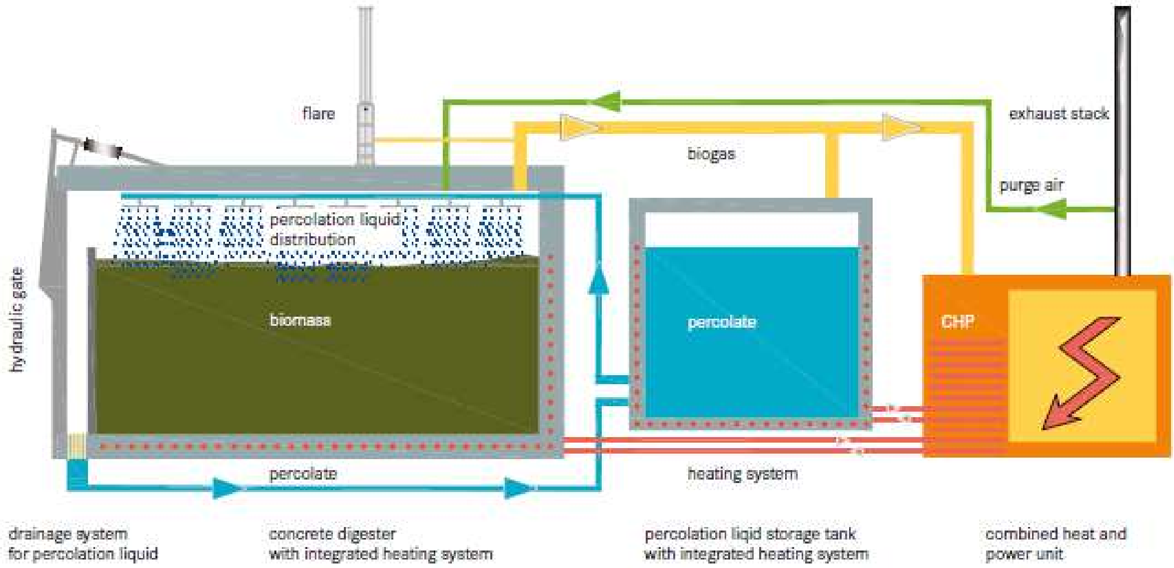


Figure 4-12 BEKON dry fermentation process flow

Figure 4-13 BEKON loading the fermenting garages

Advantages:

- easier and cheaper to build
- technically simple, less maintenance costs
- more robust against inhibitors than continuous digesters

Disadvantages:

- produces less biogas
- has lower loading rate than continuous digesters
- risk of explosion during emptying the reactor
- require more space than continuous digesters

Mechanical biological treatment

Mechanical biological treatment (MBT) is the preferred technology at Croatian regional waste management centres (Scenario 4). The general material flow is shown in the Figure 4-14.

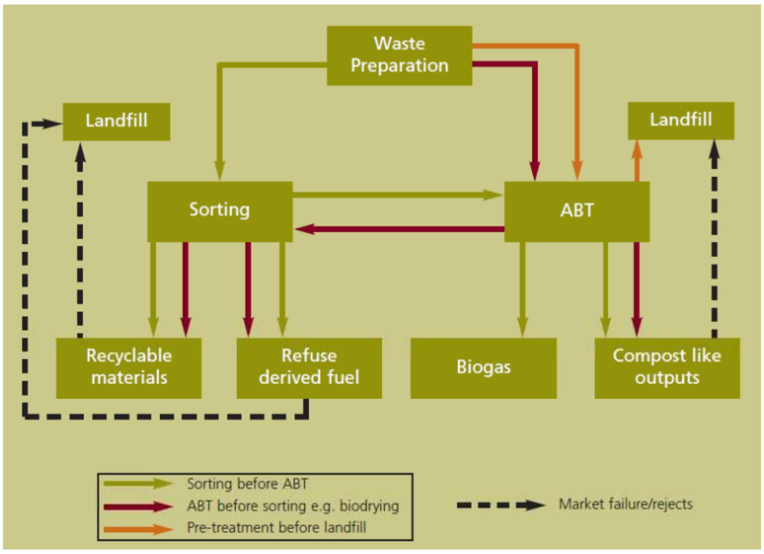


Figure 4-14 MBT waste-to-energy flow

As described in the beginning of this chapter, MBT also allows achieving waste-to-energy concept from biowaste but assumes that biodegradable fraction of MSW is not source separated but collected in bulk. A representative from mature technologies was described

(VM Press Technologies) but there are also attempts to have waste-to-energy concept without mechanical pre-treatment.

An example is REnescience technology, Denmark, (http://www.dongenergy.com/renescience/Pages/index.aspx) that uses enzymes to separate mixed MSW into different fractions without need for mechanical pre-treatment (e.g. shredding). Namely, the first step is a non-pressurised thermal pre-treatment where the structure of the biowaste is opened to make it accessible for the enzymes in the liquefaction. Advantages of this system would be less process energy needed to reach the biodegradable fraction of MSW.

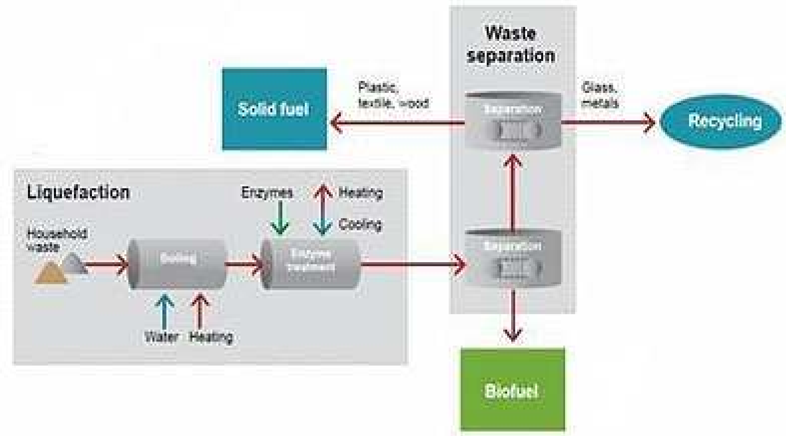


Figure 4-15 Process flow for REnescience technology

The material provided in this section intends to provide information to the beneficiary on the best practice plants related to the respective technologies that depend on the various inputs that are still not defined in waste management concept for the City of Zagreb. EIHP has no preferences and does not represent interests of any company provided in the material. The selection of the technology provider would be too early given the information.

Unfortunately, biogas technology sector is not developed in Croatia which means that all technology providers would be foreign suppliers. Most of them have already representative office opened either for Croatia or region which makes them locally available technology. However, none of the represented companies has references in biogas plants in Croatia.

A small conclusion of this waste-to-energy technology overview could be that wide variety of technology exists at the market with respectable companies that prove their excellence in numerous reference plants in Europe and all over the world. Waste-to-energy concept can be closed regardless on the waste management concept implemented for the City of Zagreb as biogas can be produced from both source separated biowaste and biowaste collected as bulk mixed MSW. The difference will be in cost allocation - in source separated biowaste, the cost burden will be more on the waste management concept (more containers, educational campaign, changes in waste collection patterns...) while in bulk MSW the costs of waste collection remain the same while the investments in technology for energy recovery will be higher. From the point of energy sustainability, less process energy is needed if biowaste is collected separately.

Biogas Upgrading technology - biomethane production

The choice of biogas upgrading technology is less complicated issue and it is defined by desired biomethane quality (national legislation), hourly production capacity and biomethane demand. Overview of upgrading technologies for biogas to biomethane is shown in the Figure 4-16.

Biogas upgrading demands energy. Different upgrading technologies demand different energy intake in terms of both quantity and shape. Figure 4-17 shows energy demand for an upgrading biogas plant of 1,000 Nm3/h capacity.

Figure 4-18 provides an overview o key parameters of six commercially available biogas upgrading technologies.

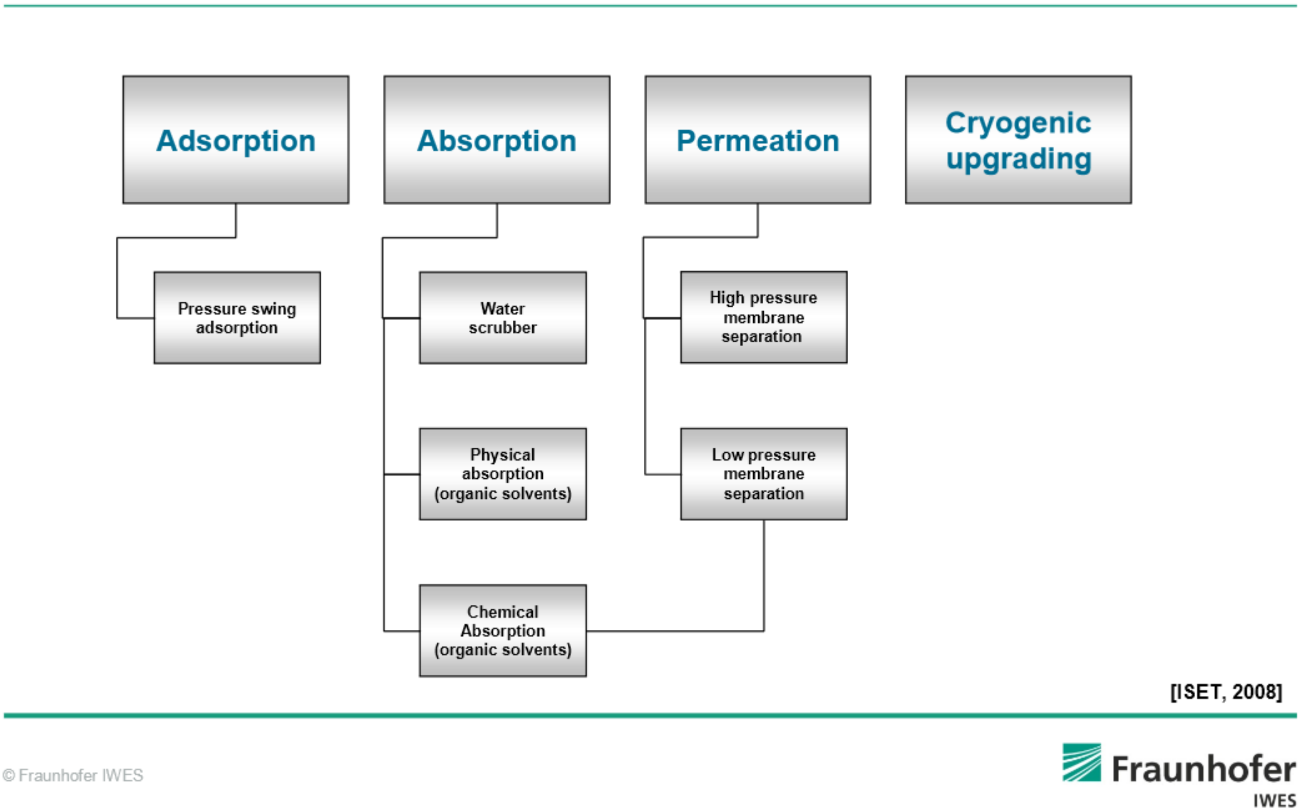


Figure 4-16 Biogas upgrading - technology overview (Fraunhofer, IEE UrbanBiogas, 2012)

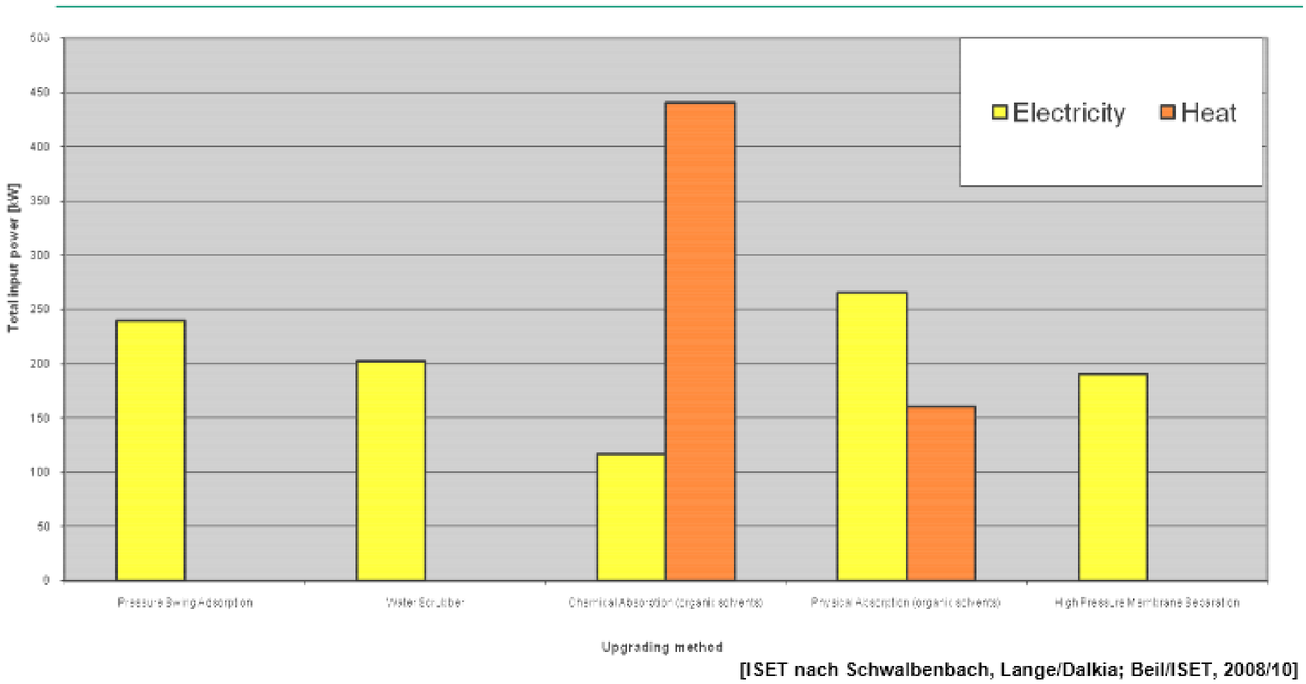


Figure 4-17 Energy demand upgrading technologies: Total input power (1,000 Nm^3/h biogas) (Fraunhofer, IEE UrbanBiogas, 2012)

		PSA	Water scrubber	Physical absorption (organic solvents)	Chemical absorption (organic solvents)	Membrane (high pressure, dry)	Cryogenic
Electricity demand	$[kWh/m^3_{BG}]$	~ 0,2 - 0,25	~ 0,2 - 0,3	0,23-0,33	~0,15	~ 0,25	0,18-0,33
Heat demand (temperature level)	[°C]	No	No	55-80	~ 160	No	No
Operation pressure	[bar]	4-7	5-10	4-7	0,1	5-10	
Methane loss	[%]	1-5	0,5 - 2	1-4	0,1		0,5 (?)
Exhaust gas treatment suggested (methane loss >1%)		Yes	Yes	Yes	No	Yes	Yes
Precision desulphurization required		Yes	No	No	Yes	Suggested	Yes
Water demand		No	Yes	No	Yes	No	No
Demand on chemical substances		No	No	Yes	Yes	No	No

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Figure 4-18 Key parameters of biogas upgrading technologies) (Fraunhofer, IEE UrbanBiogas, 2012)

Given the situation in the City of Zagreb (Robert Bošnjak et al., 2013), two technologies for biogas upgrading were selected:

- pressurised water scrubbing
- PSA.

