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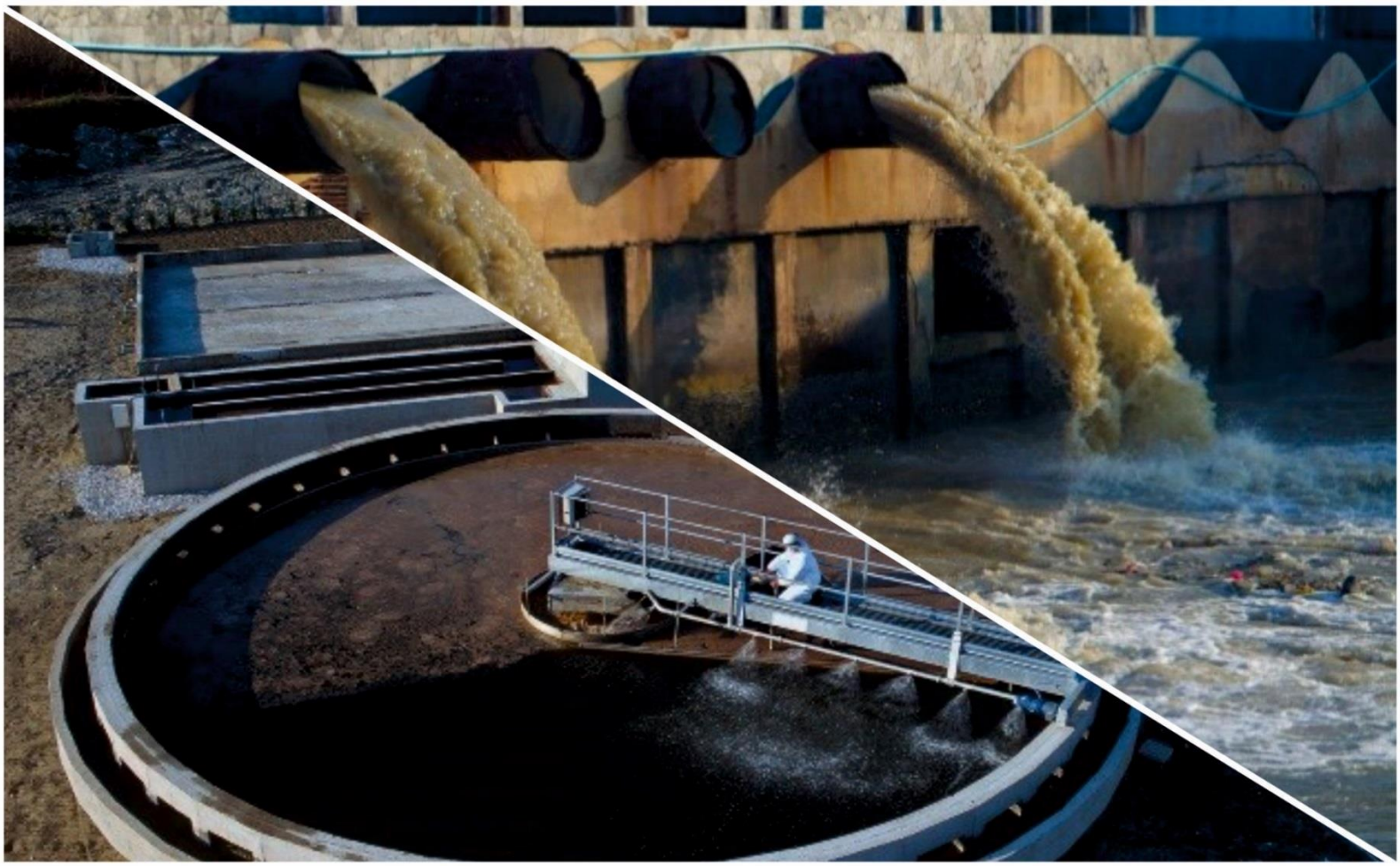
Sub-Project – Baseline study for sludge to energy plant in Udaipur

Deliverable – Final report



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Acknowledgments

The baseline study for the sludge to energy project has been commissioned as part of the Udaipur - Aarhus strategic collaboration, under the IUC-India program. The study represents the key deliverable of the Urban Cooperation Local Action Plan for the city of Udaipur. The report has been prepared by Mehali Patel (Environmental Technology Expert, IUC India project) based on secondary research, stakeholder consultations, case studies and review of recommendations.

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1 Executive summary

This chapter is the executive summary of the baseline study conducted for setting-up a sludge to energy plant in Udaipur. The chapter provides, in brief, the objectives of undertaking the study, the methodology employed, the findings from the baseline study, the lessons learnt from various international and national case studies, the existing situation in Udaipur, and the way forward.

Assignment background

Preparation of study and problem statement: The baseline study for the sludge to energy project has been commissioned as part of the Udaipur-Aarhus strategic collaboration under the IUC-India program. The study represents the key deliverable of the Urban Cooperation Local Action Plan for the city of Udaipur. The report has been prepared by Mehali Patel (Environmental Technology Expert, IUC India project) based on secondary research, stakeholder consultations, case studies and review of recommendations. The objective of the assignment is to prepare a baseline study for a sludge to energy plant in the city of Udaipur, by analysing the current status of sewage management and disposal in Udaipur and by identifying best practices employed by various national and international sludge to energy plants, so that this study can later feed into a detailed feasibility report.

Strategic cooperation between Aarhus and Udaipur: In August 2017, the city of Udaipur, Rajasthan, entered into a strategic cooperation on sustainable urban water management with the city of Aarhus, Denmark. The strategic cooperation program is supported by the Royal Danish Embassy in New Delhi under the Strategic Sector Cooperation mandate of the Ministry of Foreign Affairs of Denmark. The co-operation was formalized in December 2017 when the Mayor of Aarhus visited Udaipur city and signed a Memorandum of Understanding with Udaipur city. Both cities in April 2018, signed a project on urban sustainable water management. IUC-India is supporting the Udaipur-Aarhus city pairing through the provision of exchange visits and the development of a Local Action Plan (LAP) for efficient, sustainable and environmentally friendly wastewater and sewage treatment. The respective agreements were signed on June 4th 2019 with Udaipur and on December 18th 2019 with Aarhus.

Methodology employed: The baseline study was conceived during the discussion of the various stakeholders involved in this strategic collaboration. The study aims to provide a detailed analysis on the existing sewage treatment scenario in the city of Udaipur while also clearly laying out the way forward for development of new sludge to energy facilities. Given the spread of Covid-19 pandemic and the restrictions laid out by the Government of India, site visits and on-site collection of information was not feasible and the study is based on: a) secondary research through reports shared by IUC-India team, web search and case studies on sludge to energy plants in Denmark and India; and b) stakeholder consultations with officials of the Udaipur Municipal Corporation, HZL, Aarhus city council, Aarhus Vand (a Danish utility company), the Royal Danish Embassy, Ankur Scientific Energy Technologies Pvt Ltd, etc.

Existing status of sewage management in Udaipur

About Udaipur: Udaipur, also known as the city of lakes, is a popular destination in Rajasthan due to its lakes, palaces and scenic nature. It also serves as the district headquarters for the Udaipur district. The city, with an estimated population of 569,224[1] in year 2020 (which was 451,100, as per the census of 2011), is the sixth-largest city in Rajasthan. Udaipur has a diversified economic base with its main pillars being tourism, commerce/industries, agriculture, administration, trade, and education. Udaipur Municipal Corporation (UMC) is the main administrative body for Udaipur, under which various line departments function for operation and

[1] https://worldpopulationreview.com/world-cities/udaipur-population/

maintenance of urban services. The city of Udaipur is divided into 70 wards, all of which are under the jurisdiction of the UMC.

Sewage sector: As per discussions held with Udaipur Municipal Corporation, the city on average, generates 57 million litres per day (MLD) of sewage. The city has an 82 km long sewage network[2], along with a 7,700 m trunk line in Udaipur. The city also has ~40,000 septic tanks and 139 open drains that hold and carry the remaining sewage. The main drainage body of Udaipur is the Ayad River which subsequently drains out into the Udaisagar Lake. UMC officials also added that the sewerage network coverage is slated to increase to ~62.5% over the next 4-5 months with the support of the AMRUT program, smart city project and Rajasthan urban infrastructure development project (RUIDP).

Sewage treatment plants (STPs) in Udaipur: The city currently has three commissioned STPs for treatment of sewage. The first STP, with a capacity of 20 MLD, was commissioned in 2014 while the second STP, with a capacity of 25 MLD, was commissioned in 2019. Both the STPs use moving bed bio reactor (MBBR) technology, followed with claritube flocculator and filters, to produce high-quality treated water suitable for reuse at the Hindustan Zinc Industrial Complex in mining and smelting operations. The sewage treated by these STPs is partially received from the city sewage network, while the remaining sewage is intercepted from the city's 139 open drains. 50% of the sewage treated by the operational STPs is being utilised by the HZL industrial complex and the other 50% is discharged into the rivers of Udaipur. The third STP, deploying Sequencing batch reactor (SBR) technology, has been recently commissioned and is operating at its full capacity of 10 MLD. The input for this plant is the nearby drains and it will subsequently be connected to the trunk line. A fourth STP with capacity of 5 MLD is slated to be commissioned in the coming few months.

Sludge generation and disposal: The 25 MLD and 20 MLD STPs together produce 4.5 tonnes of sludge every day, which is dumped at various solid waste management facilities in and around Udaipur. The recently commissioned 10 MLD STP is slated to start generating 0.6 tonne to 1.0 tonne of sludge per day on connection with the sewage trunk line. With the commissioning of the additional STP of 5 MLD, the total amount of sludge produced in Udaipur will increase to 5-6 tonnes per day. To date, Udaipur does not generate energy from sewage or sludge generated from the STPs. Please refer section 6.3 of the report for detailed calculations on the sludge generation estimates.

Learnings from the city of Aarhus

About Aarhus: Aarhus is the second largest city in Denmark with a population of around 350,000[3]. The population of Aarhus is both younger and better-educated than the national average which can be attributed to the high concentration of educational institutes in the city, including Aarhus University. The economy of Aarhus is predominantly knowledge and service-based, strongly influenced by the Aarhus University and the large healthcare industry. Being one of the largest industrial ports in northern Europe with the largest container terminal in Denmark, the port of Aarhus serves as a container traffic hub. The greater Aarhus area has the world's most dense concentration of wind energy companies and represents as much as 87% of Denmark's entire turnover from wind energy[4]. The Aarhus City Council is the city's supreme authority in terms of decision making, allocation of funding and making final decisions on the recommendation of the City Executive Board.

Wastewater treatment plants (WWTPs) in Aarhus: The city of Aarhus has four operational WWTPs, in Marselisborg, Egaa, Aaby and Viby, respectively, which are operated by Aarhus Vand, a 100% Aarhus municipality-owned utility company. The company started producing energy from biogas around 31 years ago. All these WWTPs employ the activated sludge process using multiple digesters for the treatment of wastewater. The capacity of these digesters range from 1300m^3 to 3000m^3. Marselisborg is the largest WWTP

[2] "Understanding Water Flows in Udaipur", Heinrich Böll Foundation-India and Development Alternatives Group, October 2018
[3] https://www.statbank.dk/BY1
[4] https://web.archive.org/web/20141103095546/http://www.aarhus.dk/sitecore/content/Subsites/CityOfAarhus/Home/Welcome-from-the-Mayor.aspx

in Aarhus and has three digesters, each having a height of 8-10 metres and a capacity of 3000m^3. The wastewater plant generates ~30 tonnes of untreated sludge per day. The sludge generated from the treatment process is wet in nature and has only ~24% dry matter (post final dewatering). This sludge is used to produce energy in the form of heat and electricity. The Marselisborg plant, in 2016, produced 40% more electricity than its internal requirement and 2.5 GW of heat for the district heating system without adding external organic waste or carbon.

Key learnings from Aarhus: The city of Aarhus has been generating energy from its WWTPs for more than three decades and a lot can be learnt from their experience of converting sludge to energy. First and foremost, the best way to make the entire process of sludge to energy conversion efficient is by integrating a WWTP with a standalone energy generation plant or upgrading the existing plant by installing wastewater/sludge to energy technologies. This will enable the energy plant to have a constant supply of fresh and high-quality sludge for production of energy. Second, if it is not possible to integrate the WWTP with the energy plant, the energy plant should be set up as close to the source of sludge as possible and should be located in connection to a central road as the sludge for treatment at the plant will be received through vacuum trucks. This not only helps solve the problems related to transportation of sludge, it makes sure that the plant always receives a fresh supply of sludge. Third, a large amount of land is required to set up machinery for a sludge to energy plant and for possible future expansion. Fourth, the process of sludge to energy conversion is technically advanced and requires manpower with adequate technical know-how to operate the plants. Lastly, anaerobic digestion of sewage sludge forms methane-rich biogas, which can be utilized as fuel to offset heat and electricity consumption of the wastewater/sewage treatment plant or can be further used for distribution. Methane production in digesters is directly related to the organic matter content of the waste. Hence, wastewater rich in organic matter (carbon content), has ultimately more potential of generating energy.

Learnings from other national and international cities

Cities covered: Apart from Aarhus, sewage treatment plants in other cities such as Copenhagen (Denmark) and Vadodara (India) were studied as part of this baseline study. These cities have adopted different and efficient methods to treat the incoming wastewater/faecal sludge and convert it into a useful end product in the form of energy, heat, fertilizer, etc. The key highlights from the study of these cities are captured below:

Copenhagen, Denmark: The Lynetten plant in Copenhagen is operated by BIOFOS (Denmark's largest wastewater treatment operator) where the wastewater is treated mechanically, biologically, and chemically to ensure it meets the strict standards set by the local environmental authorities. The plant utilizes the sludge generated from wastewater treatment for climate-friendly electricity, biogas, and district heating for the grid. For every 100 units of energy consumed, the plant sends back 260 units of energy to the grid. It has a capacity to treat 2.35 tons of dry solids per hour and produced 18,740 MWh of district heating during the first six months of 2016.

Vadodara, India: The recently inaugurated sludge to energy plant in Vadodara uses faecal sludge stored in the septic tanks of the city as an input. The plant has a capacity to treat 200 KLD of faecal sludge and uses one of its kind omni-processor technology for treatment and reduction of waste. The liquid sludge is treated using the MBBR technique and produces industrial grade water to the tune of 135 KLD while the solid part is treated using the combustion technology and produces 140 KwH of electricity per hour. The plant also undertakes tertiary treatment to produce 14 KLD distilled water. The plant is currently energy neutral and also has an additional waste to energy component retrofitted for converting municipal waste to energy. Once operational, the waste to energy component will enable production of energy which may be used for other purposes or sold back to the grid.

Conclusions and way forward

Need for sludge to energy project: Given the international precedent set by the WWTP plants in Aarhus, particularly the Marselisborg WWTP, it is evident that energy generated from wastewater/sludge not only helps in making the WWTPs/STPs self-sufficient in terms of energy, the electricity and heat produced can be used for various commercial purposes as well. The setup of sludge to energy plant will also lead to odor reduction and utilization of methane thereby increasing the quality of life of the city's citizens as well as improvement in the carbon footprint of the city. Further to the aforementioned points, the sludge to energy will have significant environmental benefits such as reduction in soil and water pollution, significant reduction in the landfilled area, and improvement in the overall hygiene and health of the areas surrounding the landfill. Since the sludge generated from the commissioned STPs in Udaipur is not currently put to any productive use and is directly dumped into the landfill site without using any scientific method for its treatment, there is an immediate need for a sludge to energy project in the city.

Key considerations and learnings from Aarhus: The learnings and best practices from the city of Aarhus can be employed when implementing the sludge to energy plant project in the city of Udaipur. Since conversion of sludge to energy does not fall under the mandate of existing STPs being operated by HZL, UMC will need to tender contracts for setting up of integrated STPs with sludge to energy plants. UMC will need to provide or assist the private developer in procurement of suitable land (proximity to source of sludge, size, etc.). Further, it would be imperative to employ manpower that has the requisite technical knowhow to operate the energy plants. The private player may be required to organise technical capacity building workshops for its manpower before commissioning the energy plants and during its operation. Alternatively, and depending on relevant parameters (e.g., cost, availability of land), private entities could fund this project as part of their Corporate Social Responsibility contribution. Both the parties (government as well as private player) will need to formulate and sign a contract highlighting the key roles and responsibilities of each party.

Way forward: Having established the need for a sludge to energy plant in the city of Udaipur through this baseline study, the UMC should undertake or assign a detailed feasibility study in this regard. The baseline study prepared as a part of this assignment should feed into the feasibility study. The feasibility study should cover the following in detail:

- Sewage and sludge monitoring program: The Aarhus city team in collaboration with UMC is also planning to undertake a sewage monitoring program to evaluate the quality of sewage in Udaipur and the consequent sludge generated from the sewage treatment plants. The findings of the monitoring program will feed into the feasibility report.
- Technical feasibility – This part of the feasibility report should cover all the technical aspects in detail, including but not limited to selection and detailed assessment of all technologies available for sludge to energy conversion and their comparison with omni-processor technology employed at the Vadodara faecal sludge treatment plant (FSTP), costs related with each technology and its feasibility, availability of encumbrance-free and suitable land (proximity to source of sludge, size, etc.), potential users of energy generated in terms of heat and electricity, input and output specifications of the project along with its performance standards, legal and regulatory assessment, social and environmental assessment and risk assessment along with mitigation
- Financial feasibility – The feasibility study should also undertake a detailed financial assessment of the project, with a detailed estimation of capital expenditure, operational expenditure and revenue, quantum of electricity to be generated, electricity tariff, subsidies required, sensitivity analysis and value for money analysis. Although a preliminary cost benchmarking has been undertaken for various sludge to energy recovery methods, it is recommended that a detailed financial feasibility of these technologies is undertaken at the feasibility stage including various parameters such as required capacity, location of

project, land required, associated capital costs, operating costs, overheads, etc., so as to select the most efficient and affordable technology to be implemented at the Udaipur sludge to energy plant.

- Project structure – This includes roles and responsibilities of various stakeholders, particularly that of the private developer and the implementing agencies, possibility of integration with existing STPs by increasing HZL's scope of work, mode of contracting such as public private partnership (PPP) or engineering, procurement and construction (EPC), mode of payment, contract duration, etc.
- Bid process management – The feasibility study should also provide the details regarding the next steps in project preparation and execution i.e., bid process management. This part should explain in detail the number of stages that will be employed for the procurement process, bidding parameters, including technical and financial parameters, appointment of transaction advisors, formation of data rooms, preparation of bidding documents, etc.