More detailed description of this technologies can be found at web sites of IEE UrbanBiogas (www.UrbanBiogas.eu) and IEE BiomethaneRegions (www.BiomethaneRegions.eu).

Pressurised water scrubbing physically bounds the absorbed gas components to the scrubbing liquid, in this case water. Carbon dioxide has a higher solubility in water than methane and will therefore be dissolved to a higher extend, particularly at lower temperatures and higher pressures. In addition to carbon dioxide, also hydrogen sulphide and ammonia can be reduced in the biomethane stream using water as a scrubbing liquid. The effluent water leaving the column is saturated with carbon dioxide and is transferred to a flash tank where the pressure is abruptly reduced and the major share of the dissolved gas is released. As this gas mainly contains carbon dioxide, but also a certain amount of methane (methane is also soluble in water, but to a smaller extent) this gas is piped to the raw biogas inlet. If the water is to be recycled back to the absorption column, it has to be regenerated and is therefore pumped to a desorption column where it meets a counter current flow of stripping air, into which the remaining dissolved carbon dioxide is released. The regenerated water is then pumped back to the absorber as fresh scrubbing liquid (www.BiomethaneRegions.eu).

Advantages are:

- no heat demand
- methane loss can be minimised
- no pressurised desulphurisation is required
- no demand on chemical substances

Disadvantages are:

- water demand
- biomethane contains oxygen and nitrogen
- biomethane is saturated with water - needs drying (i.e. glycol scrubbing)
- exhaust gas treatment is suggested (methane loss >1%)

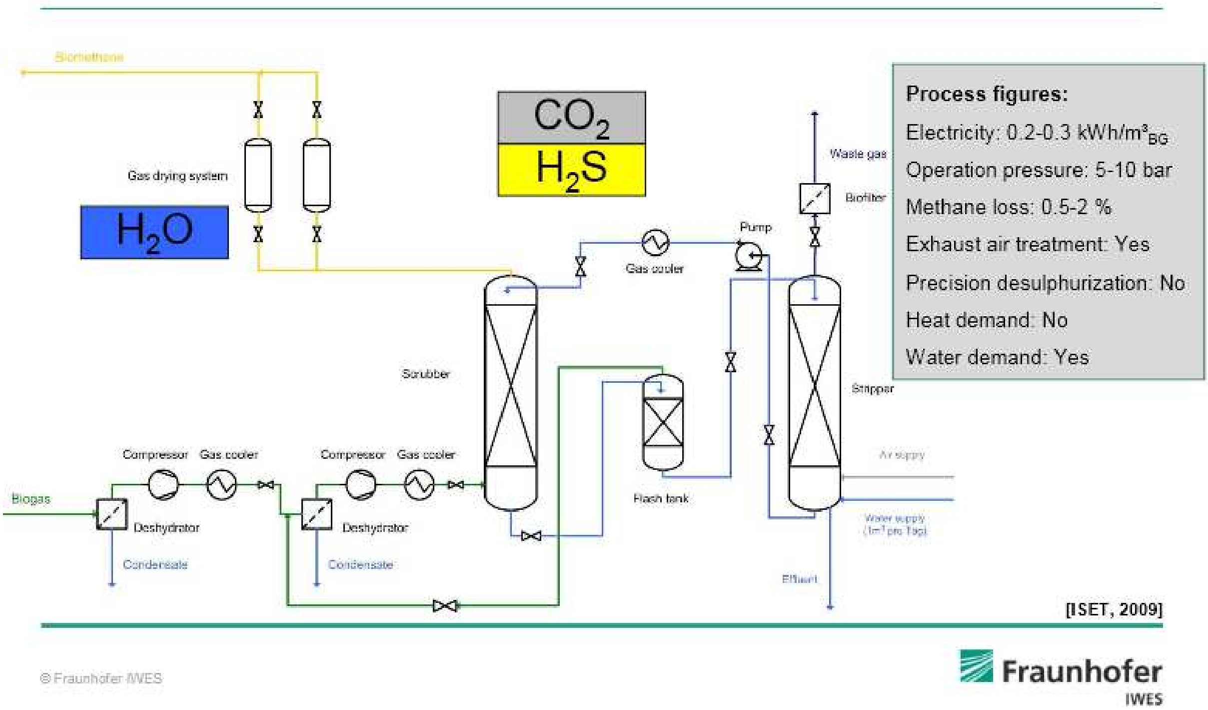

Figure 4-19 Flowsheet pressurised water scrubbing with process figures (Fraunhofer, IEE UrbanBiogas, 2012)

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Figure 4-20 Water scrubber (with regeneration) upgrading unit (Fraunhofer, IEE UrbanBiogas, 2012)

Pressure Swing Adsorption (PSA) is based on different adsorption behaviour of various gas components on a solid surface under elevated pressure. Usually, different types of activated carbon or molecular sieves (zeolites) are used as the adsorbing material. These materials selectively adsorb carbon dioxide from the raw biogas, thus enriching the methane content of the gas. After the adsorption at high pressure the loaded adsorbent material is regenerated by a stepwise decrease in pressure and flushing with raw biogas or biomethane.

During this step off-gas is leaving the adsorber. Afterwards, the pressure is increased again with raw biogas or biomethane and the adsorber is ready for the next sequence of loading (www.BiomethaneRegions.eu).

Advantages are:

- no heat demand
- methane loss can be minimised
- no demand on chemical substances
- no water demand

Disadvantages are:

- pressurised desulphurisation is required
- exhaust gas treatment is suggested (methane loss >1%)

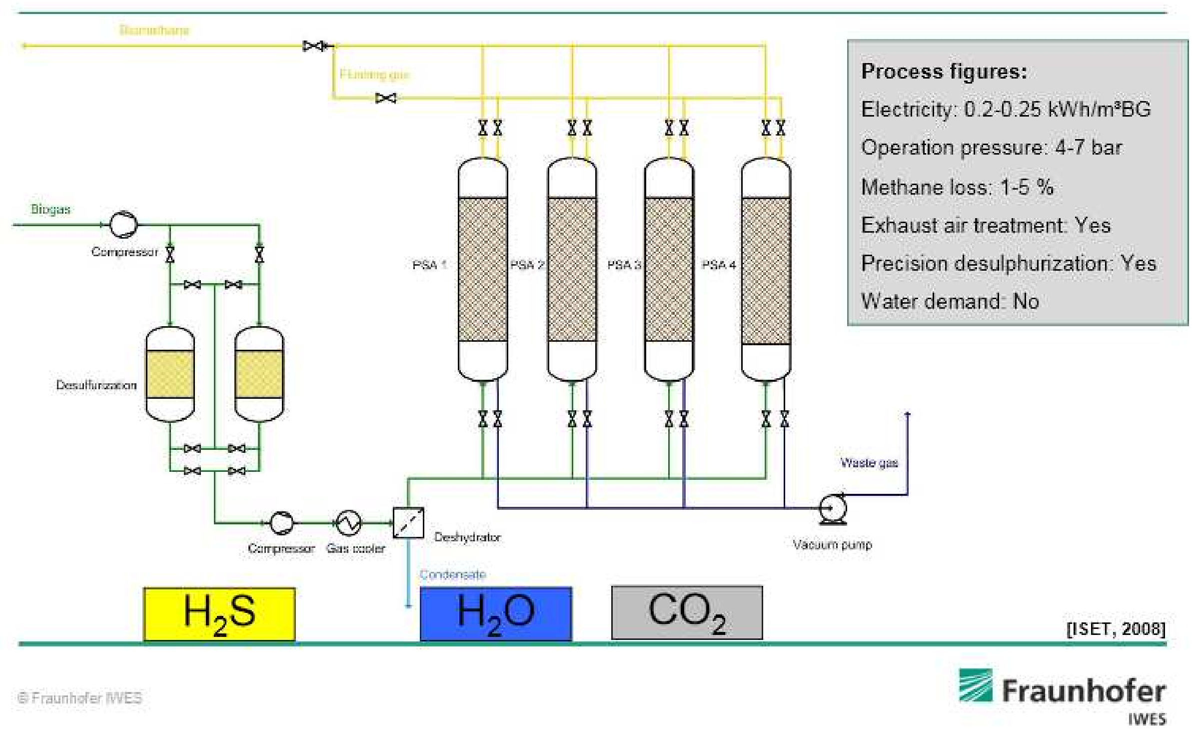

Figure 4-21 Flowsheet of PSA upgrading process with process figures (Fraunhofer, IEE UrbanBiogas, 2012)

Figure 4-22 PSA upgrading unit (Fraunhofer, IEE UrbanBiogas, 2012)

4.2 Plant location

In absence of concrete plant locations, EIHP has chosen to provide methodology for decision makers how to assess a location for biogas/biomethane production from the technical point of view. Naturally, this methodology would be a piece of a much larger puzzle that would lead to the optimal location of biogas/biomethane production for the City of Zagreb.

The aim of this section is to develop the methodology for technical - energy evaluation of possible locations for production of biogas/biomethane. The methodology will be demonstrated on several real-life sites in the City of Zagreb. It is important to emphasise that this methodology is referring only to the technical pre-conditions for biogas/biomethane production in real world. All other aspects that are necessary for final implementation of waste-to-biomethane concept (waste management, spatial aspects, environmental protection aspects, socio-economic aspects...) are not part of this research.

EIHP has presented this methodology on several occasions:

- 3rd Task Force Meeting for Biogas/biomethane production - 10th June 2013
- Public Consultation event - 17th June 2013
- 2nd Task Force Meeting for Biogas/biomethane use - 9th July 2013
- Stimulation of Investments in Biomethane in Croatia - 10th July 2013.

At each of the event, both the audience and experts were invited to contribute to the methodology improvement by presenting the publicly well known obstacles in deciding for the real location. The overall outcome is that the methodology has been positively appraised and upgraded by two additional criteria. The following text provides insight in time-line of methodology development.

The methodology starts with four given criteria in the Biogas/biomethane Production template (Fraunhofer, 2012):

1. road access
2. neighbourhood acceptance
3. sufficient electrical power supply access
4. access to low to medium pressure natural gas grid.

Neighbourhood acceptance criteria is very difficult to assess for the City of Zagreb as it would demand public opinion survey that was not executed. In general, there is a strong NIMBY attitude among the citizens although UrbanBiogas survey has shown that citizens are willing to accept biogas/biomethane facility running on waste under certain conditions that need to be tackled (Bošnjak, Robert & Vidović, Danko, 2012). This criteria has been excluded from the evaluation methodology as it belongs more to the socio-economic aspects that need to be thoroughly addressed when actual location will be selected.

Access to low to medium pressure natural gas grid criteria has been transformed to Access to medium pressure natural gas grid due to the City of Zagreb's natural gas grid characteristics. More details on access to natural gas grid and biomethane use in general for the City of Zagreb can be found in Biomethane Use Concept for the City of Zagreb (Robert Bošnjak et al., 2013) - the final part of waste-to-biomethane concept for the City of Zagreb.

EIHP has added five additional criteria for technical evaluation of the viable biogas/biomethane production location:

1. economic feasibility of the investment via maximisation of biogas production
2. availability of (additional) substrate
3. maximisation of useful energy obtained from biogas
4. sufficient space for the plant

5. minimal spatial alterations.

During the Public Discussion event (17th June 2013 at Public Tribune of the City of Zagreb), a biogas/waste water expert (Kulišić, 2013) suggested an additional criteria that was accepted:

6. waste water treatment facility

In addition, at 2nd Task Force Meeting for Biogas/biomethane use (Jurić, 2013), additional criteria was suggested by a representative from Ministry of Agriculture, Unit for Water Management:

7. water protection zones.

At the discussion, EIHP has said that the methodology was demonstrated on locations suggested by the draft of Waste Management Plan for the City of Zagreb and Spatial Plan of the City of Zagreb envisaged for some kind of waste management and that water protection zones were included in that selection. It turned out that this was not the true so EIHP has accepted this additional criteria. The source for assessing water protection zones is a document A Summary of Strategic Study on Environmental Impact of the Draft Waste Management Plan for the City of Zagreb by 2015 (OIKON, IGH, IPZ Uniprojekt, 2012).

Finally, the methodology is consisted of 10 criteria. The actual sites in the City of Zagreb on which methodology was demonstrated are selected based on the Spatial Plan of the City of Zagreb (Prostorni plan Grada Zagreba) which is referring to the additional criteria no. 5: minimal spatial alterations.

Spatial Plan of City of Zagreb (Prostorni plan Grada Zagreba) defines locations for Overall waste management system for City of Zagreb:

1. **Resnik**: Location for waste management (thermal waste processing plant)
2. **Prudinec**: Waste disposal is due by 2010. The site is to be closed and remediated.
3. **Novačica**: ex-clay excavation site, to be converted for construction waste recycling site.