2 List of acronyms & abbreviations

Abbreviation	Full form
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BMGF	Bill & Melinda Gates Foundation
BOD	Biological oxygen demand
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
CPHEEO	Central Public Health and Environmental Engineering Organisation
CSP	City Sanitation Plan
CSR	Corporate Social Responsibility
CSTF	City Sanitation Task Force
EU	European Union
FSTU	Faecal Sludge Treatment Unit
GCom	Global Covenant of Mayors
GoI	Government of India
HAM	Hybrid annuity model
HH	Households
HZL	Hindustan Zinc Limited
IEC	Information, education & communication
IUC	International urban cooperation
JDA	Jaipur Development Authority
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KLD	Kilo Liters per Day
KwH	Kilo watt hours
LAP	Local action plan
LPCD	Litre per capita per day
LPH	Liters per hour
MBBR	Moving Bed Bio Reactor
MBR	Membrane Bio Reactor
MLD	Millions of liter per day
MOHUA	Ministry of Housing and Urban Affairs
MoUD	Ministry of Urban Development
NGO	Non-governmental organisation
NLCP	National Lake Conservation Plan
NUSP	National Urban Sanitation Policy
ORC	Organic rankine cycle
PHED	Public Health Engineering Department
PPM	Parts per million
PPP	Public private partnership

Abbreviation	Full form
SBM	Swachh Bharat Mission
SBR	Sequencing Batch Reactor
SOP	Standard operating procedure
STP	Sewage treatment plant
TSS	Total suspended solid
UIT	Urban Improvement Trust
ULB	Urban Local Body
UMC	Udaipur Municipal Corporation
VMC	Vadodara Municipal Corporation
WHO	World Health Organization
WWTP	Waste water treatment plant

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4 Introduction

This chapter contains the background of the assignment and the objectives of this baseline study. It also briefly explains the methodology followed in preparation of this study and the current scenario pertaining to wastewater/sludge management in the city of Udaipur.

4.1 Background information

Baseline study: The baseline study for the sludge to energy project has been commissioned as a part of the Udaipur-Aarhus strategic collaboration under the IUC-India program. The study is aimed at capturing the existing sewage management scenario in Udaipur including details such as amount of sewage generated, sewage network coverage, stakeholder involvement and responsibilities, existing sewage treatment facilities, national and international best practices and recommendations and way forward. The study relies on desk based secondary research, undertaking stakeholder consultations, and analyzing case studies.

Program objectives: The IUC programme's overall objective is to contribute to improved international urban policy diplomacy and increased decentralised cooperation on sustainable urban development and climate change. The programme has two components: a) City/Sub-national cooperation on sustainable urban development to strengthen European Union (EU) - India cooperation among selected city/sub-national governments, as well as between the national level and the EU, on sustainable urban development while contributing to India's Smart Cities Mission, AMRUT and other national and international sustainable urbanisation processes; and b) Cooperation on sustainable energy and climate adaptation and mitigation, and access to clean and affordable energy, by building upon the Global Covenant of Mayors (GCoM) initiative in line with existing India-EU commitments.

Udaipur-Aarhus cooperation: In August 2017, a strategic cooperation on sustainable urban water management between the city of Udaipur, Rajasthan and the city of Aarhus, Denmark was initiated. The strategic cooperation program is supported by the Royal Danish Embassy in New Delhi under the Strategic Sector Cooperation mandate of the Ministry of Foreign Affairs of Denmark. The co-operation was formalized in December 2017 when the Mayor of Aarhus visited Udaipur City and signed a Memorandum of Understanding with Udaipur city. Both cities in April 2018, signed a project on urban sustainable water management. The primary focus of the co-operation is urban sustainable water management with the following suggested outcomes: a) Improvement of the Ayad River ecosystem by improving water quality, management of wastewater and setting up of a sludge to energy project, b) Improvement of the drinking water quality and c) Achievement of the UN sustainable development goals.

IUC Programme: International Urban Cooperation-India (IUC-India) is supporting the Udaipur-Aarhus city pairing through the provision of exchange visits and the development of a LAP for efficient, sustainable and environmentally-friendly wastewater and sewage treatment. One such initiative under the IUC-India collaboration is to undertake the baseline study for the setup of sludge to energy project in Udaipur. The baseline study has been initiated in line with the insights received from key stakeholders in both the cities and will enable the UMC to understand and counter the challenges to the adoption of this technology.

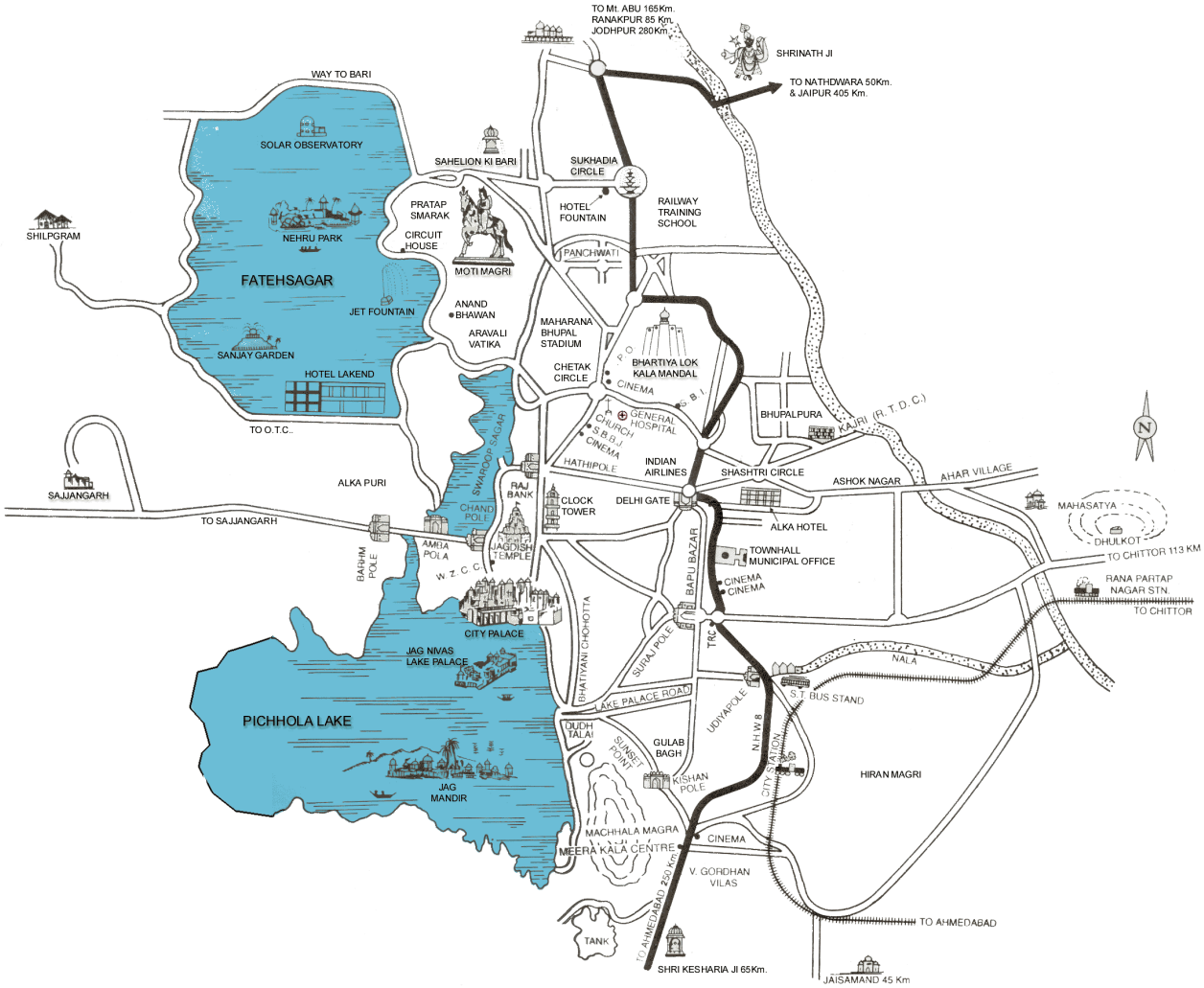
4.2 City profile - Udaipur

About the city: Udaipur, popularly known as the city of lakes, is the 6th largest city (in terms of population) in the westerly state of Rajasthan having an estimated population of 569,224[5] (which was 451,100, as per the census of 2011). The city is spread over an area of 64 sq. km.[6] (city map of Udaipur is presented in Figure 1)

[5] https://worldpopulationreview.com/world-cities/udaipur-population/
[6] https://www.ircwash.org/sites/default/files/udaipur.pdf

and has a population density of 8,000 person/sq. km. UMC is the main administrative body for Udaipur, under which various line departments function for operation and maintenance of urban services. The city of Udaipur is divided into 70 wards, all of which are under the jurisdiction of the UMC.

Figure 1: Udaipur city map



Source: http://www.udaipurplus.com/travel/udaipur-map.htm

Economic profile: Udaipur has a diversified economic base. The major pillars of the city's economy are tourism, agriculture, minerals and industries. As per the District Census Handbook, 2011, Udaipur had a per capita income of INR 24,135 (or € 291)[7]. Udaipur, with its lakes, and historic places and architecture, is a major destination for tourists visiting Rajasthan. As per the fact finding mission report on Udaipur by the Royal Danish Embassy, Udaipur hosts 0.9 million tourists every year, of which, 80% are Indian and 20% are international. With more than 250 hotels to serve visiting tourists, Udaipur is home to some of the most popular and luxury hotels and resorts in India. The Oberoi Udaivilas was ranked as the world's number 1 hotel in 2015[8]. Some of the popular tourist destination includes Lake Pichola, Fatehsagar, City Palace, Lake Palace, Jag Mandir, Sajjangarh, and Shilp Gram. Apart from being a tourism hotspot, Udaipur also boasts of about seven universities and a number of colleges affiliated to these universities. Some of the prominent universities

[7] *Considering exchange rate of 1 INR = 0.012 €, as on May 20, 2020*
[8] *https://www.travelandleisure.com/worlds-best/worlds-best-hotels?slide=4af7e838-d662-4517-9604-dfb70af82f4f#4af7e838-d662-4517-9604-dfb70af82f4f*

include: Indian Institute of Management, Mohanlal Sukhadia University, and Maharana Pratap University of Agriculture and Technology.

Industry profile: There are 10 industrial areas in Udaipur district with 1,800 industrial units (as on March 31, 2016). Of these, registered medium and large units are 49. A snapshot of the industry in Udaipur is given below:

Table 1: Industry at a glance

S no	Particulars	Unit	Details (as on March 31, 2016)
1	Total industrial units	no.	~1,800
2	Registered medium and large units	no.	49
3	Employment in small scale industries	no.	27,423
4	Employment in large and medium industries	no.	14,164
5	Number of industrial areas	no.	10
6	Investment of micro and small enterprises	lakh	21,999
7	Investment of medium and large scale enterprises	crore	4,516

Source: http://dcmsme.gov.in/dips/2016-17/DIPR_Udaipur.pdf

Natural resources profile: Important metals found in the district are copper ore, lead, zinc and silver. Among industrial minerals, rock, phosphate, asbestos, calcite, lime stone, barites, emerald, and marble are important. The total quantity of minerals produced in and around Udaipur was 30 MT, in fiscal 2015[9]. Production of mineral is provided in the table below:

Table 2: Production of minerals, FY15

S no	Name of mineral	Production (in MT)
1	Lime stone	81,870
2	Marble	17,630
3	Lead	22,217
4	Zinc	58,970
5	Asbestos	13,670
6	Rock phosphate	9,71,440
7	Calcite	2,580
8	Banite	6,100
9	Building stone	2,19,870
10	Bajri	15,33,610

Source: http://dcmsme.gov.in/dips/2016-17/DIPR_Udaipur.pdf

4.3 Objectives of the consultancy

Establish a baseline of current practices to handle the sludge: The study has been prepared by doing extensive secondary research and multiple stakeholder consultations. As a result of this, the study analyses

[9] *http://dcmsme.gov.in/dips/2016-17/DIPR_Udaipur.pdf*

the current status of the sewage sector in Udaipur, including its population, number of households, quantum of sewage generated, sewerage network, sewage processed by sewage treatment plants, sludge generated and disposed. It covers the roles of various government organizations/agencies in the entire value chain of sewage management in Udaipur, role of private players in sludge treatment and disposal, key stakeholders related to the sludge to energy project, assessment of technologies being used by the STPs and organisational structure of the UMC. The study also estimates the amount of sewage and sludge that will be generated over the next two decades, in line with the urban development plan, demographics, proposed STPs and national norms. The study further goes on to briefly explain technologies used in sludge to energy conversion.

Present international (with a focus on the EU) and national experience on similar processes: This report covers case studies from Denmark (Aarhus and Copenhagen) and India (Vadodara) that use wastewater/ faecal sludge to produce energy. The case studies assess the technology being used at each of these treatment plants to generate energy from wastewater/sludge such as anaerobic digestion and combustion. Key considerations and corresponding challenges related to setting up a sludge to energy plant have also been identified, which include; i) integration of STP with a standalone energy generation plant in order to have constant supply of fresh sludge. In case integration of plants is not possible, the energy plant should be commissioned as close as possible to the source of sludge; ii) a large amount of land is required for setting up of machinery of a sludge to energy plant and for possible future expansions; and iii) it is important to have manpower equipped with the required technical knowhow, given that sludge to energy conversion is a technically advanced process.

Set the basis for a more detailed feasibility study: This report is a baseline study for a sludge to energy plant in Udaipur and the findings of this report will feed into a detailed feasibility study. The feasibility study should cover in detail the roles and responsibilities of various stakeholders, particularly that of the private developer and the implementing agencies; risk assessment along with mitigation; input and output specifications of the project along with its performance standards; detailed estimation of capital expenditure; operational expenditure and revenues; legal and regulatory assessment; social and environmental assessment; quantum of electricity to be generated; electricity tariff; subsidies required; availability of encumbrance free and suitable land (proximity to source of sludge, size, etc.); mode of contracting and details of bid process management; detailed analysis and viability of various sludge to energy technologies; economic assessment; sensitivity analysis; and value for money analysis.

4.4 Methodology employed

Confluence of secondary research and stakeholder consultations: The study aims to provide a detailed analysis of the existing sewage treatment scenario in the city of Udaipur. The study is based on: a) secondary research through reports shared by IUC-India team, web search and case studies on sludge to energy plants in Denmark and India; and b) stakeholder consultations with officials of the UMC, Hindustan Zinc Limited, Aarhus city council, Aarhus Vand, Royal Danish Embassy, and Ankur Scientific Energy Technologies Pvt Ltd.

Secondary research: Extensive secondary research was carried out during the preparation of this baseline study which included summarising, collating and synthesising the existing research pertaining to the city of Udaipur through reports / documents shared by Aarhus City Council, IUC-India, procured through web search and also using relevant case studies from Denmark and India:

- Documents shared by IUC-India – The IUC-India team shared a number of existing studies pertaining to urban infrastructure in the city of Udaipur which were imperative in the preparation of this baseline study. Some of these reports included the City Sanitation Plan of Udaipur, case studies on STPs operated by HZL, Understanding Water Flows in Udaipur (2018), detailed project report on sewerage work in Udaipur, Identification of urban resilient water solutions in India by Aquagreen, etc. These studies/documents provided a comprehensive overview of the current situation related to waste generation, its treatment and disposal. These reports encompass action plans for achieving 100% sanitation in the city of Udaipur

through demand generation and awareness campaigns, sustainable technology selection, construction and maintenance of sanitary infrastructure, provision of services, O&M issues, institutional roles and responsibilities, public education, etc.

- Documents shared by Aarhus City Council – In addition to inputs by the officials of the Royal Danish Embassy, Aarhus City Council and Aarhus Vand during our multiple discussions, they also shared a number of documents and web links related to the existing wastewater treatment plants in Aarhus. Some of these included Energy Technology Development and Demonstration Programme (EUDP) final report on Ega WWTP, First movers at Egaa WWTP, report on estimate on area needed for sludge production, data list for IUC India, main flow diagram of Marselisborg WWTP, etc. These documents provided in-depth data and information pertaining to operation of WWTPs in Aarhus. Further, these documents helped identify the challenges faced by the authorities during the implementation phase, best practices for operating these plants and key considerations in implementing a sludge to energy project.
- Documents procured through web search – Internet search was also carried out in order to undertake secondary research. Various reports and articles related to urban infrastructure in Udaipur and the current condition related to sewage management were referred to while preparing this study. Some of these reports included City Development Plan, smart city plan of Udaipur; organisational framework of UMC, publications on various STP technologies, etc. These reports and articles helped in identifying the problems related to various sectors in the city of Udaipur particularly in the sewage management sector. It also helped in understanding the suggestions provided by various stakeholders and the strategies developed to implement those suggestions.
- Case studies – As part of the secondary research, three case studies were analysed (two from Denmark and one from India) related to sludge to energy conversion. The case studies helped in identifying the best practices from around the world, including latest technologies for conversion of sludge to energy. The case studies also highlighted various benefits of the energy produced by these plants and showcased how proper management of wastewater/sewage can lead to a reduction in the overall carbon footprint of these plants. Case studies from Denmark (Copenhagen and Aarhus) set an important precedent as to how the converted energy can benefit the entire city, while the case study from India (Vadodara) demonstrated the key highlights of developing a standalone sludge to energy conversion plant. Further, it was possible to identify a set of key considerations that should be noted while implementing a sludge to energy project.

Stakeholder consultations: A number of stakeholder consultations were organised through video conferencing and conference calls, such as officials of the UMC, HZL, Aarhus city council and Aarhus Vand, Royal Danish Embassy, Ankur Scientific Energy Technologies Pvt Ltd, and IUC-India. Inputs and insights provided by these experts/officials were of great importance in the preparation of this study and these have been further included in relevant chapters of this study.

- Udaipur Municipal Corporation – Discussions were held with Mr. Arun Vyas, Additional Chief Engineer, UMC and Mr. Mukesh Pujari, Superintendent Engineer, UMC. The discussions were held to understand the requirements as well as the current situation and deficiencies related to sewage management in the city of Udaipur. Mr. Vyas also offered background information on the two commissioned STPs in the city with regards to their capacity, output and future plans. He has been instrumental in providing deep insights related to sewage management in the city of Udaipur.
- Officials of Aarhus Vand and Royal Danish Embassy – Discussions were held with Kamilla Kristensen Rai and Anitha Kumari Sharma, Royal Danish Embassy, Gitte Normand Anderson, Aarhus City Council, Maiken Madsen and Peter Fischer-Jensen, Aarhus Vand. These officials have been instrumental in providing deep insights pertaining to the city of Aarhus and its sludge to energy plants. The officials also briefed us on the challenges faced by the city council and Aarhus Vand during implementation and operation of these projects. They also explained various technical processes used for generation of energy from sludge, including pros and cons of popular technologies.

- Hindustan Zinc Limited – HZL is the private developer currently operating two sewage treatment plants in the city of Udaipur, with two additional plants ready for commissioning in the upcoming months. Discussion was undertaken with Mr. Vipin Arya from HZL to get an overview of the operations of the STPs. He briefed us on the various financial and legal aspects related to their agreement with the UMC pertaining to the STPs. He was instrumental in providing important details regarding the STPs including technical specifications, source of sewage, use of treated water, potential and willingness to generate energy from sludge, etc.
- Ankur Scientific Energy Technologies Pvt Ltd – Ankur Scientific is a private developer which has commissioned a faecal sludge treatment plant in the city of Vadodara, Gujarat incorporating the omni-processor technology for the conversion of faecal sludge to energy and re-usable water. This energy neutral FSTP is the first of its kind sludge to energy plant in India. Discussion was undertaken with Mr. Jignesh Shah, Business Head – Ankur Scientific, to get an overview of the technical and financial specifications of the plant along with its working.