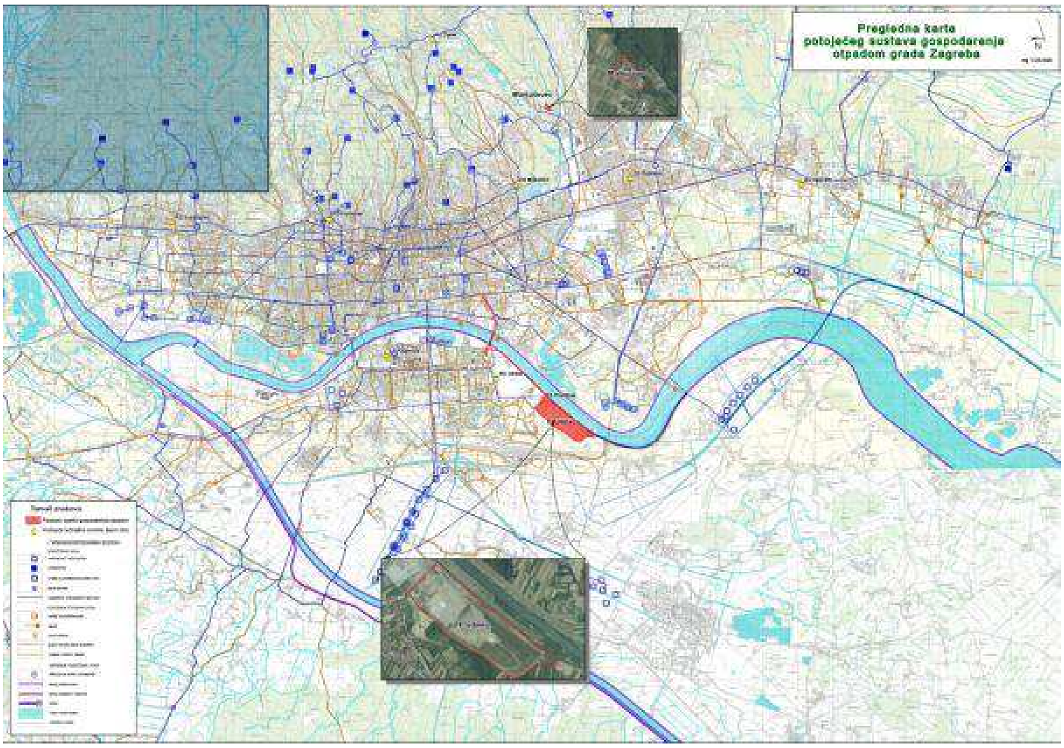

Figure 4-23 Excerpt from Proposal on Amendments on Spatial Plan of City of Zagreb: existing waste management sites

Proposal on Amendments on Spatial Plan of City of Zagreb (Prijedlog izmjena i dopuna Prostornog plana Grada Zagreba, 2012), extends waste disposal at Prudinec by 2015 and suggests locations that are under the analysis as possible sites for establishing the Overall waste management system for City of Zagreb. Locations are spatially presented at the **Error! Reference source not found.** and are:

1. **Resnik** - is under analysis on possibilities for sorting and pre-treatment of waste, temporary storage etc. on defined location for thermal waste processing plant and next to Central Waste Water Treatment Facility (WWTF)
2. **Kostanjek** - considered as recycling and disposal site for non-hazardous construction waste
3. **Resnik - Ostrovci**: investigated for possibility of recycling and non-hazardous construction waste disposal
4. **Markuševac** - examined for continuation as a composting site for biodegradable waste
5. **Novačica** - considered for management of inert waste in order to remediate the site
6. **Jankomir** - considered for treatment site for bulky waste without hazardous components and without disposal of any waste
7. **Dumovečki Lug** - considered as location for Overall waste management centre for City of Zagreb with all appropriate facilities: from collection, pre-treatment and treatment of all waste categories, except radioactive, including separate collected waste, waste sorting, recycling, biological, mechanically-biological, physicochemical and thermal waste treatments.
8. **Savica - Šanci**: next to the existing thermo-power plant, considered as a reserve location for thermal waste processing plant

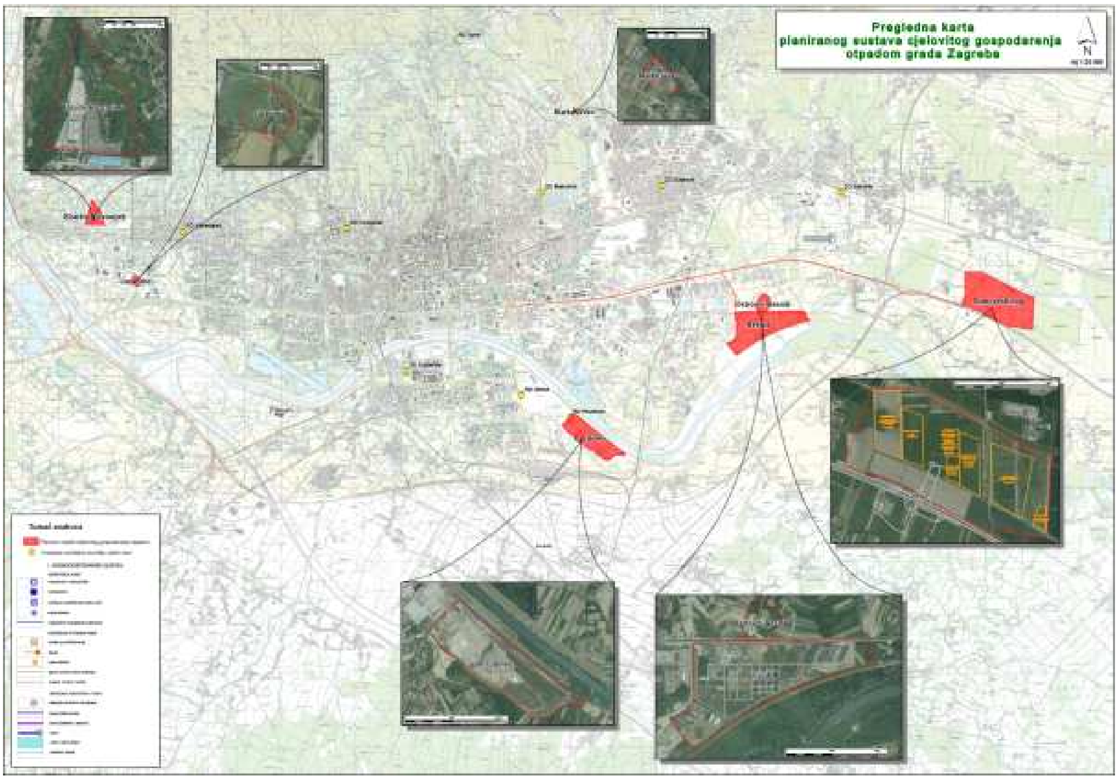

Figure 4-24 Excerpt from Proposal on Amendments on Spatial Plan of City of Zagreb: future waste management sites

Currently, biodegradable waste is used at composting facilities (Markuševac and Prudinec). The composting sites are managed by sister company of ZAGREB CH, Zrinjevac, responsible for landscape management of City of Zagreb.

Biodegradable waste from kitchens and cantinas is treated at an intensive aerobic decomposition facility followed by biodegradation within the composting site Prudinec.

Draft Waste management plan (Prijedlog izmjena i dopuna Prostornog plana Grada Zagreba, 2012), states Dumovečki Lug as the location for biogas plant to treat the separately collected biowaste from households, catering industry etc.

Since all future waste management sites are under the consideration and it is evident that existing landfilling site is at the limit of its capacity, placing "waste to energy" concept for City of Zagreb at a specific site seems to be rather challenging.

The Study demonstrates methodology for technical evaluation of biogas/biomethane production on the four locations that are considered as parts of Overall Waste Management Plan for City of Zagreb:

- **Location 1:** Prudinec - area of existing land-filling site
- **Location 2:** Resnik - joint areas of existing waste water management site and considered thermal waste processing plant
- **Location 3:** Markuševac - area of existing composting plant
- **Location 4:** Dumovečki Lug - area of considered location for Overall waste management centre for the City of Zagreb

According to the proposed methodology for evaluation of possible biogas/biomethane sites, the outcomes are:

1. **Location 1:** Prudinec - area of existing land-filling site

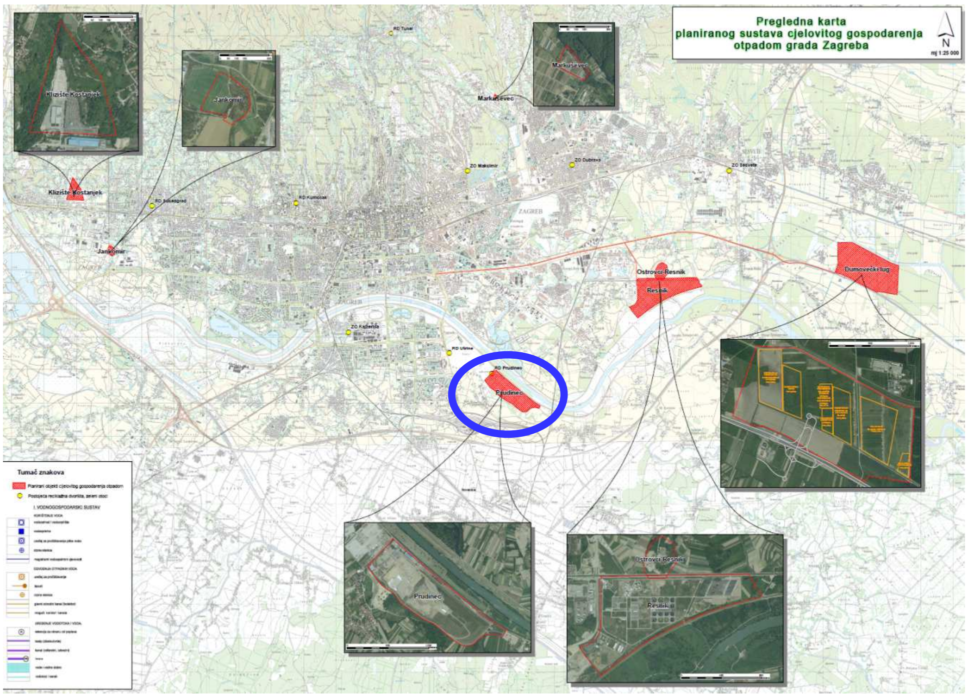

Figure 4-25 Location 1: Prudinec - area of existing land-filling site

This site is considered as it has already well developed road access and has sufficient electrical power supply. Neighbourhood is already receiving compensation fee for living next to the landfill but occasionally demonstrates its discontent toward waste management policy in the City of Zagreb. The nearest access to medium pressure natural gas grid is about 5.2 km (Figure 4-26).

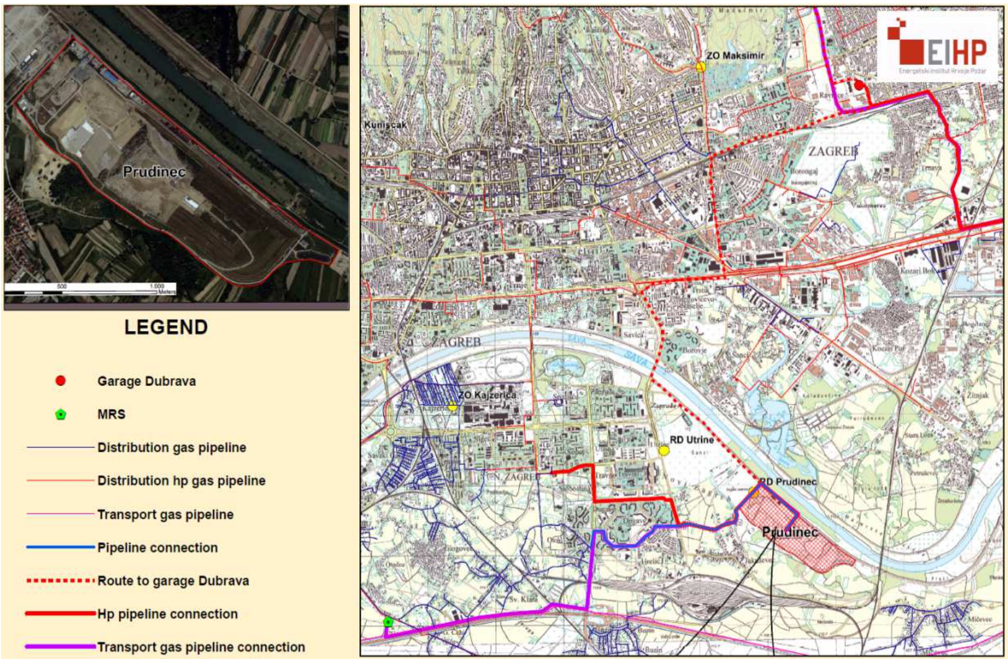

Figure 4-26 Location 1: access to the natural gas grid

The main additional criteria for investigating this location is existing landfill gas power plant and possible improvements in collection of landfill gas even after the remediation. At Prudinec, there is a landfill gas power plant, established in 2004. It has two gas engines (525 m^3/h/engine each) and total electric capacity 2x1 MW. From end 2004 till September 2010, the power plant generated 29 GWh from 29.96 Mm^3 landfill gas collected with 68 probes. Currently, the power plant is under reconstruction and will start operating in the near future (by the end of 2013) (Krivičić, 2013).

The current Feed-in tariff (FiT) system does not support preferential price for electricity from landfill gas and the electricity is purchased at average production price (0.53 HRK/kWh or 0.07 €/kWh). This could motivate power plant management to consider entering biomethane market by joining its biogas production with biowaste biogas plant in biogas upgrading facility.

Conversion efficiency of primary energy of biogas to electricity is up to 35% which inclines that biomethane use would be better at maximisation of useful energy obtained from biogas criteria. In addition, biogas from landfill could be retrieved for biogas upgrading facility in very short time. Landfill gas yield will decrease over a period of time but biowaste collection (if source separated waste management concept is implemented) will increase which is almost ideal combination of two sources for very short term biomethane use for the City of Zagreb. The more biogas is available for upgrading, the lower specific upgrading costs would be due to the economies of scale.

Area of existing land-filling site has sufficient space for biogas production and upgrading plant.