4.5 Limitations of the exercise

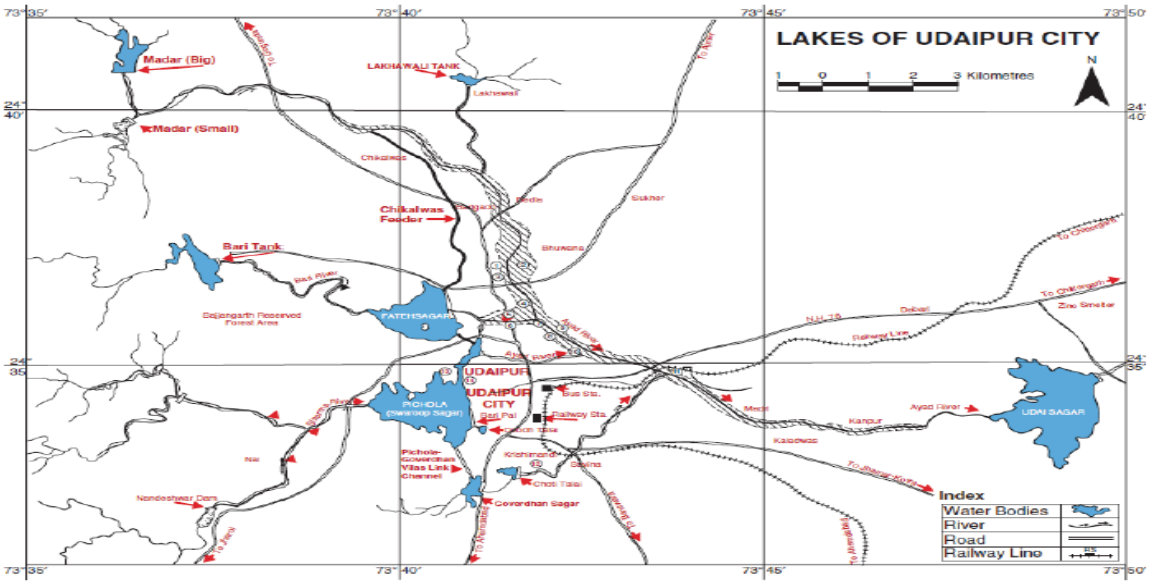
This study is a broad presentation of the current situation pertaining to sewage and its treatment in the city of Udaipur, in addition to a review of the policies dictating its management. The study is limited in the sense that it is only a baseline study to assess the as-is situation in the city of Udaipur related to the current status of operations at key STPs in the city, in addition to assessment of existing practices to handle sludge.

In the wake of Covid-19 and the subsequent restrictions laid out by the Government of India, on-ground verification of data and site visits were not feasible leading to a major limiting factor for the study – data reliability, due to the high dependence of the data in the report on secondary sources of information. This study may be further strengthened through data pertaining to results of sludge analysis, identification of any operational issues faced by HZL at their commissioned STPs, etc.

4.6 Situation analysis

Water demand and supply: As per the data provided in the report “Understanding Water Flows in Udaipur”, by Heinrich Böll Foundation-India and Development Alternatives Group (2018), the total water demand in the city of Udaipur is 115 MLD. This includes the demand of various users such as domestic, industrial, institutional, tourist and floating population. The water supply in the city is maintained by 5 surface sources (Pichhola Lake, Fatehsagar Lake, Jaisamand Lake, Badi Lake and Mansa Wakal Dam, which have been showcased in Figure 2), 4 open wells, 16 stepwells, 60 Tube wells, 199 Panghat (river bank) and 2,938 hand pumps. The 5 surface sources in the city provide raw water to the tune of 78.5 MLD, while the other ground water sources contribute a mere 5.1 MLD. The city has 10 water treatment plants with a total treatment capacity of 84.2 MLD.

Figure 2: Lakes of Udaipur



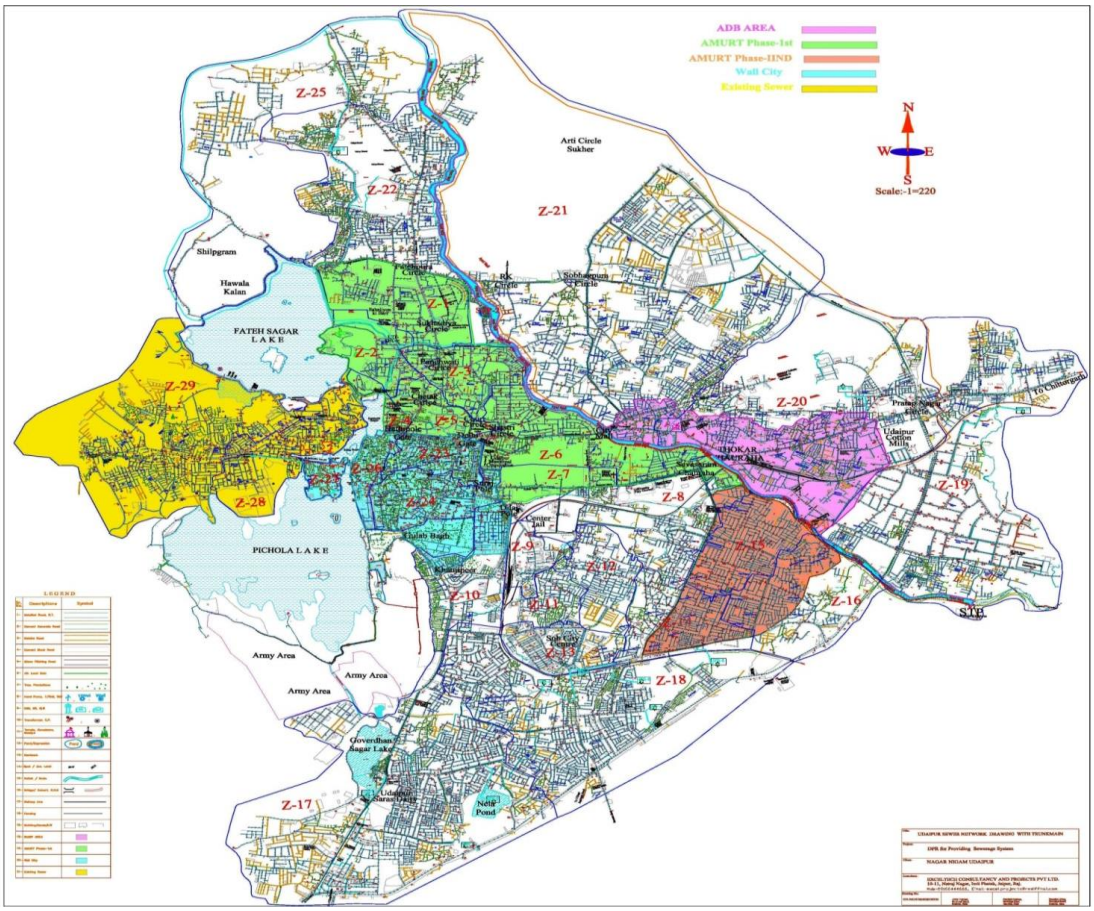
Source: "Understanding Water Flows in Udaipur", by Heinrich Böll Foundation-India and Development Alternatives Group

Sewage generation and management: As per discussions held with Udaipur Municipal Corporation, the city on average, generates 57 million litres per day (MLD) of sewage. The city has a 82 km long sewage network[10], along with a 7,700 m trunk line in Udaipur. The city also has ~40,000 septic tanks and 139 open drains that hold and carry the remaining sewage. The main drainage body of Udaipur is the Ayad River which subsequently drains out into the Udaisagar Lake. UMC officials also added that the sewerage network coverage is slated to increase to ~62.5% over the next 4-5 months with the support of the AMRUT program, smart city project and Rajasthan urban infrastructure development project (RUIDP). Figure 3, provides the proposed sewerage network for the city of Udaipur, to be developed under AMRUT and smart city program.

Sewage network: As per the report "Understanding Water Flows in Udaipur" by Heinrich Böll Foundation-India and Development Alternatives Group (2018), there are a total of 17 sewage pumping and lifting stations and the length of the pumping mains is 6.9 km. Integrated sewerage map was developed by the UMC and UIT after the lake conservation plan under the national lake revival plan was established in 2013. Under this plan, 58 km of sewerage network and a 7,700m trunk line has been laid, in addition to the 24 km sewerage line which was built by the UIT during 2002-2004, bring the total sewerage network to 82 km with a 7.7 km trunk line. From 2013-2016, Urban Improvement Trust (UIT), with the assistance of HZL, laid a 7.7 km trunk line of diametre varying from 800 mm to 1400 mm to transport the sewage to STP of 20 MLD capacity at Eklingpura, Udaipur. HZL has an already established 80km pipeline network to provide treated water to its industrial complex from the STP. Sewerage pipes are laid at 2.5 m depth and fresh water pipes at 4 m depth. This has caused the leakages from the sewerage network to contaminate the fresh water supply at weak points.

[10] "Understanding Water Flows in Udaipur", Heinrich Böll Foundation-India and Development Alternatives Group, October 2018

Figure 3: Udaipur city proposed sewerage network under AMRUT Phase 2 and smarty city plan



Source: "Understanding Water Flows in Udaipur", by Heinrich Böll Foundation-India and Development Alternatives Group

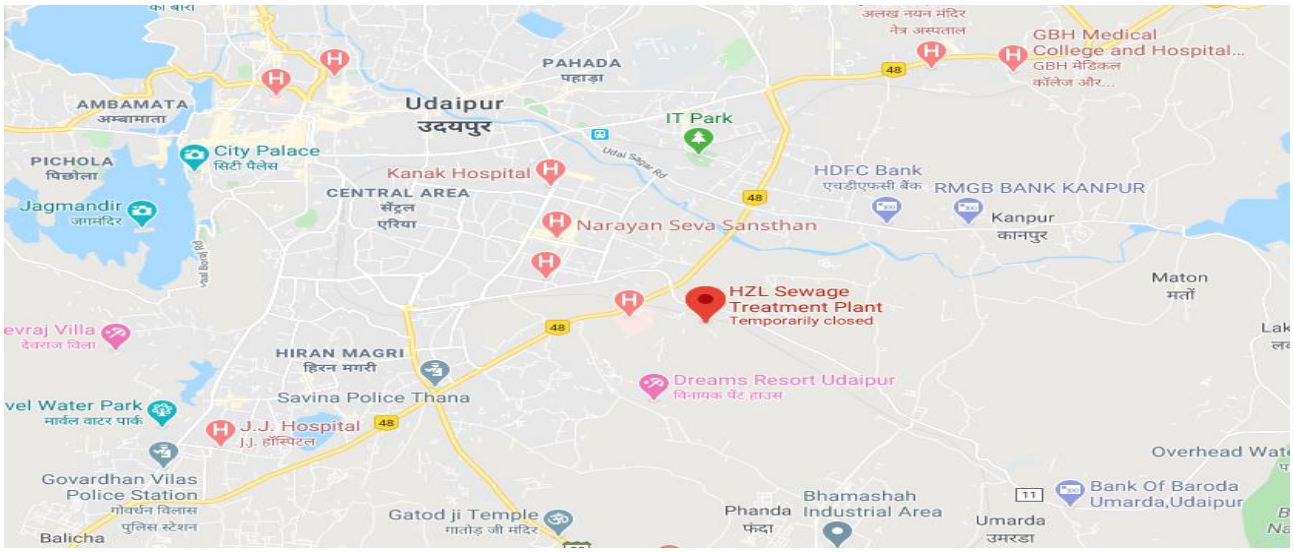
Sewage treatment plants: In association with UMC, HZL has commissioned two STPs in Udaipur, with a total capacity of 45 MLD, while two STPs with a combined capacity of 15 MLD will be commissioned in the upcoming months. The details of all the STPs have been provided below:

- 20 MLD STP - The first STP with a capacity of 20 MLD was commissioned in March 2014. The contract for this STP was awarded on sole source basis and a MoU was signed between the UMC and HZL. As per information provided by HZL, this project was undertaken as a part of their CSR programme. The land for this project was procured by HZL and the capex and opex requirements were also met by HZL. The STP uses MBBR technology, followed with claritube flocculator and filters to produce high quality treated water suitable for reuse. 50% of the sewage treated by the STP is being utilised by the Hindustan Zinc industrial complex and the other half is discharged in the nearby water bodies. This STP generates 2.0 tonnes of sludge per day (with a dry matter percentage of ~25-30%), which is dumped by the UMC at the existing solid waste management facilities in and around Udaipur. Further, total land area occupied by both the 20 MLD and 25 MLD STPs is 2.75 hectares. The pictures of the 20 MLD STP have been provided in Figure 4, below.

Figure 4: Sewage treatment plant - Udaipur

- 25 MLD STP – The second STP with a capacity of 25 MLD at Eklingpura was commissioned in January 2019. The contract for this STP, along with two other STPs (total capacity of 15 MLD) was awarded through open tendering by the UMC under which HZL emerged as the preferred bidder and signed a PPP contract with a 15 year concession period. The land for this STP was procured by HZL and the capex and opex requirements were also met by the private developer. The STP uses the MBBR technology, followed with claritube flocculator and filters to produce high quality treated water suitable for reuse. 50% of the sewage treated by the STP is being utilized by the Hindustan Zinc industrial complex and the other half is discharged in the nearby water bodies. This STP generates 2.5 tonnes of sludge (with a dry matter percentage of ~25-30%) per day which is dumped by the UMC at the existing solid waste management facilities in and around Udaipur. The location of the STP at Eklingpura has been highlighted in the map in Figure 5.

Figure 5: Sewage treatment plant – Eklingpura, Udaipur



Source: Google Maps

- 10 MLD STP – HZL has recently commissioned its third STP with a capacity of 10 MLD. The STP occupies a land area of 0.49 hectare, provided by UMC, and uses the sequencing batch reactor (SBR) technology for the treatment of sewage. The capex and opex for the plant will be borne by HZL. The plant is currently using the sewage input from the nearby drains and is slated to be connected to the trunk line. At present, the STP generates 4-5 kilograms of sludge (dry matter percentage of ~20%) which is slated to increase to 0.6 tonne to 1 tonne per day once the STP is connected with the trunk line. As per UMC officials, the low quantum of sludge generated can be attributed to two major reasons – a) the low quality of incoming sewage and b) deployment of SBR technology which produces lower amount of sludge as against the MBBR technology.
- 5 MLD STP – HZL is in the advanced stage of commissioning another STP, with a capacity of 5 MLD. This STP was awarded through open tendering by the UMC under a PPP agreement with a concession period of 15 years. The land for the STP will be provided by the UMC, while the responsibility of bearing the capex and opex requirement for the plant will be undertaken by HZL. The STP will occupy a land area of 0.19 hectare. This STP will use the sequencing batch reactor (SBR) technology for the treatment of sewage. On commissioning of this STP, the total capacity of all the STPs will become 60 MLD, which is more than the amount of sewage generated (57 MLD) by the city of Udaipur. Further, the new STP along with the existing STP will generate 5-6 tonnes of sludge per day.

Effluent concentration of sewage inlet and outlet for 25 MLD and 20 MLD STP: As per the monthly average data provided by UMC, the Biological Oxygen Demand (BOD) of incoming sewage at both the STPs is 147.1 mg/ liter and outgoing treated sewage from the 25 MLD STP and 20 MLD STP is 5.5 mg/ liter and 6.0 mg/ liter, respectively. Chemical Oxygen Demand (COD) of incoming sewage at both the STPs is 264 mg/ liter and outgoing treated sewage from the 25 MLD STP and 20 MLD STP is 15.2 mg/ liter and 19.9 mg/ liter, respectively. Total Suspended Solids (TSS) of incoming sewage is 156.2 mg/ liter while that of outgoing treated sewage from the 25 MLD STP and 20 MLD STP is 3.5 mg/ liter and 3.8 mg/ liter, respectively. The effluent concentration of sewage inlet and outlet for these plant is based on the information provided by UMC for the month of September 2020. UMC had earlier also shared the effluent discharge parameters in July 2020, these have been tabled in Annexure 1 of the report. Further, the effluent discharge standards of the operational STPs in Udaipur are in line with the standards stipulated by Ministry of Environment, Forest and Climate Change, India. The effluent discharge standards as mandated by the ministry have been provided in Annexure 3 of the document. Further details related to the chemical composition of the outgoing sewage, as per provided by UMC, have been provided below:

Table 3: Effluent concentration of sewage inlet and outlet – as of September 2020

Parameter	25 MLD STP	20 MLD STP
Sewage inlet		
Biological oxygen demand (mg/liter)	147.1	147.1
Chemical oxygen demand (mg/liter)	264.0	264.0
TKN[11] as N (mg/liter)	17.1	17.1
Total phosphate (mg/liter)	3.2	3.2
Suspended solids (mg/liter)	156.2	156.2
Total dissolved solids (TDS)	902.0	902.0
pH	7.0	7.0
Sewage outlet		
Biological oxygen demand (mg/liter)	5.5	6.0
Chemical oxygen demand (mg/liter)	15.2	19.9
TKN as N (mg/liter)	6.9	7.6
Total phosphate (mg/liter)	1.4	1.3
Suspended solids (mg/liter)	3.5	3.8
Total dissolved solids (TDS)	864.7	888.5
pH	7.0	6.9

Source: UMC

Effluent concentration of sewage inlet and outlet for 10 MLD STP: The 10 MLD STP has been functioning at its full operating capacity, processing an average flow of 7,779 m^3 of sewage in the month of September 2020. The key operating parameters pertaining to the input and output quality to and from the STP has been presented in Table 4 and 5 below, these values represent the average values for the month of September 2020:

Table 4: Sewage inlet parameters for 10 MLD STP – as of September 2020

Parameter	10 MLD STP
Biological oxygen demand (mg/liter)	132.2
Chemical oxygen demand (mg/liter)	232.1
pH	7.8
TSS (mg/liter)	134.2
NH4-N (mg/liter)	6.1
N-Total (mg/liter)	12.6
PO4 (mg/liter)	6.7
Fecal Coliform (MPN/100 ml)	$1.35*10^4$

[11] *Total Kjeldahl Nitrogen*

Source: UMC

Table 5: Sewage outlet parameters for 10 MLD STP – as of September 2020

Parameter	10 MLD STP
Biological oxygen demand (mg/liter)	7.5
Chemical oxygen demand (mg/liter)	33.6
pH	7.6
TSS (mg/liter)	4.8
NH4-N (mg/liter)	2.5
N-Total (mg/liter)	5.9
PO4 (mg/liter)	1.2
Fecal Coliform (MPN/100 ml)	25.3

Source: UMC

Sludge from commissioned STPs: As per the data provided by UMC, the quantum of sludge generated by the 25 MLD STP and 20 MLD STP is 2.5 tonne/day and 2 tonne/day, respectively. The 10 MLD STP currently generates 4-5 kilograms of sludge, the quantum of this sludge is slated to increase to 0.6 to 1.0 tonne once the STP is connected with the trunk line. The sludge generated by the 25 MLD and 20 MLD STPs has a dry matter content of 25% to 30% while that from 10 MLD STP has 20% dry content. The monthly average BOD of the sludge generated from the 25 MLD STP and 20 MLD STP is 668 mg/ liter and 596 mg/ liter, respectively, while the COD of the sludge generated from the 25 MLD STP and 20 MLD STP is 347 mg/ liter and 286 mg/ liter, respectively. The sludge related effluent parameters for 10 MLD STP are not yet available. The details related to the sludge generated from the 25 MLD and 20 MLD STPs are provided in the table below, these values are based on the data provided by UMC as on July 22, 2020:

Table 6: Sludge from commissioned STPs

Parameter	25 MLD STP	20 MLD STP	10 MLD STP
Volume (daily) (tonne)	2.5	2.0	4-5 kgs[12]
Dry matter (%)	25-30%	25-30%	20%
Biological oxygen demand (mg/liter)	668	596	-
Chemical oxygen demand (mg/liter)	347	286	-

Source: UMC

Challenges faced while implementing the STPs: Land acquisition was the greatest challenge for completing the project. Firstly, in terms of selecting a location for the STP which was close to the city and financially viable, and secondly, in negotiating with local stakeholders that were concerned about the potential visual and odour impact. The neighboring community was involved in the technology selection and the operational and maintenance elements of the contract, which resulted in building trust and support for the project. There were operational difficulties at the beginning of the project at both the STP and the industrial complex. The main issues at the STP were related to reliability and optimisation issues as well as inconsistent incoming sewage quality. At the industrial complex, there were challenges related to switching from freshwater to a treated effluent water quality that had higher total dissolved solids. The problem was resolved by marginally modifying

[12] *Slated to increase to 0.6 tonne to 1.0 tonnes on connection with the trunk line*

the treatment process. Further, during the initial phases, the STPs were being fed sewage from the septic tanks in the city and thus they did not receive enough quantity of sewage which is required for the MBBR treatment process. However, the sewage quantity has improved recently due to laying of new sewage pipeline which bypass the septic tanks.