As existing waste management facility, it will require minimal spatial alterations and has waste water protection measures (leachate management) implemented. However, waste water treatment facility will be necessary if wet AD is chosen. This location belongs to III.

category of water protection zones (Limitation and Control Zone) that allows biogas production from biowaste only with special (additional) waste water management measures as described in decision on protection of water springs for the City of Zagreb (Odluka o zaštiti izvorišta Stara Loza, Sašnjak, Žitnjak, Ivanja Reka, Petruševac, Zapruđe i Mala Mlaka, 2007).

Combining all above stated, economic feasibility of the investment via maximisation of biogas production criteria highlights this site as a plausible location for biogas/biomethane production.

2. **Location 2: Resnik** - joint areas of existing waste water management site and considered thermal waste processing plant

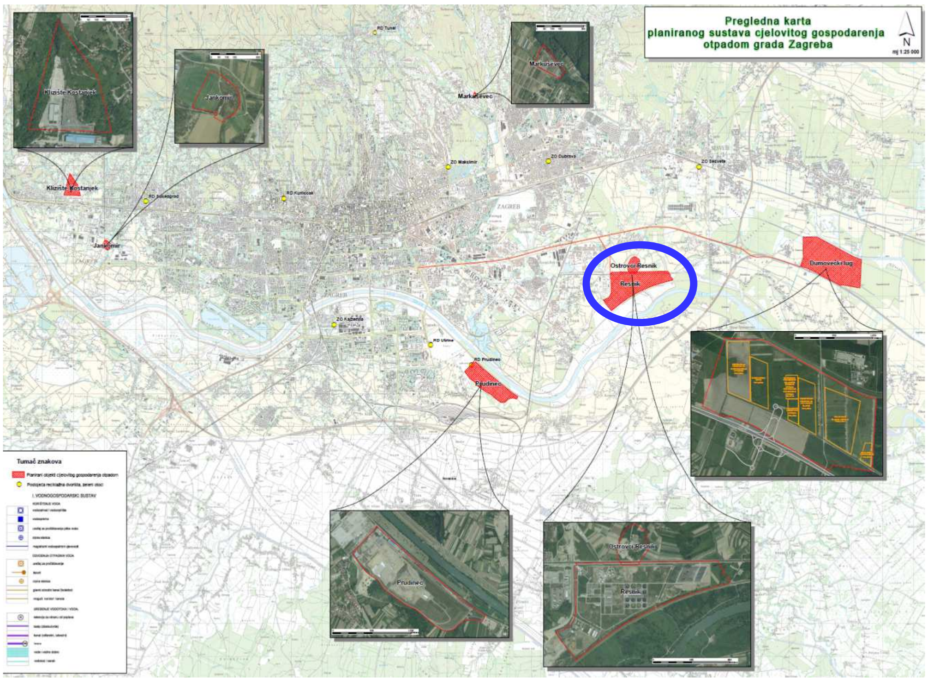

Figure 4-27 Location 2: joint areas of existing waste water management site and considered thermal waste processing plant

This site is considered mostly due to the existing biogas plant and availability of existing facilities for treating the waste water after the (wet) AD process. According to our opinion, it has limited road access for regular biowaste supply but that criteria should be verified more by someone directly involved in waste management. Delivery would be through populated suburb of City of Zagreb (nuisance due to increased traffic) but the plant itself is sufficiently remote from the settlement. The location has sufficient electrical power supply. Access to medium pressure natural gas grid is about 0.5 km (Figure 4-28).

The main additional criteria for investigating this location is existing power plant operating on biogas from waste water treatment sludge and existence of waste water treatment facility. There are numerous examples where biowaste and primary and excess sludge from waste water treatment plants are combined in one biogas production and use plant. Examples are. Hnriksdal biogas plant of Stockholm Vatten (Sweden), Linköping biogas plant of Svensk Biogas (Sweden) which also includes incineration plant, Borås biogas plant (Sweden) is connected with 7 km biogas pipeline with WWTP to combine upgrading (Hahn, 2012); Grindsted Municipality Biogas Plant (Denmark) (Martins Niklass et al, 2012).

The Central WWTF has a biogas plant with installed capacity of 2x1,5 MWel. It uses biogas in a CHP where a part of heat is used internally and electricity is sold to the grid. The current

Feed-in tariff (FiT) system does not support preferential price for electricity from landfill gas and the electricity is purchased at average production price (0.53 HRK/kWh or 0.07 €/kWh). This could motivate power plant management to consider entering biomethane market by joining its biogas production with biowaste biogas plant in biogas upgrading facility.

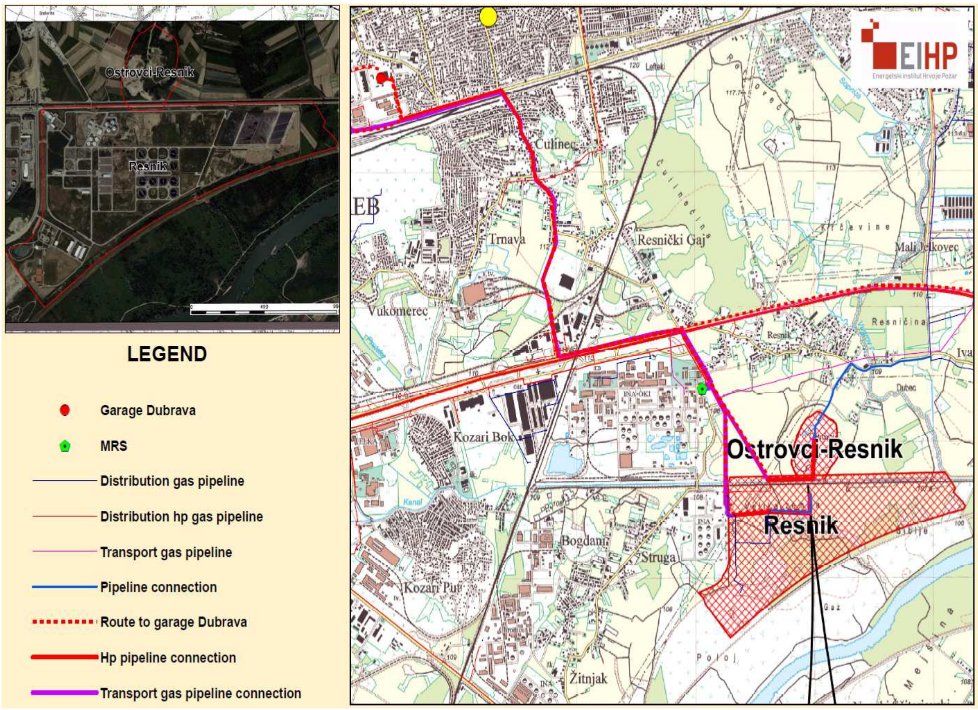

Figure 4-28 Location 2: access to the natural gas grid

Conversion efficiency of primary energy of biogas to electricity is up to 35% which inclines that biomethane use would be better at maximisation of useful energy obtained from biogas criteria. The more biogas is available for upgrading, the lower specific upgrading costs would be due to the economies of scale.

Area of this location has sufficient space for biogas production and upgrading plant. In addition, biogas production from biodegradable fraction of MSW could improve efficiency of considered thermal waste treatment facility nearby. One technology of waste treatment (separation) could be installed for both facilities. Produced digestate could be dried and as used as RDF.

As this area has already existing Central WWTP, it will require minimal spatial alterations for biogas/biomethane production and it fits well in the considered waste management concept (existing waste water treatment facility, using digestate as RDF in thermal facility). This location belongs to III. category of water protection zones (Limitation and Control Zone) that allows biogas production from biowaste only with special (additional) waste water management measures as described in decision on protection of water springs for the City of Zagreb (Odluka o zaštiti izvorišta Stara Loza, Sašnjak, Žitnjak, Ivanja Reka, Petruševac, Zapruđe i Mala Mlaka, 2007).

Combining all above stated, economic feasibility of the investment via maximisation of biogas production criteria, symbiosis with existing (biogas production, waste water treatment facility) and considered (thermal waste treatment facility) facilities plus vicinity of natural gas grid access highlights this site as a plausible location for biogas/biomethane production.

3. **Location 3:** Markuševac - area of existing composting site for biodegradable waste

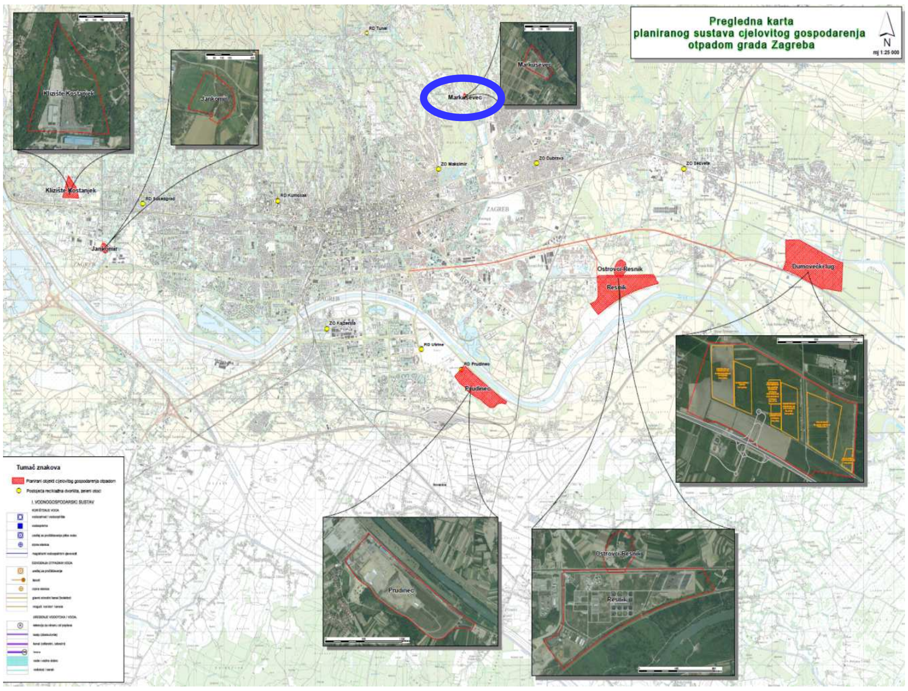

Figure 4-29 Location 3: Markuševac - area of existing composting facility

At the location Markuševac, there is already executing aerobic degradation of organic matter (composting) and the compost is used for landscape management of green areas within City of Zagreb or sold. Compost handling is managed by sister company of ZAGREB CH: Zagreb holding - branch Zrinjevac. Digestate originated from biogas production could be also used for composting.

Figure 4-30 Delivering fresh material from landscape management to the composting site Markuševac (source: http://www.zrinjevac.hr/default.aspx?id=566)

Figure 4-31 Composting site Markuševac from air (source: http://www.zrinjevac.hr/default.aspx?id=566)

Figure 4-32 Collecting compost for packaging (source: http://www.zrinjevac.hr/default.aspx?id=566)

Figure 4-33 Packaging of end -product (compost) for market (source: http://www.zrinjevac.hr/default.aspx?id=566)

Road access needs to be investigated if it is able to facilitate more frequent traffic due to the delivery of biowaste. Biogas/biomethane production would not add additional worries for the neighbourhood but the actual acceptance should be verified. There is sufficient electrical power supply and access to medium pressure natural gas grid is about 0.4 km (Figure 4-34).

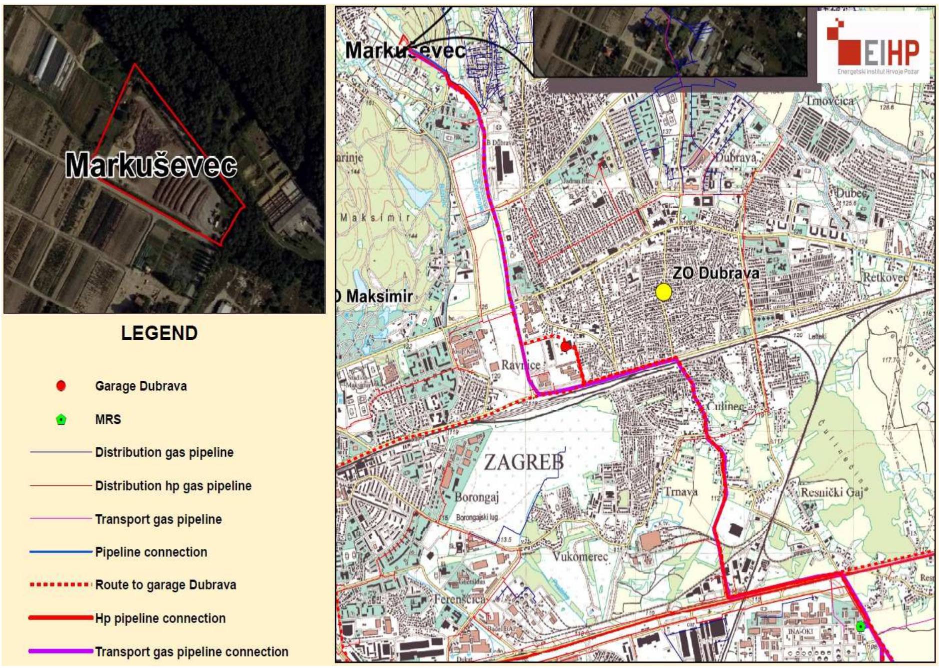

Figure 4-34 Location 3: access to the natural gas grid

Main additional criteria for including this location in methodology demonstration are lower cost for digestate management, additional substrate availability (grass cuttings and other green waste from landscaping the green areas of the City of Zagreb) and not being listed at water protection zone areas.

In case of combining biowaste with green waste from landscaping, it is very likely that some of the dry AD technologies will be selected where waste water treatment facility would not be necessary.

Wurzer Umwelt GMBH biogas plant (Germany), Ganser Entsorgung biogas plant (Germany), Lille Métropole Communauté Urbaine (France) (Martins Niklass et al, 2012) are examples of connecting biogas production from biowaste and composting of green waste and digestate.

Sufficient space for the plant might be an issue as the composting plant is operating at the verge of its maximum capacity. This could also affect negatively the minimal spatial alterations criteria.