Environmental benefits of sludge to energy plant: The sludge to energy plant will have several environmental benefits including benefits such as reducing land utilised for landfilling, improvement in overall hygiene conditions and odor, reduction of soil pollution, improvement in emissions and air pollution, and reduction in water pollution. The environmental benefits of the proposed sludge to energy plant has been described below:

- Reduction in landfilled area – The sludge generated from the STP plants is currently being dumped at the city's landfill without any further treatment. This unscientific practice leads to several challenges such as air pollution, soil pollution, and inefficient use of land. The land used for dumping sludge can be used for other productive activities such as green area development, municipal solid waste treatment, landscaping etc.

- Improvement in emissions and air pollution – Air pollution is major challenge faced by many cities in the country. The unscientific method of sludge dumping leads to emission of harmful gases such as methane and green-house gases which result in degradation of air quality in the city. The scientific treatment of sludge by the means of sludge to energy plant will result in reduction of these emissions and improve the quality of air in and around the Udaipur city.

- Improvement of hygiene conditions and reduction of odor – The dumping of sludge results in building up of pathogens and disease causing microorganisms as well as emitting of foul smell which impacts the residents of the nearby areas. This also affects the development and economic activities in the nearby areas. The sludge to energy plant will result in reduction of the untreated sludge and will enable improvement in the hygiene and odor situation in and around the landfill area

- Improvement in soil pollution – The untreated sludge once dumped in the landfill seeps into the land. This causes a depletion in the quality of the water table around the landfill area. It needs to be noted that water is a scare and important resource in the state of Rajasthan and depletion of the natural water table quality can have severe consequences for the residents in the city. The sludge to energy plant will prevent the depletion of the water table as commissioning of the plant will prevent the dumping of sludge in the Udaipur.

- Reduction in water pollution – Tourism is a major economic activity in Udaipur, the city is also called the city of lakes. The lakes in the city are gradually drying up and also face a severe challenge on the pollution front. The sludge to energy plant will enable tackling the water pollution from the discharge of sewage or sludge into water bodies such as rivers and lakes. The improvement in pollution levels of the lake will also enable further development of the tourism activities in the city.

5 Baseline analysis

This chapter gives a brief on various policies and guidelines related to waste water and sewage management issued by national and state agencies. It identifies the major stakeholders related to this project and outlines the organisational structure of UMC. It also briefly discusses the technical aspects of the commissioned STP and future plans of UMC pertaining to sewage management in Udaipur.

5.1 Policy framework

National Urban Sanitation Policy, Ministry of Housing and Urban Affairs[13]: Recognising that sanitation is a state subject and on-ground implementation and sustenance of public health and environmental outcomes require strong city level institutions and stakeholders, the Government of India came up with a set of national guidelines in the form of a National Urban Sanitation Policy in 2008. The overall goal of the policy is to transform urban India into community driven, totally sanitised, healthy, and livable cities and towns. The policy provides guidelines on draft framework for developing state sanitation strategies. Some of these are:

- Clear assignment of institutional responsibility, resources and capacities - State urban sanitation strategies must clearly delineate ULB responsibilities. Where partial or incomplete regulations exist, states will need to make concerted efforts to devolve powers, roles, and responsibilities along with financial and personnel resources necessary for ULBs to discharge their functions. The ULBs will also have to be accorded wide-ranging powers over agencies that currently carry out sanitation related activities in the city but are not directly accountable to them, e.g., parastatal and public health engineering departments (PHEDs).
- Setting standards at state level – This includes a) environmental outcomes, e.g., State Pollution Control Board standards on effluent parameters, diminishing water resources, impact of climate change, use of low energy intensive onsite/decentralised wastewater treatment technologies, distributed utilities etc. and b) processes, e.g., safe disposal of on-site septage and c) service delivery standards and public health outcomes.
- Planning and financing at state level - ULBs will need to be made responsible for planning and financing of public infrastructure, and leveraging private investments as may be required for achieving outcomes. The problem of shortage of funds needs to be factored in. In this regard, states will need to devolve adequate and predictable resources to ULBs through setting tariffs, inter-governmental fiscal transfers, and devising targeting of subsidies to the poorest of the poor households. The issue of recovery of O&M cost through introduction of user charges collection of dues needs to be emphasised as a means of ensuring accountability as well as financial sustainability. In doing so, state government's support to ULBs will need to be increasingly re-oriented to reward achievement of outcomes.
- Service delivery in cities - ULBs will need to be responsible for asset-creation and managing systems including service delivery. In this context, the ULB may bring in public, private, and community agencies/groups to provide services on its behalf. But the final accountability with regard to performance in sanitation will have to be that of the ULB. Departments currently carrying out these responsibilities will need to be accountable to the respective ULBs. The state governments will need to make explicit directions in this regard, including roles for non-governmental and community based organisations.

National Policy on Faecal Sludge and Septage Management (FSSM), Ministry of Urban Development[14]: The key objective of the urban FSSM Policy is to set context, priorities, and direction for, and to facilitate, nationwide implementation of FSSM services in all ULBs such that safe and sustainable sanitation becomes

[13] *https://smartnet.niua.org/content/ce856338-d63d-4963-873f-1a97d9e30474#:~:text=The%20policy%20envisions%20that%20%22All,the%20urban%20poor%20and%20women%22.*
[14] *http://amrut.gov.in/upload/newsrelease/5a5dc55188eb0FSSM_Policy_Report_23Feb.pdf*

a reality for all in each and every household, street, town and city. It is envisaged that state-specific FSSM policy, strategy and guidelines conforming to the national policy will be developed by each state. Key implementation steps include:

- State-level implementation strategy - In line with the National FSSM Policy each state is expected to develop and issue an FSSM Implementation Strategy and Plan Guideline. In accordance with State Policy and Plan, the Guidelines should provide an overall state-level framework, objectives, timelines and implementation plans to the ULBs. Rules, bylaws, regulations and operative guidelines for faecal sludge and septage management will address specification such as design of septic tanks, delineation of private and public responsibilities in relation of faecal sludge and septage management, frequency of desludging, methods and location of transport, treatment and safe disposal, etc.

- ULB level implementation **-** Each ULB is expected to develop a detailed FSSM plan in conformity to the National FSSM policy and respective state guidelines on FSSM. Citywide assessment of FSSM is the key step for FSSM process planning. Such plan should be technically appropriate and financially feasible. Assessment in each area entails review of available information at city level, identifying information gaps, and conducting field studies where necessary. Each FSSM plan will have a specific monitoring and evaluation framework to continuously gauge implementation progress and document lessons for constant improvement.

State Sewerage and Waste Water Policy, Rajasthan[15]: The Government of Rajasthan issued a State Sewerage and Waste Water Policy in 2016, as the guiding handbook on matter related to urban development for all the respective ULBs in the state. Key guidelines/policies related to wastewater treatment and reuse of treated effluent and sludge, as mentioned in the policy document are:

- Treatment of wastewater - Treated wastewater effluent should be considered a water resource and added to the water stock for reuse. Priority will be given to agricultural reuse of treated effluent for unrestricted irrigation. Studies should be conducted and projects designed and implemented to store the excess treated wastewater in surface reservoirs.

- Treatment of sludge - Plans and studies for power generation from sludge, if proven technically, economically and financially feasible, will be made with due attention to environment impacts. Sludge produced from the treatment process would be processed so it may be used as fertiliser and soil conditioner. Care must be taken to conform to public health and environment protection norms. Governing local body can sell the treated waste water and digested sludge to generate revenue.

5.2 Key stakeholders

Udaipur Municipal Corporation (UMC): The Udaipur Nagar Parishad was converted to UMC in April 2013. It is governed under the Rajasthan Municipalities Act, 2009 and is the main administrative body for Udaipur city, under which various line departments' function for O&M of urban services. Udaipur has 70 wards under the jurisdiction of UMC. Among other things, roles and responsibilities of UMC include: urban planning, including town planning, regulation of land use and construction of buildings, planning for economic and social development, public health, fire safety and solid waste management. With regards to underground sewage systems, UMC is only responsible for O&M along with monitoring and evaluation. Further, UMC is entirely responsible for septage/faecal sludge management in Udaipur, including financing and creating assets, O&M, tariff and revenue collection, and monitoring and evaluation.

Urban Improvement Trust (UIT): UIT is a statutory body under the Rajasthan Urban Improvement Act, 1959. UIT is responsible for overall development of Udaipur that includes implementation of development plans and infrastructure in the notified UIT areas, both, rural and urban. Earlier, when UMC was not a corporation and

[15] *https://urban.rajasthan.gov.in/content/raj/udh/rudsico/en/urban-infra/state-sewerage---waste-water-policy-2016.html#*

was a much smaller entity, much of urban development work was undertaken by UIT. Since the formation of Udaipur Municipal Council and subsequently, the Corporation, much of the area of Udaipur city now comes under the jurisdiction of UMC. This has led to some overlap in roles and responsibilities of these two bodies. With regard to the underground sewage system in Udaipur, UIT is responsible for financing and creating the asset, while UMC is responsible for its O&M, and monitoring and evaluation.

Public Health and Engineering Department (PHED): The PHED is a line department of the Government of Rajasthan, which is responsible for supplying potable water to every citizen of the state. In Udaipur too, PHED is responsible for each and every aspect of water supply including planning and design, construction/implementation, organization and management and regulations. PHED is also responsible for tariff implementation and revenue collection related to underground sewage system. The complete responsibility matrix of all the concerned departments is given below:

Table 7: Responsibility matrix of various organisations

Particulars	Financing	Asset creation	O&M	Tariff & revenue	Monitoring & evaluation
Water supply	PHED	PHED	PHED	PHED	PHED
Public/community toilets	UIT and UMC	UIT and UMC	Sulabh, UIT and UMC	Sulabh, UMC	UIT and UMC
Underground sewage system	UIT	UIT	UMC	PHED	UMC
Septage/faecal sludge management	UMC	UMC	UMC, private players	UMC, private players	UMC, private players
Solid waste management	UMC	UMC	Private players /NGOs	Private players/NGOs, UMC	UMC

Source: USAID Factsheet

Hindustan Zinc Ltd: HZL is a Vedanta Group company which operates in the zinc, lead and silver business. HZL currently operates two STPs in Udaipur and two more are slated to be commissioned in the coming months. The first STP was developed a part of HZL's corporate social responsibility (CSR) project, while the second was developed under a PPP agreement between HZL and UMC. The land for both the STPs was procured by HZL and all the requirements related to capex and opex of the commissioned STPs were fulfilled by HZL.

State government and agencies: The Government of Rajasthan is the prime authority which through its line departments and other agencies such as PHED, public works department (PWD), Rajasthan Housing Board, tourism department, Rajasthan State Pollution Control board, etc., formulate strategies, policies and regulations, and streamline the urban development of the entire state. It also provides funding support for major projects related to various aspects of urban development such as public health and safety, town planning and development, water and sanitation, etc. All the other stakeholders will need to follow the stipulated guidelines of the Government of Rajasthan pertaining to waste to energy conversion.

5.3 Organisational setup of UMC

Udaipur Municipal Corporation: Udaipur Nagarpalika Mandal was first established in December 1922 by the Mewar dynasty. In July 1948, political members were selected and a Nagar Nigam was established. After Independence, in order to bring harmony at the Nagar Palika level, a Nagar Parishad was constituted on October 13, 1959. The Municipal Council of Udaipur (Nagar Parishad) was converted to UMC in April 2013. It is governed by the Rajasthan Municipalities Act, 2009 and there are 70 wards under its jurisdiction. The

complete organizational structure has been showcased in Figure 6 and the sub-wings/constituents of the UMC have been defined below.

Executive wing: UMC comprises an elected body and an executive body. The elected body is headed by the mayor and includes corporators (parshad) representing the 70 wards. UMC has 14 divisional (ward) committees, out of which seven are mandatory under Section 55 of the Rajasthan Municipalities Act, 2009. These committees include elected members from wards, officials of respective departments from the corporation, and the nominated members. Some of the major committees are: finance, health and sanitation, slum improvement, and development. The committees have been assigned responsibilities for a department. The finance and executive committees are the financial decision-making bodies.

Administrative wing: The municipal commissioner is the executive authority of the municipal corporation. The municipal commissioner is one of the authorities entrusted with carrying out the provision of Municipalities Act, 2009. For administrative convenience, the corporation is organised into various functional departments, such as: engineering, public health, fire, revenue, law, town planning, and accounting. The other functional areas are public relations and human resource development.

Engineering department: The superintending engineer (SE) is the technical head of the engineering wing. He is responsible for technical features and designs, and monitoring and inspection of works under his control. The executive engineer is the technical head of the division and overall charge of the execution of engineering works pertaining to the subject/ jurisdiction allocated. The executive engineer is supported by an assistant and junior engineers.

Fire department: This department falls directly under the commissioner which is headed by the fire officer and supported by assistant fire officer. The department looks after fire-related emergencies in the city.

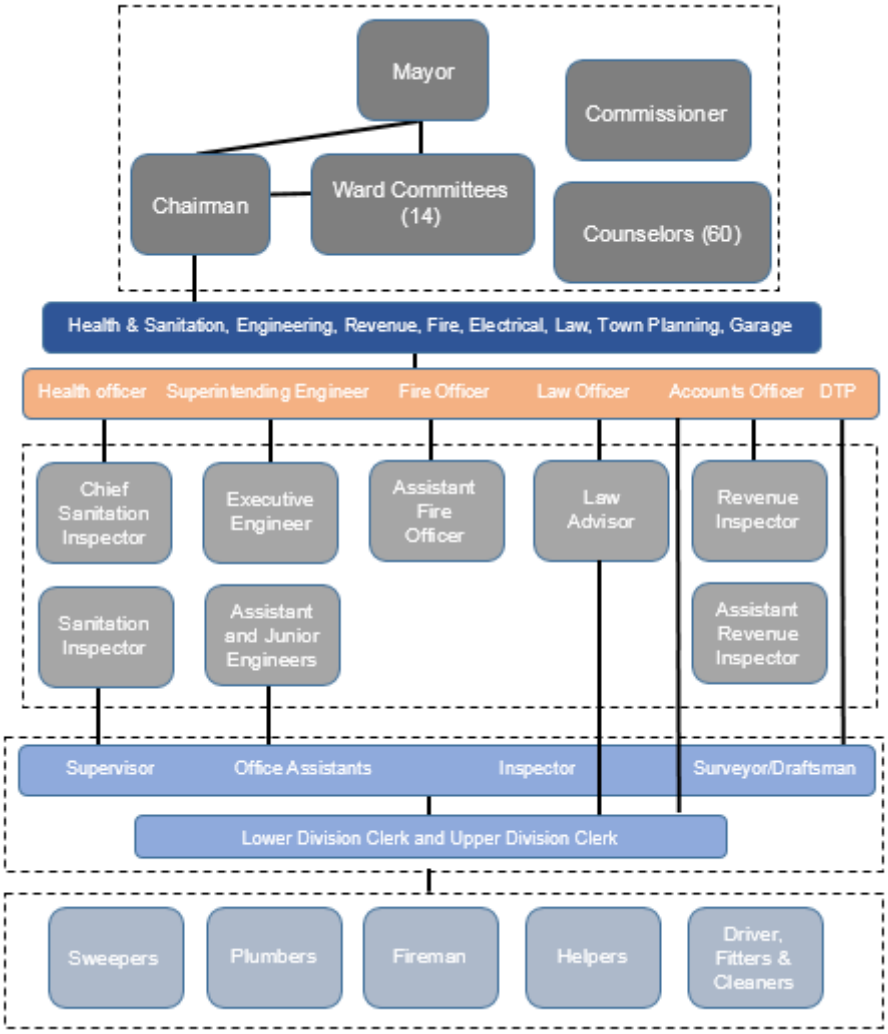
Public health department: This is headed by a health officer (HO). The HO is assisted by the chief sanitary inspectors of the respective zones. SWM has been taken care of by this department. It is also involved in spraying medicines, and managing health and environment aspects in Udaipur.

Revenue department: It is responsible for collecting taxes such as development, advertisement, and entertainment taxes, issuing notices for recovery of tax, and monitoring revenue collections of UMC. The department is headed by a revenue officer who is assisted by revenue inspectors and assistant revenue inspectors.

Town planning department: The deputy town planner heads this department in UMC. He/she is responsible for the integrated and planned development of the city. The town planner has to ensure proper implementation of building rules, zoning regulations, layout rules, and other rules of town planning. The department can also initiate action against all unauthorised constructions and land use changes, and illegal layouts and sub-division of plots.

Law department: This department is headed by the law officer and legal advisor. It mostly looks after the legal matters of UMC.

Figure 6: Organisational structure - UMC



Source: City development plan, Udaipur

5.4 Technologies, treatment process, and system description

Existing technology at STPs: The total sewage treatment capacity of Udaipur after the commissioning of two additional STPs will become 60 MLD, which is more than the amount of sewage being generated by the city as on date. Of the four STPs, the existing STPs with a capacity of 20 MLD and 25 MLD each use the moving bed bio reactor (MBBR) technology followed with claritube flocculator for sewage treatment. The new STPs will employ the sequencing batch reactor (SBR) technology.

MBBR technology followed with claritube flocculator: The MBBR technology used by the two operational STPs in Udaipur has been described below:

- How it works - The MBBR process utilises floating plastic carriers (media) within the aeration tank to increase the amount of micro-organisms available to treat the wastewater. The micro-organisms consume organic material. The media provides increased surface area for the biological microorganisms to attach to and grow in the aeration tanks. The increased surface area reduces the footprint of the tanks required to treat the wastewater. The media is continuously agitated by bubbles from the aeration system that adds oxygen at the bottom of the first compartment of the aeration tank. The microorganisms consume organic material. When compared to conventional secondary treatment it provides superior efficiency and value.

The MBBR is a complete mix, continuous flow-through process which is based on the biofilms principle that combines the benefits of both the activated sludge process and conventional fixed film systems without their disadvantages. Further details related to the technical components required for a 25 MLD STP, as per a standard operating procedure (SOP) document shared by UMC, have been provided in Annexure 4.

- Critical aspects - A crucial factor in the MBBR process is the sufficient and frequent contact between the wastewater components and the microorganisms attached to the carrier (biofilm). The necessary mixing of the carrier elements in the reactor (reaction tank) can be achieved using the process air supply required in aerobic treatment processes. In anaerobic treatment processes, the carriers in the reaction tank can be moved properly by pumping water or by using immersed, slowly-rotating mixers. The characteristics and quality of the biofilm establishing on the carrier surface is not only influenced by sheer forces in the tank but also by the composition and the loads of the pollutants in the wastewater (substrate). The more the wastewater is polluted with biodegradable pollutants, the more intense and faster the growth of biomass.
- Pros and cons – The pros of using the MBBR technology are as follows: takes up small amount of space, since it only uses one tank and maximises surface area through carriers; is a low maintenance process that doesn't require tasks like backwashing or cleaning membranes; effectively resists shock loading and can respond to variations in influent; and is exceptionally efficient, with low hydraulic retention time (HRT) of 3-4 hours for biochemical oxygen demand and nitrogen removal. The disadvantages of using the MBBR technology are: requires continuous monitoring, though minimal intervention; can attract insects with specific system models not designed to keep them out.

SBR: The new STPs with a capacity of 10 MLD and 5 MLD each, which will be commissioned in the next few months, are proposed to utilise a different technology called SBR.

- How it works - SBR is a different configuration of the conventional activated sludge systems, in which the process can be operated in batches, where the different conditions are all achieved in the same reactor but at different times. The treatment comprises a cycle of five stages: fill, react, settle, draw, and idle. During the reaction type, oxygen is added by an aeration system. In this phase, bacteria oxidise the organic matter just as in activated sludge systems. Thereafter, aeration is stopped to allow the sludge to settle. In the next step, the water and the sludge are separated by decantation and the clear layer (supernatant) is discharged from the reaction chamber. Depending on the rate of sludge production, some sludge may also be purged. After a phase of idle, the tank is filled with a new batch of wastewater. At least two tanks are needed for the batch mode of operation as continuous influent needs to be stored during the operation phase. Small systems may apply only one tank. In this case, the influent must either be retained in a pond or continuously discharged to the bottom of the tank in order not to disturb the settling, draw and idle phases. SBRs are suited to lower flows, because the size of each tank is determined by the volume of wastewater produced during the treatment period in the other tank.
- Critical aspects - Mechanical equipment, such as pumps, aerates and mixers, require continuous maintenance and control, and supply of oxygen and sludge is essential. Control of concentrations of sludge and oxygen levels in the aeration tanks is required and technical appliances (e.g., pH-meter, temperature, oxygen content, etc.) need to be maintained carefully. To make sure that optimal living conditions for the required bacteria are guaranteed and a satisfying effluent quality is met, the influent as well as the effluent should be supervised and controlled constantly, for instance, by a centralised computerised monitoring system.
- Pros and cons – The advantages of using the SBR technology includes: adapts to different volumes of influent; works with automated controls; and requires less space than a system using multiple tanks. The disadvantages of this process includes: necessitates sophisticated controls and timing units; requires more maintenance than conventional systems; and is prone to problems like discharging sludge at the wrong times and clogging aeration devices.

Difference between MBBR and SBR: The MBBR process requires less space than activated sludge systems such as SBR because of the concentrated biomass. The efficiency of the system is also less dependent on the final sludge separation. Unlike SBR, MBBR does not require recycling of the sludge[16]. In case of SBR the settling and decanting phase is quite important for the separation of active biomass from the clarified liquid, and thus, biological performance is dependent upon the separation of solids achieved during settling and decanting phase. While in case of MBBR, the active biomass is continuously retained in the reactor in suspension as well as on biofilm established on the carriers, and thus, biological performance is independent of separation of solids. Moreover, in SBR there is a requirement to maintain a sludge retention time (SRT) to allow the active biomass to remain in the reactor to achieve desired treatment goals. While in MBBR, no such SRT maintenance is required, making process operation and maintenance much simpler than SBR. Moreover, the SRT is a temperature- and other process parameters-dependent variable, which requires time to time monitoring as well as adjustment while operating SBR at optimum conditions, but in case of MBBR no such adjustment is required[17].

5.5 Maintenance procedures

MBBR: A constantly operating MBBR does not require backwashing or return sludge flows. It has minimal head-loss[18]. Coarse-bubble aeration in the aeration zone in the wastewater treatment tank provides ease of operation at low-cost. Agitation continuously moves the carrier elements over the surface of the screen thus preventing clogging. Maintenance of MBBR system includes screening, influent equalisation, clarifier system, sludge handling and integrated control system. There is no need to maintain food to microorganism (f/M) ratio as there is self-maintenance of an optimum level of productive biofilm. Skilled labour is required for routine monitoring and operations of pumps and blowers.

The Standard Operating Procedure (SOP) document for the STP, provided by UMC, highlights various best practices and steps to properly maintain various components of the 25 MLD STP. The maintenance procedures stipulated in the SOP document are: *a)* the grit separator channel should be cleaned every day; *b)* proper and efficient removal of silt in the grit separator channel will improve the functioning of sewage treatment; *c)* distribution channel in the MBBR tank should be cleaned every day; *d)* reactor should be de-sludged every day to maintain proper mixed liquor suspended solids (MLSS); *e)* daily tests should be conducted to check the levels of COD, suspended solid, pH, dissolved oxygen, ammonia and dissolved phosphate, while BOD levels should be checked weekly; *f)* foaming in the aeration compartment in the first week of operations should be tackled with antifoam dosing; *g)* sludge from the sludge sump should be regularly pumped out; *h)* dried sludge cakes should be regularly removed from the sludge sump; and *i)* launders of the clarifier tube flocculater should be kept clean.

SBR: Since the heart of the SBR system is the controls, automatic valves, and automatic switches, these systems may require more maintenance than a conventional activated sludge system. An increased level of sophistication usually equates to more items that can fail or require maintenance. The level of sophistication may be very advanced in larger SBR wastewater treatment plants requiring a higher level of maintenance on the automatic valves and switches.

5.6 Commercial / financial aspects

Revenue: The UMC had a total revenue of INR 23,318 lakh (€ 28 million)[19] in fiscal 2019, which comprised various tax revenues and revenue from activities specified in the bye-laws. The total revenue in fiscal 2018 was INR 18,937 lakh (€ 23 million), while that in fiscal 2017 was INR 18,349 lakh (€ 22 million). UMC earns a

[16] https://www.cleantechwater.co.in/blog/the-difference-between-sbr-mbr-and-mbbr-sewage-treatment-plants/
[17] https://www.scribd.com/doc/128636235/Comparison-of-SBR-and-MBBR-technology
[18] *Head loss-The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, or fittings.*
[19] *Considering exchange rate of 1 INR = € 0.012, as on May 20, 2020*

significant amount of its revenue through various grants from the government such as NULM, AMRUT, finance commissions, etc. The grant received by UMC under AMRUT increased from INR 1,648 lakh (€ 2 million) in fiscal 2017 to INR 3,835 lakh (€ 5 million) in fiscal 2019. Further, UMC also received grants of INR 913 lakh (€ 1 million) and INR 218 lakh (€ 0.3 million) in fiscals 2017 and 2018, respectively, under the Swachh Bharat Abhiyan. With regards to sewage management, UMC earned INR 38 lakh (€ 45,821) in fiscal 2019 as sewage collection tax-AMRUT and septic tank cleaning, which was more than the INR 30 lakh (€ 36,174), earned in fiscal 2018.

Expenses: UMC had total expenses of INR 25,457 lakh (€ 31 million) in fiscal 2019 which comprised various revenue and capital expenses. The expenses in fiscal 2019 were higher as compared with that in previous years: INR 20,425 lakh (€ 25 million, for fiscal 2018) and INR 16,774 lakh (€ 20 million, for fiscal 2017). UMC spent a total of INR 464 lakh (€ 0.5 million) in sewage and drain construction work as capital expenditure, which was less than that spent in fiscal 2018 (INR 529 lakh/ € 0.6 million). Further, UMC incurred revenue expenditure of INR 5 lakh (€ 6,029) for sewerage cleaning in fiscal 2019 (INR 47 lakh in fiscal 2018/€ 56,673). On account of UMC incurring more expenses than the income generated, it had been facing losses of INR 1,489 lakh (€ 2 million) and INR 2,139 lakh (€ 3 million) in fiscals 2018 and 2019, respectively.

5.7 Future plans

Sludge to Energy Plant: During our discussions with the officials of UMC, it was highlighted that the sludge generated from the existing STPs in Udaipur was being dumped at the landfill sites and not utilised by the city for any productive use. Hence, in line with the policies laid out in the State Sewerage and Waste Water Policy, UMC plans to generate energy from this sludge. The cooperation between the cities of Udaipur and Aarhus will lead to identification of best practices in carrying out sludge to energy conversion and help in applying them to Udaipur for efficient and profitable conversion of energy from sludge.

Implementation of key learnings: The learnings and best practices from Aarhus and other cities will need to be employed when implementing the sludge to energy plant project in Udaipur. Since conversion of sludge to energy does not fall under the mandate of existing STPs being operated by HZL, UMC will need to tender contracts for setting up of integrated STPs with sludge to energy plants. UMC will also need to provide or assist the private developer in procurement of suitable land (with proximity to source of sludge, suitable size, etc.). Further, it would be imperative to employ manpower that has the requisite technical know-how for operating the energy plants. The private player may be required to organise technical capacity building workshops for its manpower before commissioning the energy plants and even during its operation.

Detailed Feasibility Study: UMC will need to undertake an exhaustive project preparation exercise, including the preparation of a detailed feasibility study for a sludge to energy plant. The baseline study prepared as a part of this assignment should feed in to the feasibility study. The study should cover in detail the following:

- Technical feasibility **-** This part of the feasibility report should cover all the technical aspects including, but not limited to: identification and detailed assessment of all technologies available for sludge to energy conversion and their comparison with omni-processor technology employed at the Vadodara sludge to energy plant, costs related with each technology and their feasibility, availability of encumbrance free and suitable land (with proximity to source of sludge, suitable size, etc.), potential users of energy generated in terms of heat and electricity, input and output specifications of the project along with its performance standards, legal and regulatory assessment, social and environmental assessment, risk assessment along with mitigation, and allocation of risks to different parties.
- Financial feasibility **-** The feasibility study should also undertake a detailed financial assessment of the project covering detailed estimation of capital expenditure, operational expenditure and revenues, quantum of electricity to be generated; electricity tariff, subsidies required, sensitivity and value for money analysis. Although a preliminary cost benchmarking has been undertaken for various sludge to energy

recovery methods, it is recommended that a detailed financial feasibility of these technologies is undertaken at the feasibility stage including various parameters such as required capacity, location of project, land required, associated man-power costs, overheads, etc., so as to select the most efficient and affordable technology to be implemented at the Udaipur sludge to energy plant.

- Project structure **-** This includes roles and responsibilities of various stakeholders, particularly that of the private developer and the implementing agencies, possibility of integration with existing STPs by increasing HZL's scope of work, mode of contracting such as PPP or EPC, mode of payment, contract duration, etc.
- Bid process management **-** The feasibility study should also provide the details regarding the next steps in project preparation and execution i.e., bid process management. This part should explain in the detail the number of stages that will be employed for the procurement process, bidding parameters including technical and financial parameters, appointment of transaction advisors, formation of data rooms, preparation of bidding documents, etc.

6 Future trends

This chapter provides an estimate of future trends of various parameters such as demographics, macroeconomic indicators, urban development policy and plans, and sludge generation.

6.1 Demographic trends

As per the Census of India, the population of Udaipur in 2011 was 451,100, which makes it the sixth largest city in Rajasthan. UMC population accounted for 2.65% of the urban population of the state in 2011 and 74.14% of the urban population of the Udaipur district. As per the City Development Plan document, area of Udaipur city increased from 37 sq km to 64 sq km in 2013. The city sanitation plan (CSP) prepared by NF Infratech Services Pvt Ltd, provides the population projections for the city of Udaipur for the next 20 years using multiple methods such as arithmetic, geometric and incremental, using the base as the population as per the Census of 2011. However, while calculating the final projections of population, NF Infratech has used the average of all the methods as per standard practice. The projections, as per the CSP, have been provided in the table below.

Table 8: Projected population of Udaipur

Year	Arithmetic	Geometric	Incremental	Projected population (average)
2021	5,24,350	5,77,959	5,21,347	5,41,219
2025	5,53,395	6,37,826	5,48,351	5,79,857
2031	5,96,964	7,39,452	5,87,956	6,41,457
2035	6,26,010	8,16,047	6,13,759	6,85,272
2041	6,69,578	9,46,069	6,51,562	7,55,736

Source: City Sanitation Plan, Udaipur, by NF Infratech Services Pvt Ltd

6.2 Urban development policy and plans

Urban development policy: All matters related to waste water, sewage, faecal sludge, and septage management in Rajasthan are governed by two policies: State Sewerage and Waste Water Policy, 2016 and Draft Policy on Faecal Sludge and Septage Management, 2018. These policies stipulate state wide regulations pertaining to proper handling, treatment and disposal of various kinds of waste being generated in the state. However, the policy documents have limited rules and regulations related to waste to energy generation. There are no set guidelines on various emission factors related to energy production from sludge or faecal waste. Hence, the policy document should be updated to include rules and regulations pertaining to energy generation from waste. These can include standard carbon emission factors, standardised procedures and technology to be implemented while commissioning of treatment plants, energy usage policy, price per unit, etc.

Development plans: As per our discussions with the officials of UMC, it is clear that the municipal corporation is exploring opportunities for production of energy from sewage sludge. Through this cooperation with Aarhus city they are targeting to identify best practices in terms of technology to be used for power generation through sludge, handling various challenges and key considerations before commissioning the energy plants.

6.3 Estimating sludge generation flows

Basis for estimation: To estimate the demand of water and corresponding production of sewage in the upcoming years, the study refers to the calculations provided in the City Sanitation Plan (CSP) prepared by NF Infratech. The estimated demand of water and the sewage production was then used to calculate the amount of sludge that would be generated during the same period.

Water demand: In order to calculate the demand of water, a standard norm of 135 LPCD water supply, stipulated by the Bureau of Indian Standards, has been assumed till 2041 by NF Infratech. The total water demand for the city is calculated by adding the water demand for different sectors which includes household demand, bulk demand (15%), demand from floating population (3%), and unaccounted water that is distributed/ treatment loss (15%). Thus the total water demand for the city is calculated as 104.0 MLD, 115.2 MLD and 135.7 MLD for 2025, 2031 and 2041, respectively. The detailed trend has been summarised below:

Table 9: Estimating total water demand

Year	Population (lakh)	Household demand, MLD	Bulk demand, MLD (15%)	Floating population, MLD (3%)	Unaccounted water, MLD (15%)	Total demand, MLD
2025	5.8	78.3	11.7	2.3	11.7	104.0
2031	6.4	86.6	13.0	2.6	13.0	115.2
2041	7.6	102.0	15.3	3.1	15.3	135.7

Source: CSP

Sewage generation: As per the CSP, the sewage or black water generation for future can be calculated at 80% of the water demand (as per the CPHEEO[20] manual). Further, the amount of water supply for this purpose can be assumed as 135 LPCD (as per the Bureau of Indian Standards). Based on these assumptions and the study made projections related to sewage generation in the coming years. Accordingly, at 80% of water demand, the sewage produced will be 83.2 MLD for the projected population of 5.4 lakh for 2025. Similarly, it is estimated at 92.2 MLD for 2031 and 108.6 MLD for 2041. The sewage generation projections have been provided in the table below:

Table 10: Sewage generation projection

Year	Water demand (MLD)	Population (lakh)	Sewage flow (MLD) (80% of water demand)
2025	104.0	5.8	83.2
2031	115.2	6.4	92.2
2041	135.7	7.6	108.6

Source: CRISIL analysis

Sludge generation: As per the data received from UMC, the two commissioned STPs using the MBBR technology, currently generate on average, 4.5 tonne of sludge daily. In addition, the 10 MLD STP which uses SBR technology will generate sludge between 0.6 tonne to 1 tonne per day, on connection with the sewage trunk line. The soon to be commissioned STP having a capacity of 5 MLD will add to the quantum of sludge generated. It is estimated that the once all the four STPs are operational, the STPs shall generate sludge to the tune of 5-6 tonne per day. This estimated sludge, from four STPs, has been considered as the base for projecting the future sludge output. It is expected that by 2031 and 2041, Udaipur would have commissioned

[20] *Central Public Health and Environmental Engineering Organisation*

STPs with a capacity that can treat 100% of the sewage generated by the city. Hence, by 2031, Udaipur would be generating 8-9 tonne sludge per day, through their STPs, which will further increase to 9-11 tonne per day by 2041. Following table provides an estimate of sludge generation in Udaipur in the coming years.

Table 11: Sludge generation projection

Year	Total sewage flow (MLD)	Installed capacity of STPs (MLD)[21]	Installed capacity of STPs (% of total sewage flow)	Sludge generated (tonne per day)
2020	57	45	79	4.5
2021	60[22]	60	100	5.0 - 6.0
2025	83	83	100	6.9 - 8.3
2031	92	92	100	7.7 - 9.2
2041	109	109	100	9.1 - 10.9

Source: CRISIL analysis and UMC

[21] *The projection for installed capacity of STP is based on the sewage generated in the city. We assume that the city will either need to add capacity to existing plants or build new plants to cater to the increase in sludge generated.*
[22] *Based on UMC estimates*

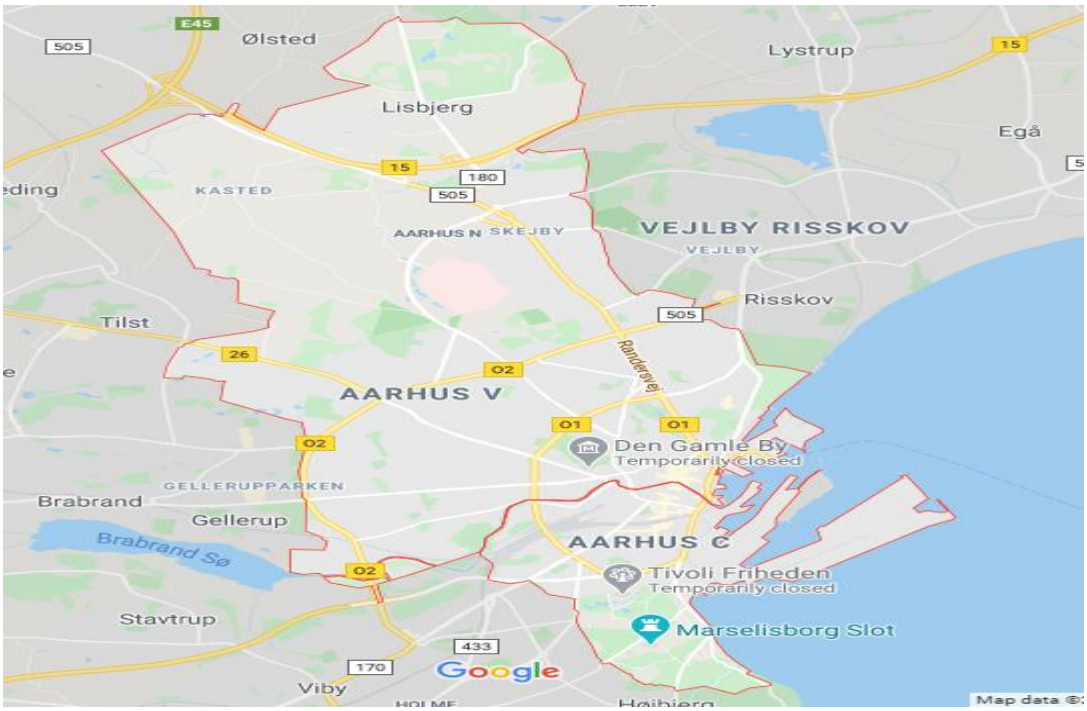
7 International & national best practices

The following chapter analyses two cases studies from Denmark and one from India, to assess the best practices in energy generation from waste, particularly wastewater/sewage sludge.