4. **Location 4:** area of considered location for Overall waste management centre for the City of Zagreb

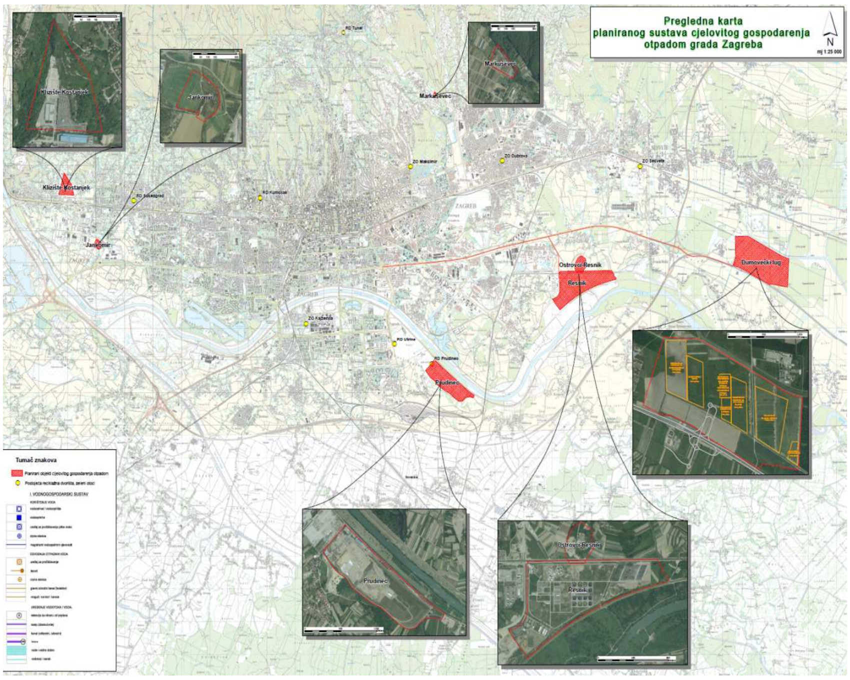

Figure 4-35 Location 4: Dumovečki Lug - area of suggested central waste management facility for the City of Zagreb

There is sufficient road access to the site and no neighbourhood in the vicinity to be upset by anaerobic digestion of organic matter from municipal waste. Sufficient electrical power supply most likely exists but if not, it will be constructed during the overall waste management site erection. The access to medium pressure natural gas grid is 5.4 km (Figure 4-36).

This location allows biogas/biomethane production from both waste management options: source separated biowaste and collection in bulk as an integral part of MSW. Waste water treatment facility will be necessary additional investment.

If this location will be selected as a location for centre overall waste management for the City of Zagreb, biogas/biomethane production will not provoke any additional changes in the space and there will be sufficient place for the plant.

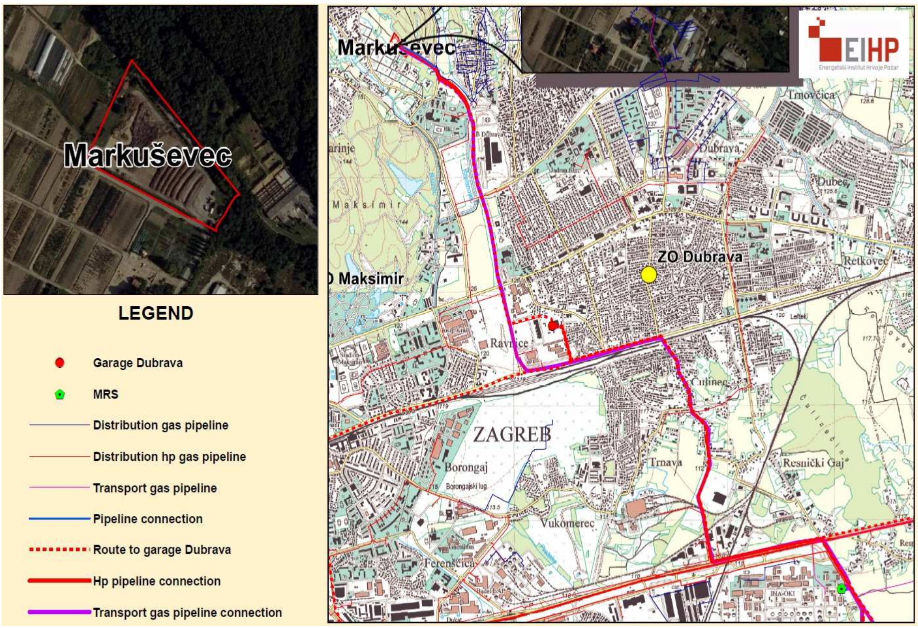

Figure 4-36 Location 4: access to the natural gas grid

The table below shows a results matrix of applied methodology on differed real location at the City of Zagreb for production of biogas/biomethane from biowaste.

Table 4-3 Summary of considered locations for biogas/biomethane plants for City of Zagreb

Criteria	Location			
	1	2	3	4
Road access	+	-/+	-/+	+
Sufficient electrical power supply	+	+	-/+	+
Access to medium pressure natural gas grid	-/+	+	+	-/+
Economic feasibility of the investment via maximisation of biogas production	+	+	-	-
Availability of (additional) substrate	+	+	+	-/+
Maximisation of useful energy obtained from biogas	+	+	-	-
Sufficient space for the plant	+	+	-/+	+
Minimal spatial alterations	+	+	-/+	+
Waste water treatment facility	-	+	-/+	-
Water protection zones	-/+	-/+	+	+
Overall score	**+: 9** **-: 3**	**+: 10** **-: 2**	**+: 8** **-: 7**	**+: 7** **-: 5**
Location rating	**2**	**1**	**4**	**3**

4.3 Economy

As described to the detail in the Technology section, at this point there is insufficient information that would allow any more detailed economic analysis for biogas production from biowaste in the City of Zagreb. The focus of this section is to provide a starting point for real economics once when decide to implement this waste-to-biomethane concept.

At this point, there are several information existing:

- current cost of landfilling the biowaste
- current cost of composting the biowaste

As described in the chapter Survey of the available feedstock, landfilling cost is 322.36 HRK/t which means that Zagreb CH saves that amount for each ton of biowaste diverted from landfilling.

As AD always generates two products: biogas and digestate, digestate management should be also considered. Digestate could be disposed in the way that currently collected biowaste is managed: to the composting plant. The cost of composting is 200 HRK/t.

In case of dry AD, for each diverted ton of biowaste from landfilling Zagreb CH would save 122.36 HRK.

Economy will also depend on the existing facilities on the chosen location as well as dry matter content of the substrates used for biogas production. Given the numerous unknowns in the waste management concept and location selection, the economy section will aim to deliver general framework how economy will work in terms of investments and O&M costs instead of providing real numbers of a specific biogas plant.

Biogas production from biowaste represents added value to the waste by utilizing another source of renewable energy. However, its first step is always waste management that does not necessarily has to end with energy recovery from biowaste although European Commission strongly recommends that.

There are two starting points from which economy of biogas/biomethane production from biowaste could go:

1. source separated biowaste
2. biowaste collected in bulk as integral part of MSW.

The Figure 4-37 shows the path from delivery of source separated biowaste to the placing the biowaste to the digester (the beginning of the biogas production). Naturally, the more pre-treatment needed for preparation of biowaste for AD, the investment would be higher.

It is also negotiable where biogas production starts - from delivery of biowaste or from accepting prepared biowaste for biogas production. This will be more elaborated in the section Stakeholders.

From the point of energy recovery from biowaste, it is preferable that biowaste arrives to the biogas plant in as shorter time as possible as degradation of organic matter starts immediately and biogas yield decreases proportionally.

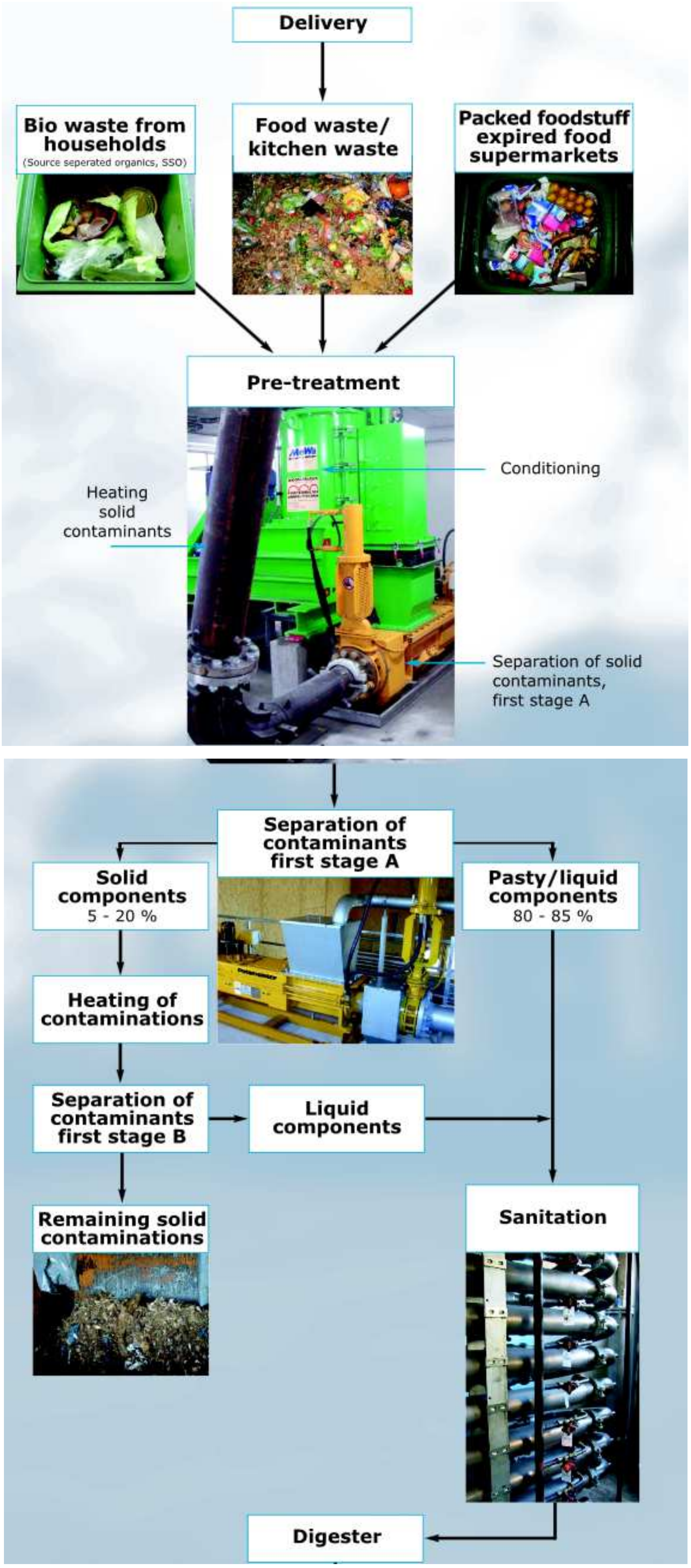

Figure 4-37 Process flow from delivery of biowaste till digester (source: www.fitec.com)

Investment and O&M costs will vary slightly across the countries but labour costs, insurance, consumables, plant development, land purchase will actually make the difference in the investment. As a general guide, assumptions for labour proportion in CAPEX and OPEX from a study ordered by European Commission (ARCADIS, 2009) could be used (Table 4-4).

Table 4-4 Proportion of Labour associated with CAPEX and OPEX (ARCADIS, 2009)

Treatment	Labour Proportion of CAPEX	Labour Proportion of OPEX
Landfill	20%	50%
MBT	30%	34%
AD	25%	30%

Investment costs

The biogas/biomethane plant on biowaste would be the first of its kind in Croatia and there are little information on the actual investment costs. However, using the average investment for plant of that type in developed waste-to-biomethane market and adapting it to the national situation would provide a sufficient approximation to start from.

If biowaste comes with the wrapping, a shredder (plastic bags) or press (packaging) must be added to the investment. A shredder would be 0.5 mil. € but it can be obtained second-hand as well.

Separation from packaging material, sand, stones, egg shells, cutlery, plastics, bones... would be also necessary.

If biowaste collected at source at satisfactory purity (without wrapping such as plastic bags), then only "adaptation" to the usual biogas production technology is pasteurization/sanitation unit that would cost about 1 mil. €, depending on the biowaste quantity.

A quotation was asked from the presenters at the Stimulating investments in Biomethane in Croatia (10th July 2013, Zagreb) for an investment in the pre-treatment technology for the City of Zagreb. Teknoxgroup, a national representative of Komptech, provided a quotation for Scenario 1 pre-treatment. The proposed composition of pre-treatment equipment to produce fermentation suspension is consisted of:

1. Shredder
2. Screw conveyor
3. Dissolver
4. Wetscreen
5. Collecting tray
6. Worm extruder
7. Pumps
8. Macerator
9. Piping
10. Compressed air system

The estimated price for investment costs of such a pre-treatment plant would be 1.67 mil. € or 84 €/t (including engineering, electrical equipment, montage...).

Investment in a biogas plant running on biowaste would be as same as in biogas plant running on agricultural feedstock. Currently, there are 8 agricultural biogas plants in Croatia where 7 of them are of 1 MW_{el} installed capacity. The average investment is 4,500 €/kW which is some 60% higher than its counterpart investment in Germany.

On the other hand, if biowaste collected in bulk, pre-treatment is different:

- manual biowaste separation (low investment, high operation costs)
- shredder and less pressure press
- high pressure press.

Each of the above stated option bares its costs.

Most usual solution in this situation is to have one processing line combined with MSW separation where "biosoup" - a liquefied organic substance from biowaste - is directly pumped into biogas plant. Some evolving projects for energy recovery from MSW for cities of Varaždin and Čakovec (EKO-TEHPROJEKT, 2013) suggest that overall investment (adaptation of existing facility, pre-treatment and biogas production and biogas use in a 1 MW_{el} CHP) would be about 12 mil. €.

An investigation of waste-to-energy technologies for the City of London (Authority, 2008) faces the same obstacles in providing more detailed costs as detected in this Study: "A recent procurement exercise by SLR involving many different types of biogas technologies, established the operating costs for a 100,000 te/yr plant treating mixed MSW, with no depreciation or other finance costs, to be in the range of £11-£32/te" or 12.7-37 mil.€.

A study commissioned by DG Environment, EC, (ARCADIS, 2009) has investigated specific capital (CAPEX) and operational (OPEX) costs for all EU-27 member states according to the waste-to-energy technology. It grouped them according to weighted average cost of capital (WACC) for specific process by country banding. Croatia is not included but it could be included in the "high risk band" together with Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia. Assumed for this risk band in respect of waste-to-energy technology is:

- MBT: 19%
- AD: 16%

Country specific CAPEX for high risk band countries by technology type are presented in the table below.

Table 4-5 High risk band countries - specific CAPEX (in 2009 €/t) (ARCADIS, 2009)

Country	Landfill	MBT		AD		
		Stabilisation	Biodrying	Electricity Only	CHP	Gas Upgrading
BG	118	165	180	287	366	337
CZ	124	180	195	307	391	360
EE	122	174	189	299	381	351
HU	123	178	194	305	388	358
LV	119	169	183	292	372	342
LT	120	171	186	295	376	346
PL	123	177	192	303	386	355
RO	119	168	182	290	370	340
SK	122	175	190	300	382	352
SI	129	191	208	322	411	378
Average	121.9	174.8	189.9	300	382.3	351.9
Range	118-129	165-191	180-208	287-322	366-411	337-378

Croatian CAPEX would, most likely, fall under this range presented in the

Table 4-5.

Operation and maintenance costs

The O&M cost will consist of labour costs, consumables, maintenance and repair, capital-expenditure-depended costs (depreciation, interest and insurance), energy needed for running the plant, insurance...

The O&M cost will greatly depend on the quality of biowaste received to the biogas plant and on the business model that the plant will function.

For a 500 kW_{el} biowaste biogas plant operating in Germany, assuming that substrate is delivered with prior pasteurization/sanitation treatment, would be about 0.4 mil. €/yr with the following assumptions:

- 15 €/h assumed for labour costs
- maintenance & repair is 1-2%, depending on the component
- interest rate 4%
- depreciation is linear over 20 years
- insurance 0.5 of the total capital costs

An investigation of waste-to-energy technologies for the City of London (Authority, 2008) claims that O&M cost remain constant with the size of the plant and estimate them for a 20,000 t biowaste capacity 0.5-0.6 mil.€/yr or 23-29 €/t biowaste.

Country specific OPEX (ARCADIS, 2009) for high risk band countries by technology type are presented in the table below.

Table 4-6 High risk band countries - specific OPEX (in 2009 €/t) (ARCADIS, 2009)

Country	Landfill	MBT		AD		
		Stabilisation	Biodrying	Electricity Only	CHP	Gas Upgrading
BG	5	13	14	27	28	33
CZ	6	14	16	29	30	35
EE	5	14	15	28	29	34
HU	5	14	16	29	30	35
LV	5	13	15	28	28	33
LT	5	13	15	28	29	34
PL	5	14	15	29	30	35
RO	5	13	15	27	28	33
SK	5	14	15	28	29	34
SI	6	15	17	31	32	38

Average	5.2	13.7	15.3	28.4	29.3	34.4
Range	5-6	13-15	14-17	27-31	28-32	33-38

Specific OPEX per high risk band countries (Table 4-6) shows much narrower range than specific CAPEX per technology and Croatian OPEX would, most likely, fall under this range.

Biogas upgrading investment and O&M costs

As biogas upgrading technology, water scrubbing and PSA are selected as most appropriate technologies given the national legislation, natural gas grid characteristics of the City of Zagreb and estimated hourly biomethane production (Robert Bošnjak et al., 2013).

Again, the difference from reference investment cost will be mostly project development related as such investment would be the first of its kind in Croatia.

Approximation of investments needed for the maximum biogas yields per scenario (Table 3-7, Table 3-8, Table 3-9 and Table 3-10 - yield in 2020) is provided for both water scrubbing and PSA technologies using the Biomethane Calculator (www.BiomethaneRegions.eu).

Table 4-7 Estimation of needed investment in biogas upgrading for the City of Zagreb

Scenario (biogas yield in 2020)	Water scrubbing	PSA
Scenario 1		
Investment costs (in mil. €)	1.29	1.11
Total annual costs (in mil. €)	0.28	0.24
Specific cost per m3 raw biogas (€ct/Nm3)	13.69	11.47
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	2.30	1.92
Scenario 2		
Investment costs (in mil. €)	1.71	1.35
Total annual costs (in mil. €)	0.42	0.34
Specific cost per m3 raw biogas (€ct/Nm3)	10.25	8.41
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	1.72	1.41
Scenario 3		
Investment costs (in mil. €)	1.66	1.32
Total annual costs (in mil. €)	0.40	0.33
Specific cost per m3 raw biogas (€ct/Nm3)	10.54	8.65
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	1.77	1.45
Scenario 4		

Investment costs (in mil. €)	2.56	2.08
Total annual costs (in mil. €)	0.78	0.67
Specific cost per m3 raw biogas (€ct/Nm3)	7.54	6.55
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	1.29	1.11

The table above identifies PSA as less expensive than water scrubbing technology. Namely, investment costs are lower by 23%, in average. Total annual costs (including annual capital costs and operational costs) are lower by 20% in average.

In addition, an excercise has been performed in order to see what effect on the investment and specific production cost would have the increase of biogas production. For this purpose, maximal biogas yield from biowaste was taken (Scenario 4 in 2020) to which industrial biodegradable waste was added plus existing biogas production on one of the two locations in the City of Zagreb (~500 Nm^3/h) (

Table 4-8).

Table 4-8 Effect of biogas maximisation to the investment

Scenario (biogas yield in 2020)	Water scrubbing	PSA
Scenario 4 - biowaste only		
Investment costs (in mil. €)	2.56	2.08
Total annual costs (in mil. €)	0.78	0.67
Specific cost per m3 raw biogas (€ct/Nm3)	7.54	6.55
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	1.29	1.11
Scenario 4 - biowaste + IBW		
Investment costs (in mil. €)	2.85	2.39
Total annual costs (in mil. €)	0.93	0.81
Specific cost per m3 raw biogas (€ct/Nm3)	7.26	6.29
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	1.22	1.06
Scenario 4 - biowaste + IBW + biogas from existing biogas plants (~500 Nm^3/h)		
Investment costs (in mil. €)	3.25	2.91
Total annual costs (in mil. €)	1.17	1.04
Specific cost per m3 raw biogas (€ct/Nm3)	6.82	6.04
Specific costs per kWh methane in raw biogas (Hi) (€ct/kWh)	1.14	1.01

Table 4-8 shows that boosting biogas production would increase overall investment by 11 to 28% (water scrubbing) or by 15 to 40% (PSA). Total annual costs would also increase: 19 to 49% (water scrubbing) or 21 to 56% (PSA). On the other hand, economies of scale would push the specific costs down by 5 to 12% (water scrubbing) or by 4 to 8% (PSA).

Production costs

In Germany, specific biogas production cost would be (Fraunhofer, 2012):

- agricultural biogas plants: 4 - 6 €ct/kWh
- wastewater treatment plants: <4 €ct/kWh
- co-digestion plants: <6 €ct/kWh

Specific biogas upgrading cost depend on the plant capacity and the upgrading technology: 1.3 - 2.5 €ct/kWh.

Biomethane sale price in Germany from organic waste achieves 5-7 €ct/kWh.

European Commission has also given efforts to investigate costs for MSW in the EU (Hogg, D., 2002). It provides estimations for costs of AD from biowaste (Table 4-9) which ranges from 35 to >100 €/t.

Table 4-9 Costs of AD in some EU countries (2001) (Hogg, D., 2002)

Country	AT	BE	DK	FI	FR	DE	NL	SE	UK
Cost (€/t)	80	82	67[a]	35[b]	57	109 79[c]	50-84	60-70[a]	80-96[d]

a In these cases, there may be no need for aerobic treatment of digestate

b Only basic storage of digestate for aerobic phase

c Figure for co-digestion on farm

d UK figures are estimates

Production cost could be mitigated by gate-fee. The gate fee charged by a waste treatment/recovery facility is the combination of the operating and finance costs, less any revenue from power/heat sales and recyclables, plus the profit element. The latter is determined by a range of commercial considerations and is a commercially sensitive factor, about which operators are not willing to divulge details. For example, a contract with a Local Authority for residual MSW will be on a long-term basis, producing a guaranteed cash flow. On this basis the profit margin may well be modest, as the contract will provide the base-load of the facility and allow other wastes to be accepted at a significantly higher gate fee (Authority, 2008).

According to ARCADIS study (ARCADIS, 2009) gate fees are not ‘costs’, and there are various reasons why the gate fee at a facility may differ from average costs, or marginal costs, as they might be conventionally understood. Gate fees may, depending upon the nature of the treatment, be affected by, inter alia:

- Local competition (affected by, for example, haulage costs);
- Amount of unutilised capacity
- The desire to draw in, or limit the intake of, specific materials in the context of seeking a specific feedstock mix;
- Strategic objectives of the facility operator; and
- Many other factors besides.

Any one of these can influence the market price, or gate fee, for a service offered by a waste management company.

Financing, public/private investors, funding schemes regional/national/EU, revenues, tax exemptions, tax optimising ...

Financing scheme, public/private investors, funding schemes as well as revenues will depend on how much involvement the City of Zagreb wants in the waste-to-management concept. Involvement can be specified in terms of financing, risk sharing, profit, control, management...

If the City of Zagreb decides to participate in the concept in terms of ownership, the implementation of waste-to-biomethane concept could be financed by funding schemes open for public sector.

Some of the possible sources of financing are:

1. **European Regional Development Fund (ERDF)**

ERDF aims to strengthen economic and social cohesion in the European Union by correcting imbalances between its regions. In short, the ERDF finances:

- direct aid to investments in companies (in particular SMEs) to create sustainable jobs;
- infrastructures linked notably to research and innovation, telecommunications, environment, energy and transport;
- financial instruments (capital risk funds, local development funds, etc.) to support regional and local development and to foster cooperation between towns and regions;
- technical assistance measures.

Co-financing is 50-75% of the total project eligible costs.

Eligible beneficiaries are public bodies, SMEs and R&D sector.

Implementation of waste-to-energy concept or its specific parts meets four out of eight national priorities in using this fund.

Good practice examples of this Fund are:

- reconstruction of football stadium "Ljudski vrt" in Maribor, Slovenia (10 mil.€ total budget, 3.3 mil.€ co-financing)
- futuristic public square in Eindhoven, the Netherlands (7.51 mil. € total budget, 3.2 mil.€ co-financing)
- better quality rail traffic in Slovakia (177 mil. € total budget, 88.5 mil.€ co-financing)
- revitalisation of Lake Karla, Greece (50 mil. € total budget, 37.8 mil.€ co-financing)
- ...

For more, please visit: http://www.eu-projekti.info/europski-fond-za-regionalni-razvoj

2. **Cohesion Fund (CF)**

CF is aimed at Member States whose Gross National Income (GNI) per inhabitant is less than 90% of the Community average. It serves to reduce their economic and social shortfall, as well as to stabilise their economy. It supports actions in the framework of the Convergence objective. It is now subject to the same rules of programming, management and monitoring as the ESF and the ERDF.

National financing priorities in this fund are:

3. Environmental sector
    a. improvement of environmental infrastructure with an aim of meeting the EU environmental protection standards
    b. efficient use of energy and renewable energy sources utilisation
4. Transport sector
    a. Trans-European Transport
    b. Transport infrastructure (out of TEN-T network) that contribute to the ecologically sustainable urban public transport, inter-operation of transport networks within the all EU and those that promote implementation of inter-modular traffic systems

Implementation of waste-to-energy concept or its specific parts meets all national priorities in using this fund.

Co-financing is up to 85% of the total project eligible costs (minimum budget 25 mil.€).

Eligible beneficiaries are local and regional governments, municipal waste companies owned by towns, ministries, transport and environmental agencies and similar organisations.

Good practice examples of this Fund are:

- waste water treatment in Romania (330 mil.€ total budget, total co-financing from EU funds 330 mil.€ co-financing(including EBRD))
- heating system for better environment in Timisoara, Romania (56.34 mil. € total budget, 27.13 mil.€ co-financing)
- closing of old landfills in Malta (26 mil. € total budget, 22.3 mil.€ co-financing)
- improvement in water supply system for North-West region in Czech Republic (21.9 mil. € total budget, 15.4 mil.€ co-financing)
- ...

For more, please visit: http://www.eu-projekti.info/kohezijski-fond

5. Croatian Bank for Reconstruction and Development (HBOR)

Another possible financing source would be via Croatian Bank for Reconstruction and Development (HBOR) either through its

a) usual loan schemes

An example of usual loan schemes is Loan Programme for Development of Communal Infrastructure where final borrowers are:

- Units of local and regional government
- Utility companies
- Companies and other legal entities

The purpose of the loan is investment in fixed assets: initial funding, land plots, buildings, equipment and services.

HBOR finances up to 75% of the estimated investment value, VAT not included. Exceptionally, HBOR may finance up to 100% of estimated investment value, VAT not included for units of local and regional government and utility companies in their ownership.

Disbursement period is up to 12 months, grace period up to 5 years, repayment period up to 15 years (including grace period).

Interest is 4% p.a.

For more details, please visit: http://www.hbor.hr/development-of-communal-infrastructure

b) special financing programmes.

An example of special financing programmes is currently approved a 250 mi.€ loan to HBOR by the European Investment Bank (EIB) for the financing of projects promoted by small and medium-sized enterprises (SMEs) and mid-cap companies, small and medium-sized infrastructure projects in the public sector as well as limited size investment projects in the industry sector in the area of knowledge economy, energy, environmental protection, health and education.

For more details, please visit: http://www.hbor.hr/first-eib-loan-after-croatias-eu-accession-eur-250

6. The Environmental Protection and Energy Efficiency Fund of the Republic of Croatia (FZOEU)

FZOEU is a structured extra-budgetary fund which finances projects and activities in three basic areas: environmental protection, energy efficiency, and the use of renewable energy sources. It has been established by the Law on the Environmental Protection and Energy Efficiency Fund on July 1st 2003 (Official Gazette of the Republic of Croatia No. 107/2003).

The form of financing could be:

- loans
- subventions
- financial aid and
- donations

Funds are allocated according to the public procurements.

Eligible beneficiaries are both private companies and public bodies.

For more details, please visit: http://www.fzoeu.hr/

7. Green Investment Funds (ECFs)

There are also international funds specialised in green business, namely energy efficiency (EE) and renewable energy (RE) projects.