7.1 Sludge-to-energy conversion experience of Aarhus city

City profile: Aarhus, the second largest city in Denmark with an estimated population of 280,534[23] (2020), is located on the east coast of the Jutland peninsula, in the geographical centre of Denmark with an area of 91 sq. km. (city map provided as Figure 7) Aarhus is the seat of Aarhus Municipality, and Aarhus City Council is also the municipal government with its headquarters in Aarhus City Hall. The municipality has an estimated population of 349,983 (2020). The municipality is part of Business Region Aarhus and of the East Jutland metropolitan area, which had a total population of 1.378 million in 2016. Aarhus is the principal industrial port of the country in terms of container handling and an important trade hub in Kattegat. It is a center for research and education in the Nordic countries and home to Aarhus University, Scandinavia's largest university, including Aarhus University Hospital and INCUBA Science Park.

Figure 7: City map - Aarhus



Source: Google Maps

Introduction: Around the world, water and wastewater treatment facilities are normally the single largest electricity consumer for a municipality. Typically water and wastewater treatment processes account for 25–40% of the municipal electricity consumption. The high consumption by WWTPs is not only related to the energy-intensive processes, but also due to their continuous operation cycle, 24/7 and 365 days annually. The city of Aarhus has four operational WWTP, developed at Marselisborg (provided in Figure 8), Egaa, Aaby and Viby. This case study is related to the WWTP situated in Marselisborg. Since 2010, the Marselisborg wastewater treatment plant has transformed its focus beyond minimising the energy consumed to maximising the net energy surplus. Nowadays the facility has net production of both electricity and heat, supplying the

[23] https://www.statbank.dk/BY1

district heating system in Denmark's second-largest municipality, Aarhus. The carbon footprint has been reduced by 35% accordingly. The Marselisborg Wastewater Treatment Plant increased its plant efficiency and reduced energy consumption by optimising all its processes. In 2016, the plant produced 40% more electricity than it needed and 2.5 GW of heat for the district heating system, without adding external organic waste or carbon.

Figure 8: Marselisborg wastewater treatment plant, Aarhus

Source: https://bacwa.org/wp-content/uploads/2017/06/Wastewater-Innovation-in-Denmark.pdf

Ownership: The WWTPs in Aarhus, including the one at Marselisborg, are owned and operated by Aarhus Vand. It is a state utility company with 100% ownership of Aarhus Municipality. The city has developed a detailed master-city plan while Aarhus Vand has developed wastewater plan, which includes details on laying the sewage network, it's working conditions and the provision for setting-up the WWTPs. Aarhus Vand has the ownership of the plants and is responsible for operating the WWTPs within the framework stipulated by these plans.

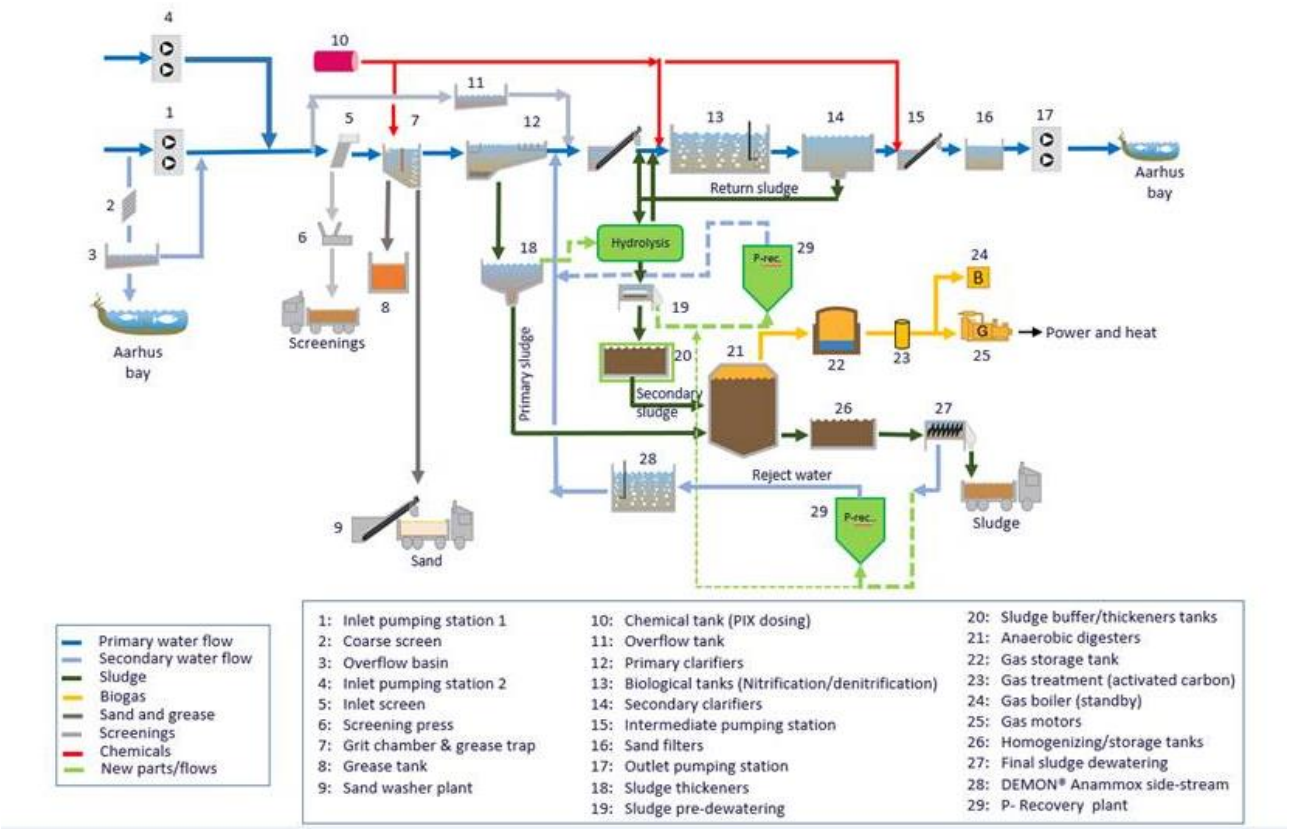
Design and construction: The design and construction of the Marselisborg wastewater treatment plant was undertaken by a contractor, the selection for whom was conducted through an open-tendering process conducted by Aarhus Vand. The tender documents stipulated compliance with certain operational parameters as a mandatory part of the construction process. Post compliance with the stipulated parameters, the plant was handed to the Aarhus Vand team. The planning process and construction for the WWTP took around 2 years.

Roles and responsibilities: The responsibility of the operation and maintenance of the WWTPs rests with Aarhus Vand. The company collects tariffs from the city residents and the income from such tariff is utilised towards the operation and maintenance of the WWTPs. Aarhus Vand does not receive any subsidy from the Aarhus city. The tariff collected by Aarhus Vand is adequate to meet both the capital and operational expenditure of WWTPs.

Technical description: At Marselisborg Wastewater Treatment Plant, Aarhus Vand implemented many energy-saving technologies, such as an advanced SCADA control system, a new turbo compressor, sludge liquor treatment based on the anammox process, in addition to optimising the fine bubble aeration system. This resulted in a reduction in power consumption of about 1 GWh/year, which corresponds to about 25% in total savings. During the same time period, the energy production was improved through the implementation

of new energy efficient biogas engines (CHP), resulting in an increase in electricity production of about 1 GWh per year. Furthermore, a new heat exchanger was installed with the aim of selling surplus heat to the district heating grid, which represents about 2 GWh per year. The detailed flow diagram of the Marselisborg WWTP has been provided in Figure 9 below:

Figure 9: Marselisborg wastewater treatment plant flow diagram



Source: Aarhus Vand

Sludge generated: The Marselisborg WWTP generates ~30 tonnes of untreated sludge per day. The sludge generated from the treatment process is wet and has ~24% dry matter (post final dewatering). For comparison, the MBBR technology used by Hindustan Zinc Limited in Udaipur has lower yield of sludge generation compared with the activated sludge process (ASP) used by Aarhus Vand at its Marselisborg treatment plant.

Heat and electricity: The Marselisborg WWTP uses the activated sludge process (ASP) for the treatment of sludge. The activated sludge process is the biological process by which non-settleable substances occurring in dissolved and colloidal forms are converted into settleable sludge which is removed from the liquid carrier (water). In general, at a WWTP, the activated sludge is settled out along with the suspended solids present in the wastewater. The Marselisborg WWTP generates both electricity and heat from the ASP treatment process. Denmark has multiple subsidy schemes pertaining to the tariff for sale of electricity generated through green sources and WWTPs. The electricity generated through the WWTPs is subsidised by the government, leading to slightly lower tariff for the energy generated from these plants. The unit rate for electricity sold by the WWTPs is DKK 0.2/KwH and is commensurate with the rate charged by the grid. During the initial phase after the commissioning of the WWTP, Aarhus Vand used to realise higher tariff per unit for electricity generated due to higher subsides and were making higher surplus.

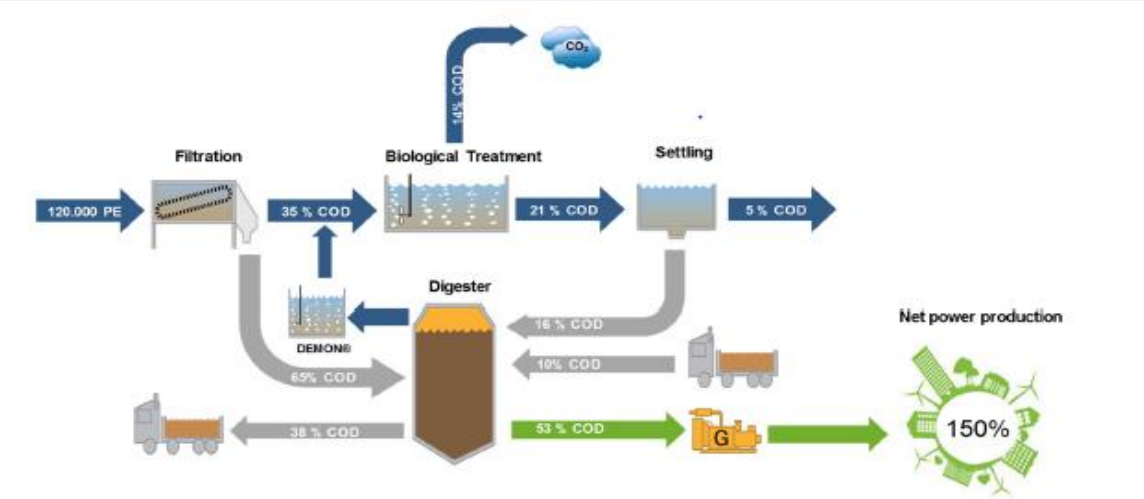
Impact of WWTP in the city: In 2015, Marselisborg WWTP had a total energy production of 9,628 MWh/ year and an energy consumption of 6,311 MWh/year, equivalent to a net energy production of 153% (2015) making it more than energy-neutral.

Introduction of innovative wastewater treatment practices in Egaa

Egaa WWTP in Aarhus was expanded during 2015 – 2017 and is now used as a reference facility with more than 30 guide tours since the beginning of the project. All the required equipment for the new processes is in place as well as the control systems. Moreover, a "Go to Market" strategy has been defined as the 'Egaa Concept'. In the first three quarters of 2018, the average net energy production was 121%, with a net electricity production at 83% and a net heat production at 193%. The lower than the expected 100% net electricity production is a result of multiple challenges faced in the carbon-harvesting process. Further optimisation of the processes is being carried out and an increase in the net energy production is expected to be seen in the very near future.

As per the report, in Denmark alone, at least 65 WWTPs could be turned into net energy producers by using the Egaa concept. This concept is a combination of multiple technologies, including: dynamic removal of carbon from the inflow using a new carbon harvest system with microfiltration (Salsnes filters – 350 micrometer) and control system, which minimise oxygen consumption in the process tanks and maximise gas production in the digester; treatment of reject water with Anammox bacteria to minimise internal nitrogen loading and reduce energy consumption; nitrogen removal with a nitration process in the main system for reduction of energy consumption; and further electricity generation through the use of surplus heat from biogas engine in an Organic Rankine Cycle (ORC). The flow diagram for the Egaa WWTP has been provided in Figure 10 below:

Figure 10: Flow diagram of upgraded Egaa WWTP



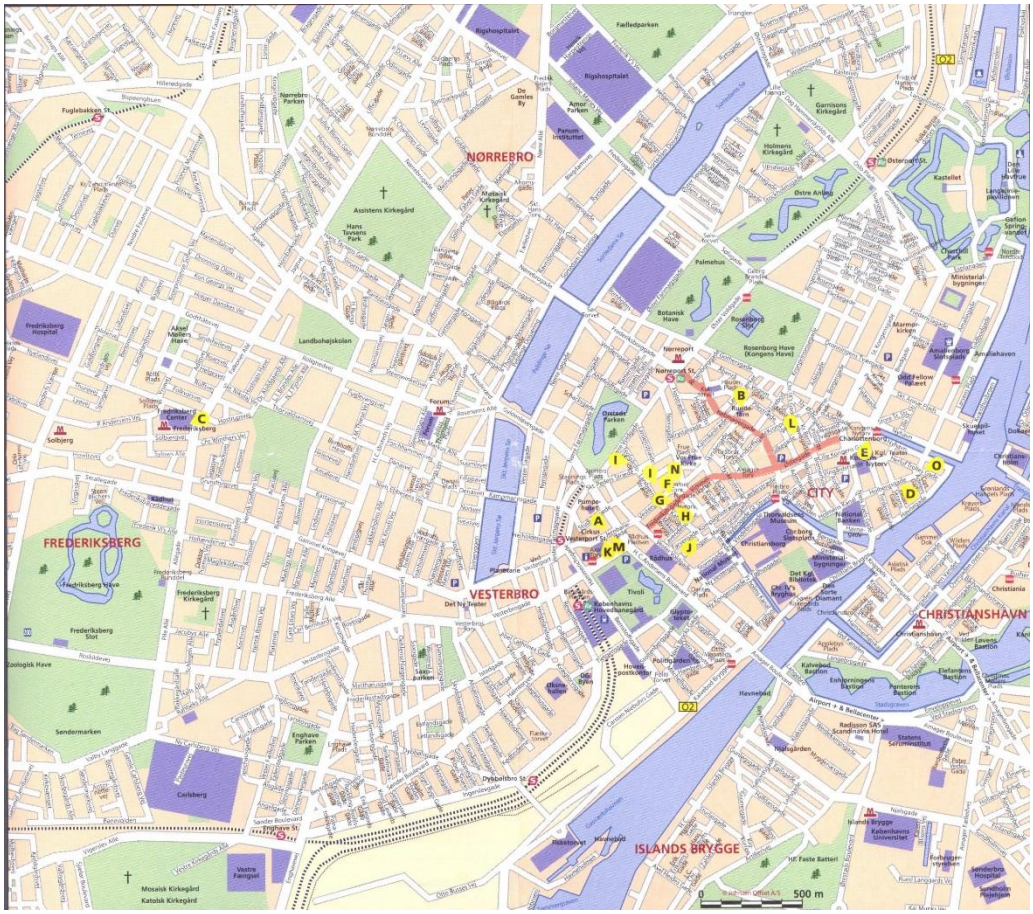
Source: Energy generation from waste water plants, EUDP

7.2 Sludge for energy at Copenhagen's largest WWTP

City profile: Copenhagen is the capital and most populous city of Denmark. As of 1 January 2020, the city had a population of 794,128 with 632,340 in Copenhagen Municipality, 104,305 in Frederiksberg Municipality, 42,989 in Tårnby Municipality, and 14,494 in Dragør Municipality. It forms the core of the wider urban area of Copenhagen (population 1,330,993) and the Copenhagen metropolitan area (population 2,057,142). Copenhagen is situated on the eastern coast of the island of Zealand, has an area of 88.25 sq.km (city map provided in Figure 11) and is home to the University of Copenhagen, the Technical University of Denmark, Copenhagen Business School and the IT University of Copenhagen. The University of Copenhagen, founded in 1479, is the oldest university in Denmark. Copenhagen Municipality is by far the

largest municipality, with the historic city at its core and is responsible for a wide variety of public services, which include land-use planning, environmental planning, public housing, management and maintenance of local roads, and social security.

Figure 11: City map - Copenhagen



Source: http://www.orangesmile.com/common/img_city_maps/copenhagen-map-1.jpg

Introduction: BIOFOS is Denmark's largest wastewater treatment operator serving a population 1.2 million in the Copenhagen metropolitan area through its treatment plants in Lynetten, Avedøre, and Damhusåen. It utilises the sludge produced from wastewater treatment to generate electricity, biogas and heat, using anaerobic digestion. The biogas is then sold off to the district gas grid and is subsequently converted to electricity, At the Lynetten plant, which is located close to the center of Copenhagen, wastewater is treated mechanically, biologically, and chemically to ensure it meets the strict standards set by the local environmental authorities. Organic matter, nitrogen and phosphorus are removed by biological treatment, and the excess phosphorus is removed from the water using chemicals. After treatment, the purified wastewater is directed to Oresund, the recipient water body that separates Denmark from Sweden. An image of the Lynetten WWTP has been provided below:

Figure 12: Lynetten wastewater treatment plant, Copenhagen

Source: Official website of Ramboll Group

Technical description of the plant: A fluid-bed incinerator has been installed together with a modern flue gas cleaning system at Lynetten. Furthermore, a flue gas condensation step has been added. Thereby, the process of sludge disposal has been turned from an energy-consuming to an energy-producing process. There is much more surplus heat available to the district heating system and there is a lot of biogas available. The main part of the high temperature heat from the boiler is first used for pre-drying of sludge and the rest of it – plus the energy from the condensation – is used for district heating. The additional surplus heat capacity is used in the local low temperature district heating network.