Here is the example:

- **The Green for Growth Fund, Southeast Europe** is the first specialized fund to advance EE and RE in Southeast Europe, including Turkey. Initiated by the European Investment Bank and KfW Entwicklungsbank, GGF is an innovative public-private partnership established to reduce energy consumption and CO_2 emissions. GGF provides refinancing to Financial Institutions to enhance their participation in the EE and RE sectors and also makes direct investments in Non-Financial Institutions with projects in these areas. The activities of GGF are supported by a Technical Assistance Facility.

For more details, please visit: http://www.ggf.lu/

- **The European Energy Efficiency Fund (EEEF)** (http://www.eeef.eu) targets investments in the member states of the European Union. The final beneficiaries of EEEF are municipal, local and regional authorities as well as public and private entities acting on behalf of those authorities such as utilities, public transportation providers, social housing associations, energy service companies etc. Investments can be made in Euro, or local currencies, however the latter is restricted to a certain percentage.

For more details, please visit: http://www.eeef.eu

8. Economic Co-operation Funds (ECFs)

ECFs are open venture capital investment funds with private equity that are established and operate in accordance with the Investment Funds Act. The aim of their establishment is to promote the development of the economy, to preserve the current and create new jobs, to strengthen the existing and start-up new business entities by means of ownership restructuring through the investment of additional capital.

Some of the ECFs operating in Croatia are:

- **Alternative Private Equity d.o.o.** www.alternative-pe.hr
- **Honestas Private Equity d.o.o** www.honestas-pe.hr
- **Nexus Private Equity Partneri d.o.o**, www.nexus-pe.hr
- **Prosperus-invest d.o.o**, www.prosperus-invest.hr
- **Quaestus Private Equity d.o.o.**, , www.quaestus.hr
- ...

9. The EU Framework Programme for Research and Innovation: Horizon 2020

Non-technical aspects of implementation of waste-to-energy concept for the City of Zagreb could be financed by applying to one of the supports within Horizon 2020.

Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. Running from 2014 to 2020 with an €80 billion budget, the EU's new programme for research and innovation is part of the drive to create new growth and jobs in Europe.

Horizon 2020 provides major simplification through a single set of rules. It will combine all research and innovation funding currently provided through the Framework Programmes for Research and Technical Development, the innovation related activities of the Competitiveness and Innovation Framework Programme (CIP) and the European Institute of Innovation and Technology (EIT).

The proposed support for research and innovation under Horizon 2020 will:

- Strengthen the EU's position in science with a dedicated budget of 24,598 mil. €. This will provide a boost to top-level research in Europe, including an increase in funding of 77% for the very successful European Research Council (ERC).
- Strengthen industrial leadership in innovation 17,938 mil.€. This includes major investment in key technologies, greater access to capital and support for SMEs.
- Provide 31,748 mil. € to help address major concerns shared by all Europeans such as climate change, developing sustainable transport and mobility, making renewable energy more affordable, ensuring food safety and security, or coping with the challenge of an ageing population.

For more details, please visit: http://ec.europa.eu/research/horizon2020/index_en.cfm

In Croatia, tax system is regulated in a centralised way and local authority has very little (city tax) or no power to influence tax exemptions or allow tax optimisation. In that manner, tax exemptions and tax optimising options are not likely to be feasible for biogas production and upgrading plant in Croatia.

Sales concept; supply agreements, contracts

Sales concept, supply agreements and contracts are issues to be fully defined upon deciding who are the stakeholders of the waste-to-biomethane concept for the City of Zagreb and what their specific roles are. The new Law on Sustainable Waste Management allows for the first time entrance of private companies in waste management business which was traditionally public sector in Croatia.

Again, the City of Zagreb is the mandated to meet the goals of Landfill Directive and Obligation of Placing the Biofuels at the national market but the way how these goals are going to be met and its role within it is fully up to the City of Zagreb.

That is why this section will provide general overview on sales concepts, supply agreement and contracts so that the beneficiary could have the first hand information when deciding on its role in the waste-to-energy concept for the City of Zagreb.

Sales concept of produced energy (biomethane) will be a type of trilateral agreement with joint waste management & biomethane production company or biomethane producing company, GPZ (City Gas Work) and Zagreb holding - branch ZET (urban public transport company for the City of Zagreb) given the biomethane use concept (Robert Bošnjak et al., 2013). As a remark, Zagreba holding ltd. has a licence (May 2013) for performing energy activities in the field of electricity production valid for five years.

Waste-to-energy concept could be divided to waste management and energy production and utilisation part. In that case, energy producer closes a supply agreement with the waste management company on delivery of biowaste with specification on timing, quality and quantity. The supply agreement also defines conditions/penalties if the waste management company does not meet the specifications in the delivery.

At the section describing production costs, the issue of gate-fees was already tackled. ARCADIS Study (ARCADIS, 2009) describes well special features of waste-to-energy market as quoted below:

"Another feature of the waste treatment market at present is the use of long-term contracts in the municipal waste market to procure services. The nature and length of these contracts, and the nature and extent of the risks which the public sector may wish to transfer to the private sector, influences the unitary payment, or gate fee, offered under any given contract. The nature of risk transfer may relate, for example, to technology and its reliability, or to specific outputs which a contract seeks to deliver, and these may, in turn, relate to existing policy mechanisms.

The key point is that the nature of the risk transfer associated with a given contract affects gate fees. In the municipal waste sector, contract prices may typically be wrapped up in the form of a single payment, which may be composed of a number of different elements associated with the delivery of the contract against the specified outputs. This ‘unitary payment’ is typically determined on a contractual basis, and so is somewhat different to gate fees which might be realised at facilities operating in a more openly competitive market.

It should also be noted that whilst much of the major infrastructure for municipal waste has, in the past, been financed using project finance, it remains possible that corporate finance could be used to support projects in future. This would have the effect of changing the cost of capital used to support any given project.

If operating in a truly competitive market with shorter term contracts, the gate fees charged by merchant plant should be closer to the true marginal costs of the treatment process. However, while merchant plants are typically developed to serve the commercial and industrial sectors, they operate in a market that is influenced by the workings of the municipal waste treatment sector and may price accordingly. Indeed, the distinction is not clear cut as some merchant plant will also handle municipal waste."

4.4 Operation

Operation specification of biogas production plant and upgrading the biogas to biomethane from biowaste available in the City of Zagreb cannot be specified at this moment. The reasons are well elaborated on several occasions in the previous material.

Once when the City of Zagreb or its executive company for waste management Zagreb holding - branch Čistoća decide on the way on biowaste collection system, a selection of biogas production technology and its size could be narrowed down.

In general, biogas production plant operates 8,000 hours per year and biogas upgrading plant 7,690 hours per year.

Detailed operation specifications will be provided by the technology supplier.

Operation details to be addressed are:

- Service time: x hours per day, y days a week, z days per year
- Staff qualification
- Number of staff
- Contracted sub suppliers for auxiliaries and maintenance and repair

On the other hand, operational items such as:

- Administration
- Public Relation

are to be managed by the City of Zagreb or defined in the contract between the energy producer and the City of Zagreb.

5 Stakeholders

Waste-to-energy concept allows full or partial fulfilment of numerous targets in the fields of renewable energy, energy efficiency and environmental protection that the City of Zagreb is either mandated or voluntarily accepted. In current situation, biomethane production and use from biowaste is not a commercially viable business venture which means that its implementation will be depending on a political decision from the Mayor's Office.

While existing economic milestones do not indicate positive numbers (e.g. by comparing the prices of biomethane production in Germany), social milestones indicate multiple benefits to the citizens of the City of Zagreb as contribution to the fulfilment of:

- landfill directive (mandatory target)
- placing biofuels at the national market (mandatory target)
- reduction of GHG emissions from transport, waste and energy sectors (voluntary target)
- combat against climate change (voluntary target)
- improvement of living standards of the citizens in terms of air and water quality (mandatory target)
- ...

In that sense, the City of Zagreb -Mayor's Office is the main stakeholder in deciding in overall waste-to-energy framework both in organisational, ownership, financing and operational aspect.

Figure bellow presents several biomethane use models that exist among European cities that have implemented waste-to-energy concept.

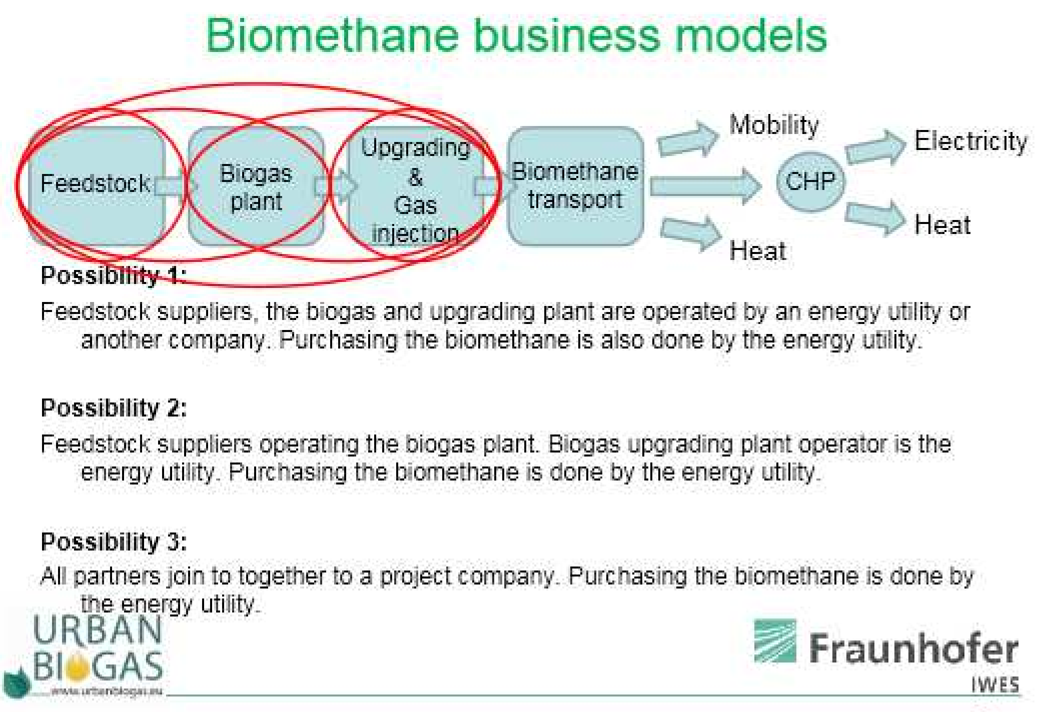

Figure 5-1 Biomethane business models (Fraunhofer, IEE UrbanBiogas, 2012)

Regardless on the decided possibility, or variations on the same, presented in the Figure 5-1, the City of Zagreb will have to keep the upper hand in management of waste-to-energy (biomethane) concept. The efficiency and business performance of the entity responsible for biogas/biomethane production and injection to the natural gas grid directly affects fulfilments of the targets set. If implementation of waste-to-biomethane concept is left to the free market, the negotiation power would be in the favour to the private company.

City Office for Energy, Environmental Protection and Sustainable Development would be the main body to support with expertise the Mayor's Office in deciding on the overall waste-to-energy concept.

Waste-to-biomethane concept combines two sectors: waste management and energy production & utilisation where each of the sector bares its obligations and risks. Synchronisation of those two sectors is crucial for implementation of the waste-to-energy concept. The City of Zagreb has founded Zagreb Holding, a company in 100% ownership of the City to manage functioning of the City. The basic task of Zagreb Holding is the effective and long-term performance of municipal tasks, with maximum protection of the environment and protection of the public interests of the local community.

Zagreb Holding is consisted of 18 branches which perform the work of the former city enterprises, with a total of about 12,000 employees. The work of the Company are grouped into three business areas:

- Municipal functions
- Transport functions
- Market functions

Branches responsible for municipal functions that already exist within Zagreb Holding and which are plausible to be involved in the waste-to-energy concept implementation are shown in the table below.

Table 5-1 Existing branches of Zagreb Holding responsible for municipal functions of the City and their plausible roles in the waste-to-biomethane concept

Branch	Section of the waste-to-energy concept	Plausible role
City Waste Disposal - Čistoća*	Waste management concept	Waste collection, Waste sorting waste delivery
	Biomethane use concept	Biomethane user
Zagreb Markets - Tržnice Zagreb	Waste management concept	Biowaste source
	Biomethane use concept	Biomethane user
Landfill Management - ZGOS	Biogas/biomethane production concept	Additional source of biogas
City landscaping - Zrinjevac	Waste management concept	Biowaste source
	Biogas/biomethane production concept	Digestate management
	Biomethane use concept	Biomethane use concept
Zagreb City Gasworks - GPZ	Biomethane use concept	Acceptance of biomethane to the grid Biomethane user

* involved in IEE UrbanBiogas as ZAGREB CH

Transport functions are performed by the branches ZET and Zagreb parking. ZET is perceived as the main user of biomethane in the first years of waste-to- biomethane concept.

The important branch in business area of market functions for implementation of waste-to-energy concept is Zagreb City Gasworks – Supply that will be responsible for delivery of the biomethane to the filling station. Zagreb plakat branch could be used for marketing, promotional and educational activities of waste-to- biomethane concept.

While the stakeholders in starting (waste management) and ending (biomethane use) point of waste-to-biomethane concept for the City of Zagreb are rather plausible, its heart (biogas/biomethane production) still needs to be defined.

City Office for Energy, Environmental Protection and Sustainable Development seems to be the lead in the defining the biogas/biomethane concept with the support of:

- City Office for Strategic Planning and City Development
- City Office for Physical Planning, Construction of the City, Utility Services and Transport
- City Office for Legal-Property Relations and the City's assets

and communication with the following branches of Zagreb Holding:

- City Waste Disposal - Čistoća
- City Landscaping - Zrinjevac
- Zagreb City Gasworks - GPZ
- Zagreb City Gasworks - supply - GPZ - opskrba
- City Public Transport Provider - ZET
- Landfill Management - ZGOS (optional)

Another plausible stakeholder in biogas/biomethane production is Zagreb's Central Waste Water Facility - ZOV in terms of additional biogas supply, waste water management and biomethane production.