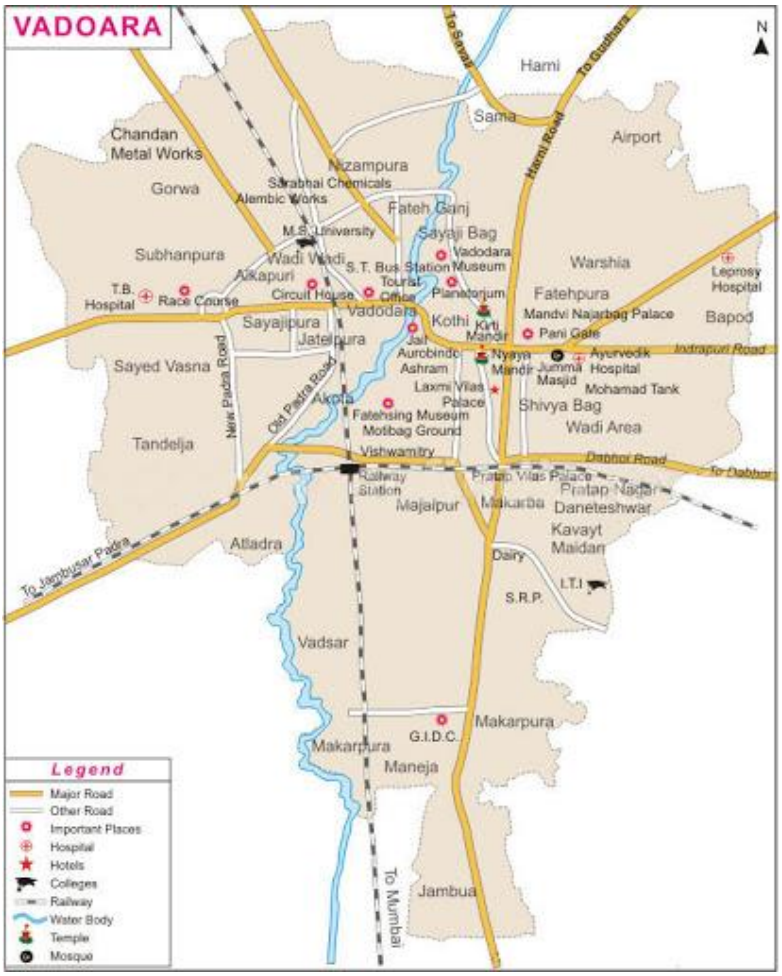
Impact: In a span of two and a half years, the wastewater treatment plant at Lynetten has gone from energy consumer to energy producer. For every 100 units of energy consumed, the plant sends back 260 units of energy to the grid. Based on the sludge separation in connection with treatment of the wastewater, more than 3 million cubic meters of biogas was produced for the Copenhagen city gas net during the first six months of 2016. This covers about one-third of consumption in Copenhagen. At the same time, the dry sludge is incinerated in Lynetten's own incineration plant, which has produced 18,740 MWh of district heating, also during the first six months of 2016.

Key data: Capacity – 2.35 tonne of dry solids per hour; sludge from 1,000,000 person equivalents; boiler production – 3.8 MW; heat from the boiler is used for drying the sludge and for district heating; flue gas condensation – 2.8 MW; heat from flue gas is used for district heating; biogas production on digester – 900 Nm^3/h; and biogas is used for city gas production to Copenhagen Energy.

7.3 Faecal sludge to energy plant at Vadodara

City profile: Vadodara, formerly known as Baroda, is the third largest city in a westerly city of India, Gujarat. It is the administrative headquarters of Vadodara District and is located at a distance of 141 km from the state capital of Gandhinagar. According to the 2011 Indian census, Vadodara metropolitan area had a population of 1.8 million. The city is a hub for large-scale industrial establishment including that of Indian Oil Corporation Limited, Gujarat State Fertilizer and Chemicals, L&T, Gujarat Alkalies and Chemicals Limited, Oil and Natural Gas Corporation and Gas Authority of India Limited. The city also boasts over 35% of India's power transmission and distribution equipment manufacturers. A city map for Vadodara has been provided below:

Figure 13: City map - Vadodara



Source: http://www.virtualvadodara.com/KV_Map.aspx

STPs in Vadodara: Vadodara has seven sewage treatment plants with a combined capacity of 276.5 MLD. Of this, Altadara, where Ankur Scientific Energy Technologies Pvt Ltd has set up a sludge to energy plant, also has two STPs with a total installed capacity of 86 MLD (43 MLD each). These seven STPs use activated sludge process (ASP) and upflow anaerobic sludge blanket (UASB) technology for treating the sewage. A snapshot of the sewage treatment plants in Vadodara has been tabled below:

Table 12: Sewage treatment plants in Vadodara

STP location	Year of Commission	Installed Capacity (MLD)	Technology
Atladara-I	2000	43	Activated Sludge Process

STP location	Year of Commission	Installed Capacity (MLD)	Technology
Atladara-II	2004	43	Upflow anaerobic sludge blanket
Tarsali	1998	52	Upflow anaerobic sludge blanket
Gajrawadi	1998	66	Activated Sludge Process
Kapurai	2010	43	Activated Sludge Process
Sayaji Garden	2010	8.5	Activated Sludge Process
Chhani	-	21	Activated Sludge Process

Source: Inventorization of Sewage Treatment Plants, Central Pollution Control Board

Overview of the faecal sludge treatment plant: The faecal sludge treatment plant has been developed under a tripartite agreement between (highlights provided in Table 13), Vadodara Municipal Corporation (VMC), Ankur Scientific Energy Technologies Pvt Ltd and Bill and Melinda Gates Foundation (BMGF). BMGF has provided a grant of INR 3,500 lakh (€ 4.2 million) for the installation and construction of the plant. The VMC has made available a piece of land admeasuring 4,000 square meters for the setup of the plant. Ankur Scientific has constructed the FSTP and is further responsible for its operation and maintenance (for 10 years).

Table 13: Parties to the tripartite agreement and their responsibilities

Agreement parties	Responsibilities
Bill and Melinda Gates Foundation	Funding of INR 3,500 lakh (€ 4.2 million)
Vadodara Municipal Corporation	Plot of land measuring 4,000 m^2
Ankur Scientific Energy Technologies Pvt Ltd	Construction and O&M of FSTP

Source: Stakeholder discussion

Technical benchmark/standards: The ISO 30500:2018 – non-sewered sanitation systems – prefabricated integrated treatment units – general safety and performance requirements for design and testing - standard was considered for the developed of the 200 KLD FSTP at Vadodara. This standard was formulated after careful and thorough research conducted by 43 scientists from ISO and was based on draft technical norms stipulated by an expert advisory group formed by TUV consisting of 37 members, in addition to several international standards on emission norms, technical parameter, and machinery standards based on EU 2015, EU 2007, USA EPA and Indian standards.

Design and technical specifications: The FSTP incorporates the core omni-processor technology, patented by BMGF and further improved by Ankur Scientific Energy Technology Pvt Ltd, along with the MBBR technology for the processing of liquid waste in to industrial grade water, dryer and turbine for electricity generation and a condenser system for production of distilled water. The FSTP at Vadodara is the first plant in India using the omni-processor technology. The plant claims to be energy neutral i.e., it generates the same amount of electricity as it consumes. Currently, the plant takes direct input from the vacuum trucks which collect and carry faecal sludge from septic tanks spread across the city. The plant can also take municipal solid waste as an input, which can be processed by a gasifier for production of electricity from such waste. The processing time of sludge from its arrival to disposal is 5 hours.

Waste to energy plant: The sludge to energy plant at Vadodara (refer figure 14) can also be retrofitted with a waste to energy plant. The waste to energy plant consisting of a gasifier will use the municipal solid waste as an input and generate additional electricity which can be sold back to the grid at stipulated prices, adding to the revenue from the plant.

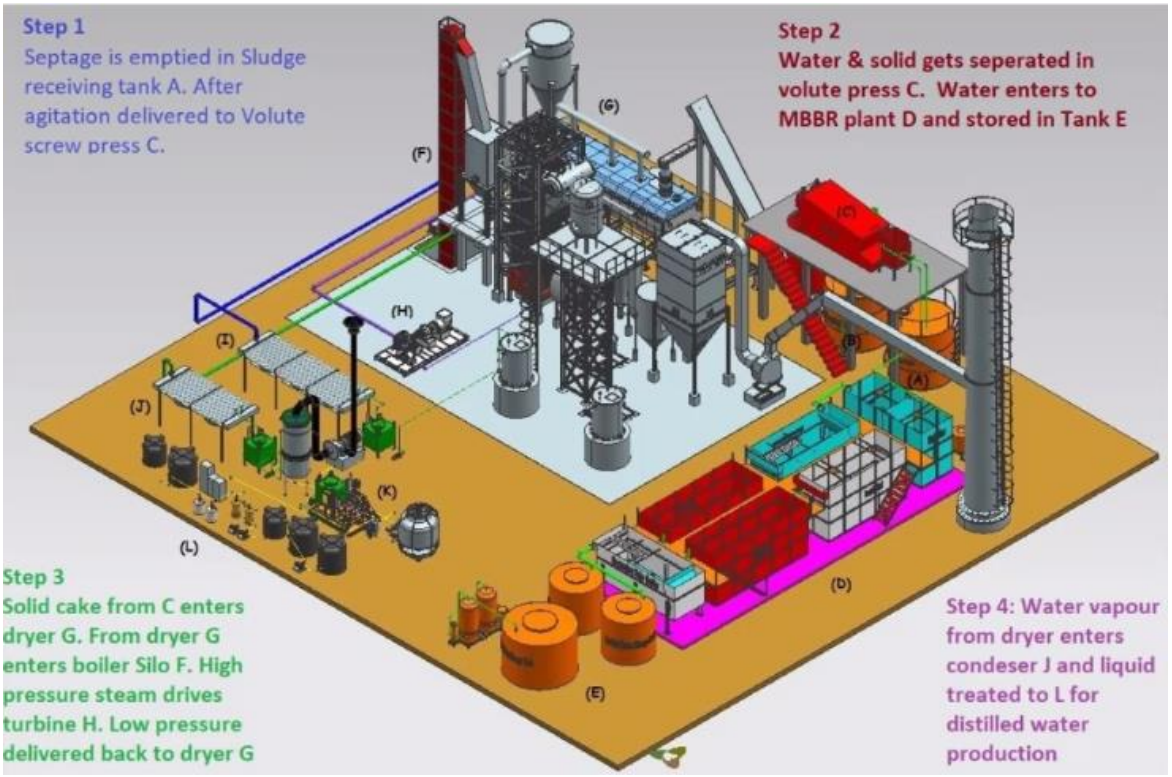
Capacity of plant and composition of sludge: The FSTP has a capacity of treating 200 kilo liters of faecal sludge per day (KLD). This sludge is composed of 97% water and 3% solids. The 3% solids comprise of

dissolved solids, suspended particles and colloidal particles (invisible to naked eye). The liquid part of the sludge is treated using the MBBR technology, while the solid part of the sludge is treated using the controlled combustion technique using a dryer and a boiler silo.

Financial: Another plant constructed by Ankur Scientific in Bangladesh was constructed at a cost of USD 6 million (€ 5 million). However, as per the promoters of the firm, this cost is slated to reduce by 30%-40% in the near future on the back of higher adoption rate. Further, the estimated annual cost of operations and maintenance for Vadodara plant is pegged at USD 100,000[24] annually (€ 84,260).

Faecal sludge treatment process: The sludge treatment process at the Vadodara FSTP incorporating the omni-processor technology largely consists of the following four steps.

Figure 14: Pictorial representation of FSTP at Vadodara



Source: https://techdirectory.stepsforsanitation.org/systems/3/

- Step 1 - The FSTP at Vadodara accepts faecal sludge from vacuum trucks as an input. After the septage is emptied in the sludge receiving tank, it is homogeneously mixed in the agitation tank so that the solid particles in the sludge do not settle down. Since colloidal particles present inside the sludge are difficult to separate, coagulants are added to the homogeneously mixed sludge so that the particles become heavy and are easier to remove in the next stage.
- Step 2 - From the agitation tank, the sludge is delivered to the volute press where the water and heavy solid particles from the sludge are separated. The separated liquid and solid content is the treated separately. Water enters the membrane-based bioreactor (MBBR) plant for further processing, 95% of which is converted in to industrial grade water. The water which is fed as input to the MBBR plant consists of suspended solids to the tune of 30,000 mg/liter, while the industrial grade water which is received as the output of the plant consists of 600 mg/liter of suspended solids. Other parameters of the industrial

[24] *https://techdirectory.stepsforsanitation.org/systems/3/*

grade water are: COD – 30 mg/liter; BOD - <10 mg/liter; and Oil and grease - <10 mg/liter. These parameters have been summarized in the table 14 below:

Table 14: Input and output parameters of the sewage

Input parameter	Value	Output parameter	Value
Suspended solids	30,000 mg/liter	BOD	<10 mg/liter
		COD	<30 mg/liter
		Oil and grease	<10 mg/liter
		Suspended solids	600 mg/liter

- Step 3 - While the liquid separated by the volute press enters the MBBR, the solid cake enters the dryer, where the moisture content of the solid is reduced to 10% of the initial levels. From the dryer, the dried solid enter the boiler silo. Combustion in the boiler occurs at 900-950 degree Celsius. The combustion process generates high pressure steam from the dried solid which is used to drive the turbine in order to generate electricity. The turbine generates 140 units of electricity per hour, which is also the required level of electricity for operating the plant, hence making the FSTP energy neutral. The step gives end product in the form of 2,000-4,000 kg/day of non-hazardous ash.
- Step 4 - The final step involves production of distilled water. The low pressure steam from the boiler silo is sent back to the dryer. The water vapors from the dryer then enters a condenser, which helps in liquefying the water vapors. This liquid then undergoes mineral dosing to produce distilled water as the final output.

Output of FSTP: The FSTP generates three outputs (highlighted in Table 15) as part of the faecal sludge treatment: electricity (1,000 KwH per day); industrial grade water (130 KLD); and distilled water (14 KLD). The industrial grade water and distilled water can be sold to a third party or the municipal corporation for revenue generation, while the electricity generated is only sufficient to cover the requirements of the FSTP itself. However, as per future requirement, the FSTP can also treat municipal solid waste using a gasifier for generating additional electricity, which can then be sold to a third party or send back to the grid for generating revenue.

Table 15: Output from FSTP

Output	Quantum	Unit price of output	Revenue potential (yearly)
Industrial grade water	130 KLD	INR 0.3 per liter	INR 142.4 lakh (€ 0.2 million)
Distilled water	14 KLD	INR 1.0 per liter	INR 51.1 lakh (€ 0.06 million)
Electricity	140 KwH per hour[25]	-	-

7.4 Key findings

The key findings from the analyses of these case studies have been presented below:

Key comparative points for the case studies evaluated: The three case studies showcased in the section above highlight two types of sludge/wastewater to energy processes – anaerobic digestion and combustion. Both the plants in Denmark, analysed above, are used to treat wastewater, while the plant in Vadodara (India) use faecal sludge as an input. The output for the plants in colder regions i.e. Marselisborg and Copenhagen is heat, biogas as well as electricity. However, the output of the faecal sludge treatment plant in Vadodara, are

[25] *Does not consider the quantum of electricity that may be produced post functioning of waste to energy unit. The plant is currently energy neutral.*

industrial grade water, distilled water, and electricity to meet energy needs. The following table presents a comparative analysis of the three case studies presented in the previous sections:

Table 16: Comparison of case studies

Parameter	Marselisborg	Copenhagen	Vadodara
Treatment process	Anaerobic digestion	Anaerobic digestion	Combustion
Input	Wastewater	Wastewater	Faecal sludge and Municipal Solid Waste
Output	Heat and electricity	Electricity, heat and biogas	Industrial grade water, distilled water and electricity
Main components	Advanced SCADA system, turbo compressor, sludge liquor treatment	Fluid-bed incinerator and flue gas cleaning system	Omni-processor system

Availability of land: The energy plants require significant amount of land for the setup of machinery and other administrative buildings. For example, the Marselisborg WWTP plant in Aarhus uses three digesters, each with a capacity of 3,000 cubic meters and a height of ~8-10 meters. In addition to these digesters, additional area is required for setting up of office buildings, generators and transmission equipment.

Proximity of energy plant to source of sludge: The quality of sludge plays an important role in the overall efficiency of energy conversion process from sludge. It is recommended that the energy plant should be set up in close proximity to the source of sludge as well as have access to a central road to facilitate continuous access to fresh sludge and aid the movement of vacuum trucks carrying the sludge. The separation of the STP and energy plants may lead to the following challenges: (a) requirement of large number of trucks for transportation of sludge from STPs to energy plant or setting-up of sludge pumping network, (b) the sludge will need to be dewatered prior to transportation by trucks/pumps to energy plant and will need to be watered again for converting it into energy; and (c) the sludge leaving digester after conversion into energy will need to be watered again, as it has a high amount of ammonia and is not good for disposal into river.

Integration of STP with sludge to energy plant: An ideal set-up to make the process of sludge-to-energy conversion efficient is by integrating the STP with a standalone energy plant or upgrading the existing plant by installing sludge-to-energy technologies. This will enable the energy plant to have a constant supply of fresh and high-quality sludge for production of energy, without investing in transportation of sludge to separate sites.

Technical know-how for operating the plants: Sludge-to-energy conversion is a technologically advanced procedure and requires significant technical know-how for the plant operation. The engineers operating the plant need to be highly trained and thus significant capacity-building measures are required at certain intervals of time to keep them abreast with the efficient operating procedures.

8 Sludge to energy recovery methods

This chapter provides an overview of various approaches for setting-up a sludge to energy plant. It further describes various sludge to energy recovery methods including anaerobic digestion, combustion, pyrolysis and gasification. A preliminary cost benchmarking for all these techniques has been provided through careful analysis of national and international case studies or findings from various research reports.