Not less significant would be the role of public awareness raising and educational campaign where Service for the Local Self-Administration: responsible for communication with citizens by local self-administration units would play a crucial role together with a professional PR agency.

5.1 Investors/owner

At this point, defining investors and owners of waste-to- biomethane concept and/or its three integral parts for the City of Zagreb would be an overreach.

Sections that describe Economics and Stakeholders provide sufficient information (sources of financing, sales concepts, supply agreements, business models...) to form a decision on items given in the Biogas & Biomethane Production template:

- Public/private investors
- Bank
- Share based funds
- Corporate form.

As highlighted in the Stakeholders section, regardless on the form and shape of the business model of the waste-to- biomethane concept company or companies, the City of Zagreb will have to maintain control in its operation.

5.2 Additional parties involved

Waste-to- biomethane concept is an interdisciplinary business venture that operates more on environmental costs than on monetary costs which means that the investment has to be clearly justified and accepted by the public.

In addition, public acceptance of waste-to- biomethane concept will also affect its implementation. Namely, if source separated collection is chosen as waste management concept, its collection rate and quality of the biowaste will depend on the willingness of the citizens to contribute.

Constant communication with the public seems to be the most important non-technical issue to consider.

Quality project and sound waste-to- biomethane concept would ensure having support from political parties and NGOs.

EIHP has presented the most controversial parts of the Biogas & Biomethane Production in the City of Zagreb at four occasions in front of the different audience (public consultations, experts at task force meetings, stimulating investments in biomethane event) and at two occasions at the national TV by July 2013. In total, at last 130 persons has seen the concept and there was no negative reaction.

Additional parties to be involved in waste-to- biomethane concept implementation to the City of Zagreb are already included in the task forces:

12. Croatian Energy Market Operator (HROTE)
13. Croatian Environment Agency (AZO)
14. Croatian Chamber of Economy
15. NGO DOOR
16. Ministry of Environmental and Nature Protection
17. Ministry of Maritime Affairs, Transport and Infrastructure
18. Ministry of Agriculture
19. Croatian Gas Association
20. green journalists

and have contributed to its development.

6 Proposal of preferable solution of biomethane production in City of Zagreb

From technical, energy and economic point of view, it seems that organising thermal (solid) and anaerobic (wet) waste treatment adjacent to the waste water treatment facility would create so called "industrial symbiosis" where the sum of performance of this symbiosis would be higher than adding each of the individual performances to the other. Industrial symbiosis is a subset of industrial ecology, with a particular focus on material and energy exchange.

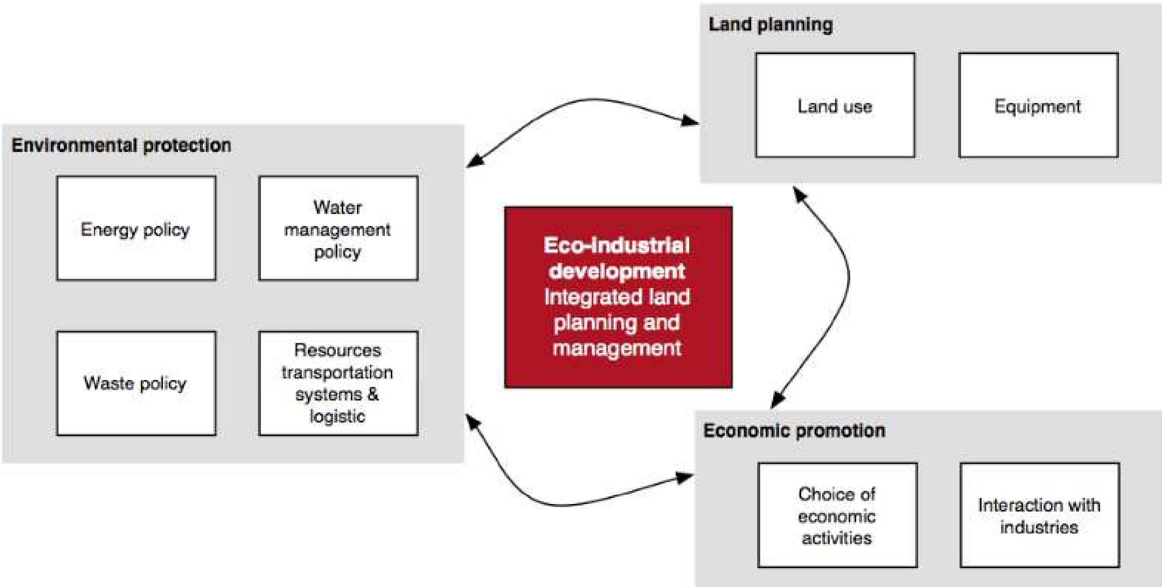

Figure 6-1 Industrial symbiosis and eco-industrial development (Massard, 2013)

The European Union has decided that sustainable development has economic, environmental and social dimensions and is an overarching goal. Competitiveness and sustainability are mutually reinforcing concepts. DG Enterprise and Industry aims to create the conditions in which European enterprises can thrive, so helping to maximise their contribution to sustainable development. Sustainable industry is one of the cornerstones of sustainable development that promotes competitiveness and resource efficiency. Industrial symbiosis integrates economic growth and environmental protection.

According to the SOFIES AG (Massard, 2013), industrial symbiosis involve economic activities in a collective approach for the reduction of environmental impact and costs. Eco-industrial development considers industrial symbiosis and sustainable resources management as an opportunity for economic promotion and land planning.

The first six areas where industrial symbiosis is particularly popular and induces most eco-innovations are related to the waste-to-energy concept (Figure 6-2).

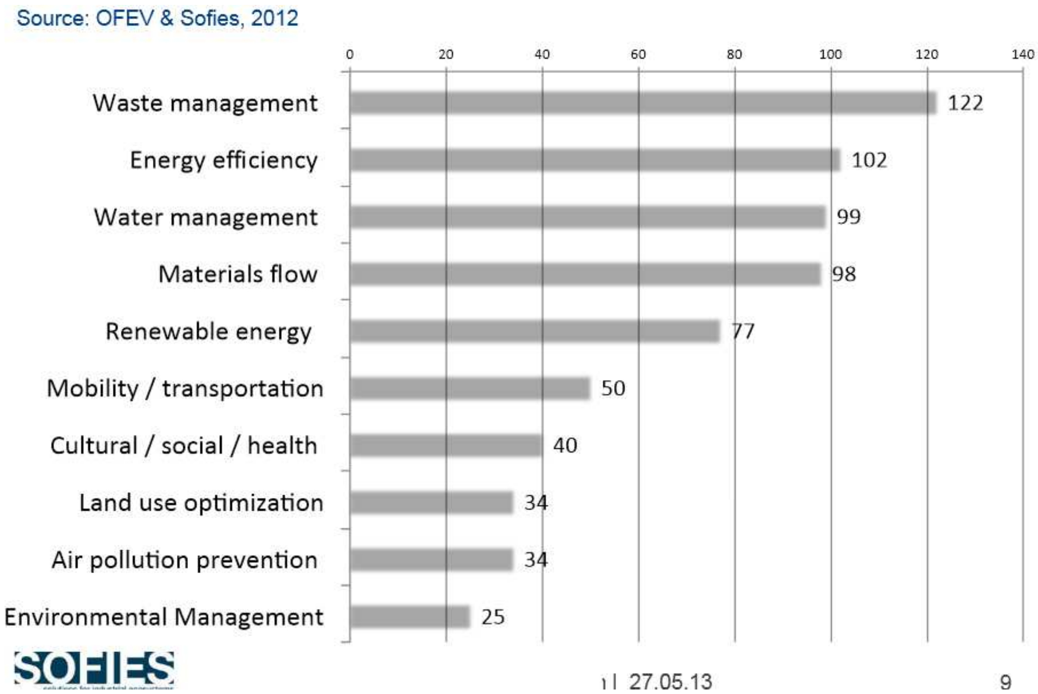

Figure 6-2 Results on the international survey on eco-innovation in industrial parks (Massard, 2013)

Given the efforts of the City of Zagreb on its green and sustainable profile already made, forming an industrial symbiosis while implementing waste-to-energy concept would be added value not only to the waste but to the overall life standard of the citizens and include the City of Zagreb among the leading cities in sustainability.

7 Strategies for a successful biomethane production in the City of Zagreb

One of the advantages of the overall implementation of IEE UrbanBiogas project in Croatia has been the support of all stakeholders involved in waste-to-energy concept for the City of Zagreb.

Additional advantage for the waste-to-energy concept is that both starting (waste management) and ending (biomethane use) are in the hands of branches of Zagreb Holding. One could notice that all the pieces of the waste-to-energy concept puzzle for the City of Zagreb exist but they are still not brought together.

Successful biomethane production starts with waste management adjusted to deliver the desirable material - biodegradable fraction of MSW suitable for AD: biowaste and green waste (except branches and other woody material).

At this point (July 2013), the answers to both questions of "how" and "when" related to sustainable waste management in the City of Zagreb are still pending. While material provided in chapter Biogas Production and Upgrading Plant supports the answer to "how", Figure 7-1 could provide some orientation on the question "when".

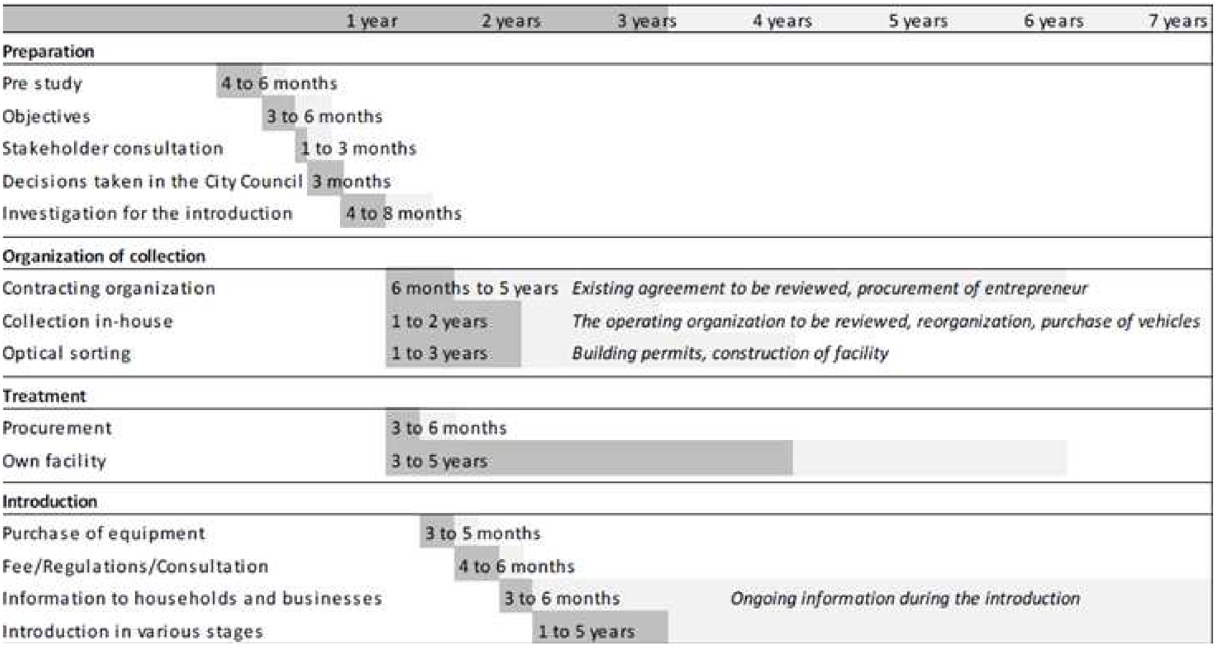

Figure 7-1 Timeline for implementing a source separation system - Swedish experience (Baxter&Al Seady, 2013)

The figure above indicates that implementation of source separation system takes about three years in Sweden which is by far more organised country than Croatia. The first mandate from Landfill Directive for Croatia is due by the end of 2013. This indicates the urgency on deciding on "how".

7.1 Creating and maintaining a sustainable demand for biomethane

Demand for biomethane is not perceived to be an issue in the City of Zagreb once when biogas/biomethane production occurs. Namely, the start up demand for biomethane is already created by existing 60 CNG public transport busses of Zagrebi holding - branch ZET plus existing vehicle fleet of City Gasworks. Additional demand will be developed gradually by converting the existing public vehicle fleet on CBM.

In the meantime, fine-tuned public awareness campaign that will communicate benefits to the citizens on having CBM vehicles would beget biomethane demand in private and business sector.

The question of higher price of CBM than its natural gas counterpart would definitively be the issue in expanding the biomethane demand beyond public sector.

There is a legal instrument to make use of biomethane as a biofuel in transport commercial to the consumer: a subsidy for biofuels production. All legal preparations were made while the level of the subsidy needs to be decided and adopted by the Government.

7.2 Inspiring investors

The easiest way how to inspire investors is by having a financially sound and risk low investment. Nevertheless, inspiring the investors is, at this moment, still at the level of question of additional investors' necessity. Namely, the City of Zagreb could decide to have the investment under its own arrangement, given the fact that EU funds allow up to 85% co-financing. In any case, the demand for investors and their inspiration will solely depend on the Mayor's decision.

7.3 Convincing authorities and oppositional groups

From the events implemented during the IEE UrbanBiogas project, EIHP team has got the impression that there is an overall consensus that business as usual in waste management in the City of Zagreb is unacceptable. Delivering waste-to-energy concept for the City of Zagreb and, if possible, creating industrial synergy within the concept would be convincing arguments that would be very difficult to fight against, especially as it has firm support in the EU policy and financing funds are available.

Within IEE UrbanBiogas, a survey on waste management in the City of Zagreb (Bošnjak, Robert & Vidović, Danko, 2012) and the general impression is that the citizens support waste-to-energy concept. The phone survey has been conducted on n=500 randomly chosen citizens where each of the local self-administration is represented. The results could be a good starting point for public awareness raising and educational campaign that will convince not only authorities but also oppositional groups.

7.4 Safeguarding a sound plant operation

Safeguarding a sound plant operation issue has been already tackled in the sections of Stakeholders and Investors/Owners. Namely, since the City of Zagreb bares the responsibility for the achievement of both mandated and voluntary targets in the field of renewable energy and environmental protection, its primary goal would be safeguarding a sound plant operation.

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