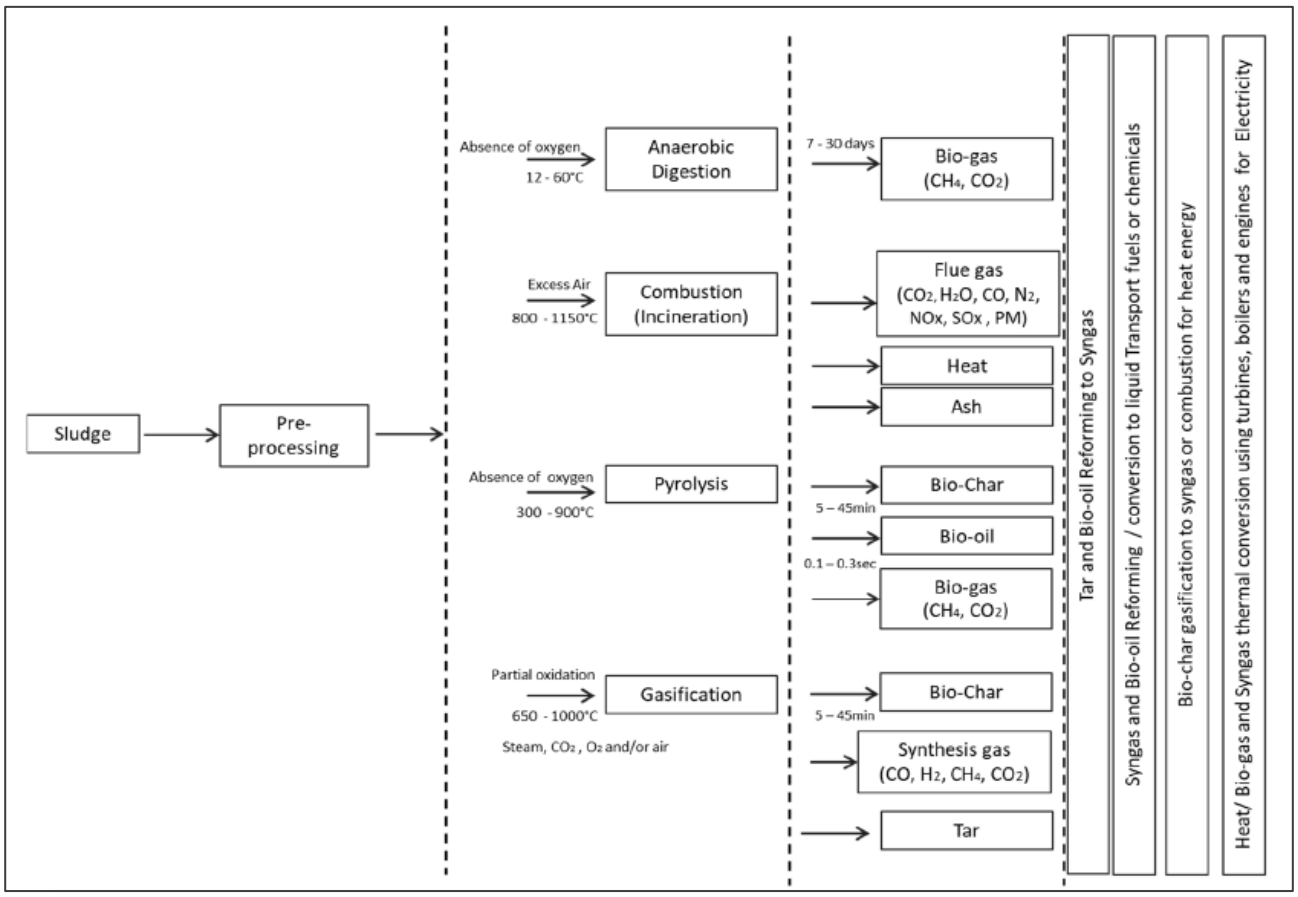
8.1 Approaches and available technologies

Approaches to sludge to energy conversion: There are primarily two approaches for sludge to energy conversion viz. integrated approach (STP is retrofitted with sludge to energy plant) and independent approach (standalone sludge to energy plant). These approaches have been described below:

- Integrated approach – This approach entails commissioning of a treatment plant for processing wastewater/faecal sludge/municipal solid waste along with a sludge to energy module based on various available technologies. This approach can also be used for retrofitting an existing treatment plant having enough available space to accommodate the sludge to energy plant and further allows for the existing technology to be successfully integrated with the energy recovery technique. Integrated STPs may use primary, secondary and tertiary treatment to separate the liquid and solid waste (bio-solids) which is then further processed using different technologies to recover energy. The bio-solids from the wastewater are then treated using anaerobic digestion, combustion, gasification, pyrolysis, etc. The final output from processing is in the form of industrial grade water, energy in the form of electricity and heat, bio-gas, other bio-fuels, etc.
- Independent approach – This approach entails commissioning of standalone sludge to energy systems separate from already existing source of treated sludge such as STP, FSTP, etc. The independent approach is primarily required when there is dearth of space at the existing treatment plants for installations of sludge to energy equipment or the existing technology at such plants does not allow for integration with the sludge to energy technology. These plants treat and process the bio-solids found in the treated sludge and produce final output in the form of syngas, flu gas, electricity, heat, renewable natural gas, other clean fuels, etc.

Technologies for sludge to energy plants: Sewage sludge is by-product of waste water treatment plants, it can be considered valuable in terms of the available nutrients or energy but can also be detrimental if we consider the presence of organic pollutants and heavy metals. The high population growth and industrial development contributes towards increase in the amount of waste water and consequently the sewage sludge generation. Thus, it becomes imperative to develop sustainable mechanism for treatment of this sludge. In this section of the report, we will examine the various methods that could be employed for treating and converting the sludge to energy. Sludge is a mixture of organic, inorganic, and living organisms resulting in an unstable, volatile and decaying matter. The treatment of such material could be biological (composting or digestion), physical (pressure, heat, vibration, microwaves), or chemical (oxidation, alkalization). All the aforementioned methods aim to destroy pathogens, eliminate odour, and reduce volatile contents to improve the effluent quality, enhance nutrient recovery and ensure safe disposal. The most common usage for recovered sludge is as fertilizer in agriculture activities, however, the increased restriction in global environmental standards has seen a sharp increase in processes such as anaerobic digestions and thermal reactions. The sludge to energy conversion can be broadly classified into two categories: a) pre-processing; and b) processing, which can further be of four types: a) anaerobic digestion; b) combustion (incineration); c) pyrolysis; and d) gasification. We have also studied various cases and research studies which use the integrated and independent approach of converting sludge to energy incorporating the above mentioned processing techniques. These have been provided in the next sub-chapters. Details of sludge to energy recovery process have been provided in the figure 15 below:

Figure 15: Potential sludge to energy recovery routes



Source: Energies 2019, 12, 60

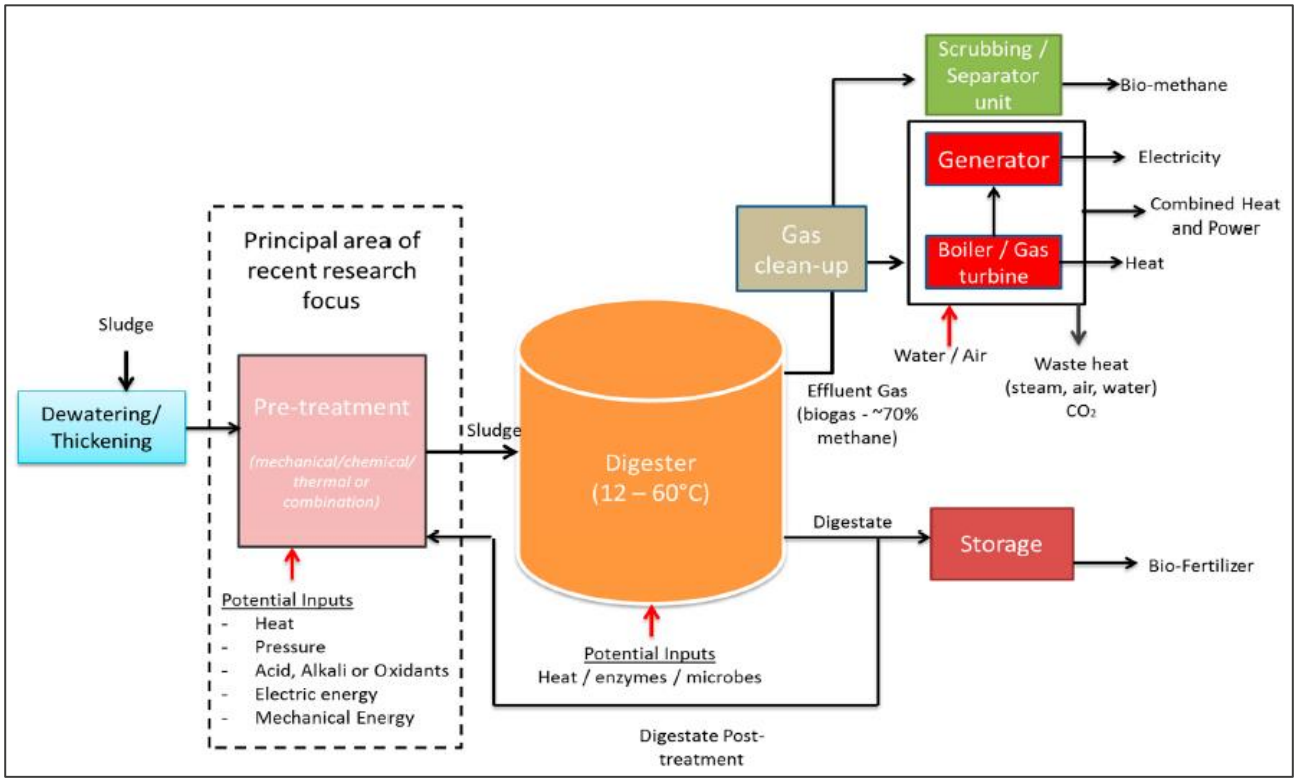
Pre-processing of sludge: The wastewater has very high moisture content which needs to be removed prior to processing the waste further. The removal of such moisture can be done through coagulation, flocculation and sedimentation process. During coagulation, coagulants are used to neutralise the non-settling solids such as clay and color producing organic elements. Coagulation results in the settling and sticking together of these small suspended particles resulting in slightly larger but still sub-microscopic particles called micro flocs. Coagulation is followed by flocculation wherein slow mixing in undertaken to facilitate the binding of smaller micro flocs into larger and visible macro flocs. Subsequently, sedimentation is used to remove the suspended particles from the water through the use of settling basins and mechanical systems for continuous removal of solids. At the end of the process, the primary sludge still has around 70-75% moisture content. The sludge then undergoes other dewatering and drying technologies such as belt presses, centrifuges, direct dryers and/or indirect dryers and vacuum filters for the removal of the bulk of fluids. The process of drying of sludge is important as it facilitates transformation of waste from wet matter to granular feedstock that can be easily handled and processed in further thermal processes.

8.2 Anaerobic Digestion

About Technology: Anaerobic digestion is a biological process that occurs in an inert atmosphere for conversion of organic compounds into biogas by the use of microorganisms. The use of naturally occurring bacteria for biodegradation comprises a series of biochemical phases including hydrolysis, acidogenesis (fermentation), acetogenesis and methanogenesis. The aforementioned stages aid the reduction of mass and volume while the organic matter is converted into biogas by the pathogens.

- Hydrolysis – It is the process of breaking down complex organic molecules into simple sugars, amino acids, and fatty acids. The breaking down of these complex molecules is essentials for the bacteria in anaerobic digesters to access the energy potential of the material. Therefore, hydrolysis of these high-molecular-weight polymeric components is the necessary first step in anaerobic digestion.
- Acidogenesis – This biological process of acidogenesis results in further breakdown of the remaining components by fermentative bacteria. The byproducts created as a result of this process are ammonia, carbon dioxide and hydrogen sulfide
- Acetogenesis – In the third stage of anaerobic digestion, simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen.
- Methanogenesis – This is the final stage of anaerobic digestion. In this step, methanogens sue the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. These components makes up the majority of the biogas emitted from the system. The following schematic describes the process of anaerobic digestion of sludge:

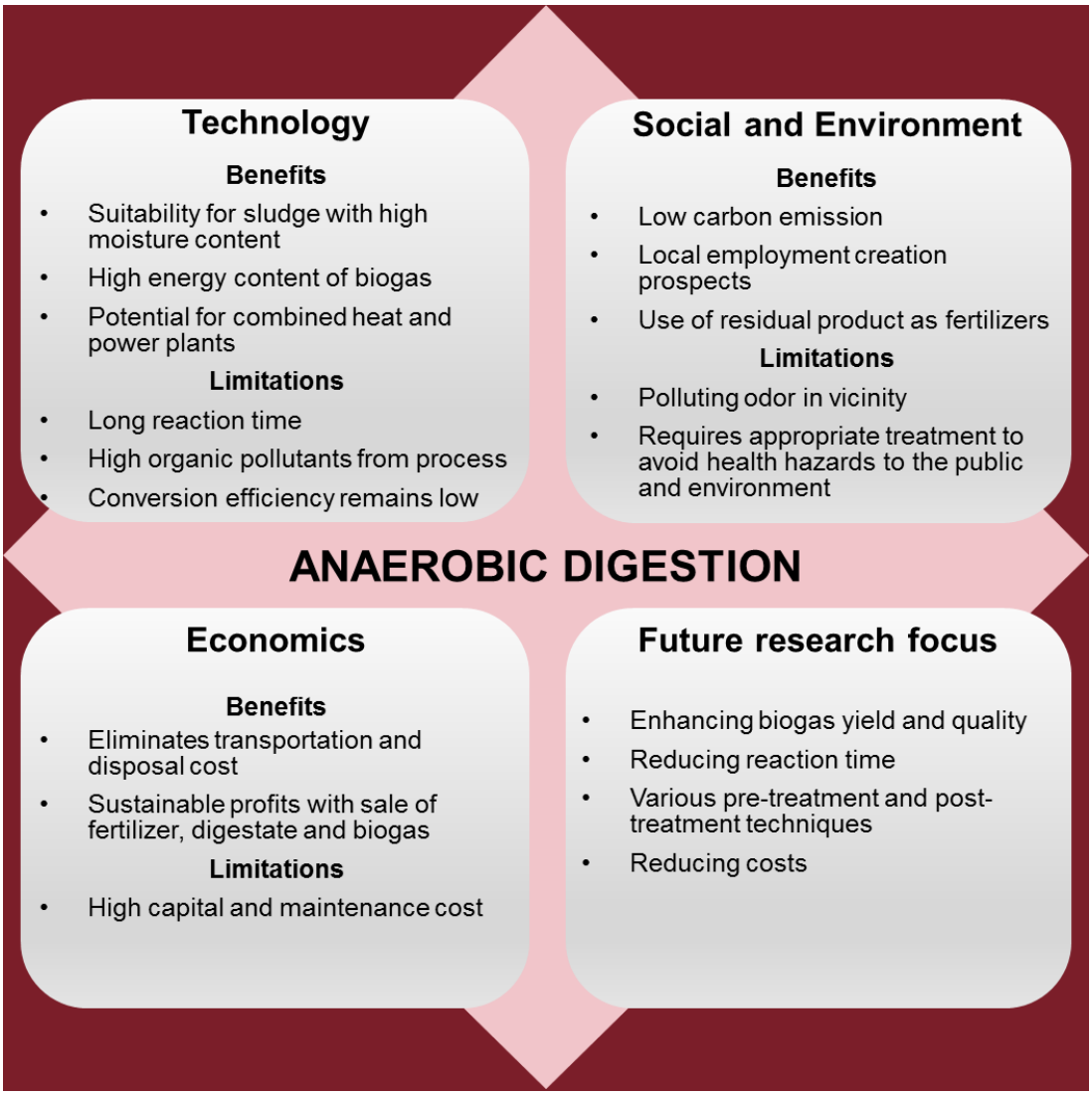
Figure 16: Anaerobic digestion of sludge



Source: Energies 2019, 12, 60

Technology assessment: Anaerobic digestion is recognized globally as a technologically matured and cost effective process used to process sludge before finally disposing it off. The use of energy derived from such a process could be used to offset 50% of the operational energy cost of a waste water treatment plant. Furthermore, the energy generated could also be used at other sources or transferred / sold to the grid. However, the process has a major limitation i.e. long reaction time and requirement of optimal reaction conditions for micro-organism development, making the technology cost effective and suitable only for large treatment plants. A brief technological, socio-environmental and economic assessment of the technology has been presented in the figure below.

Figure 17: Technological, socio-environmental and economic assessment of anaerobic digestion



Source: Energies 2019, 12, 60

Case study for cost benchmarking:

- Introduction - India's largest sewage treatment plant will be developed in the capital city of Delhi. Slated for completion by June 2022, the plant will have a capacity to treat 564 million liters[26] of waste water per day. SUEZ, a French utility company, has won the contract for building and operating the STP which includes a three-and-a-half year design and construction phase followed by an 11 year O&M phase. The STP is part of a larger action plan – Yamuna Action Plan – and will be helpful in treating the wastewater that would otherwise directly enter Yamuna River. The STP will remove 41,200 kg organic pollutant and 61,600 kg solid load per day from the river. The plant is expected to benefit the lives of 40 lakh residents living in the nearby areas. The plant will be following an integrated approach for sludge to energy conversion, using anaerobic digestion technique for energy recovery and ASP for treating the wastewater.
- Cost benchmarking and outputs – The STP will be built at a cost of INR 116,100 lakh (€ 139 million)[27]. 85% of the project cost will be provided by the Government of India through a loan received from Japan International Cooperation Agency (JICA) and the remaining 15% will be provided by Government of Delhi

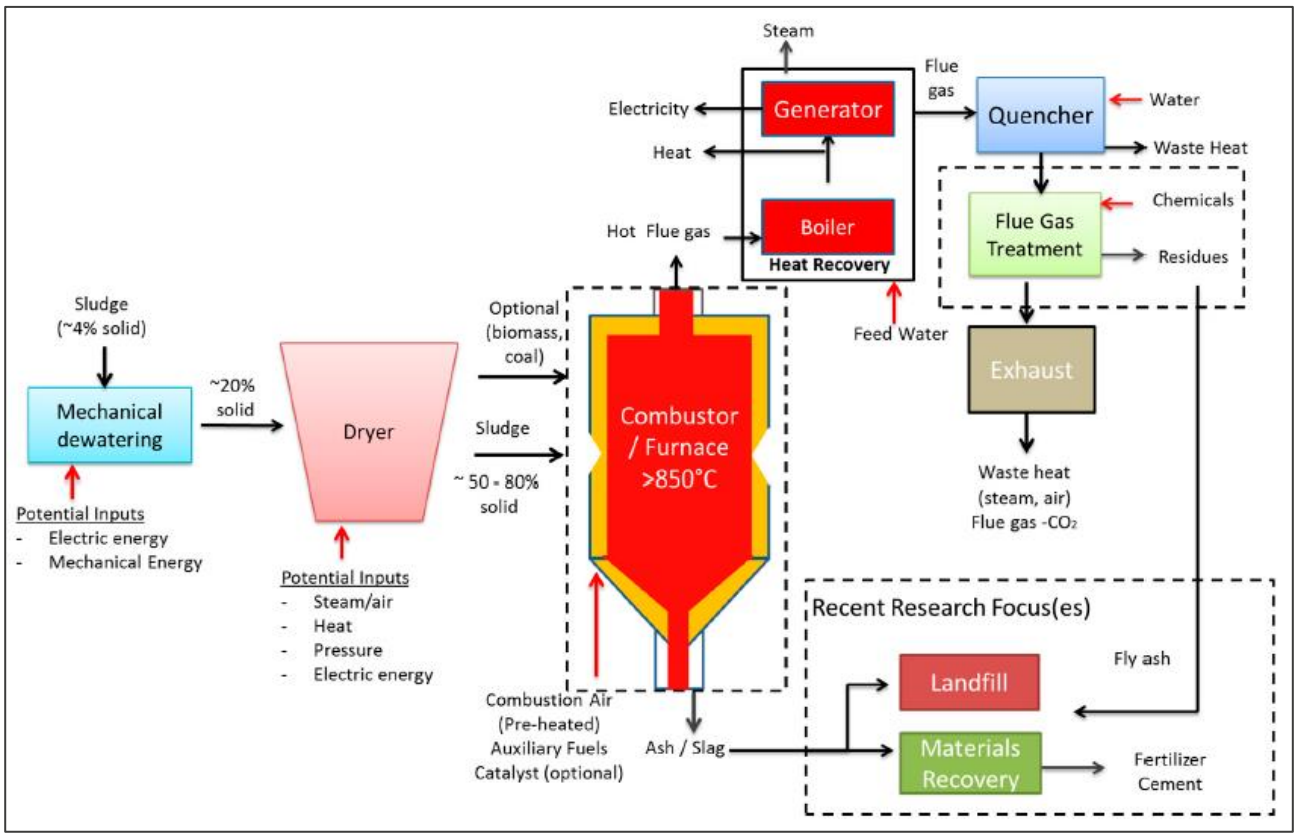
[26] *https://www.telegraphindia.com/india/how-india-s-biggest-sewage-treatment-plant-in-delhi-is-different-from-others/cid/1694191*
[27] *https://www.thehindu.com/news/cities/Delhi/indias-biggest-stp-to-come-up-at-okhla-djb/article27301495.ece*

The final output of the plant will be in the form of treated water to the tune of 500 MLD and 25,000 kWh of electricity per day. The electricity produced will meet 60% of the operating requirements of the plant itself, reducing its dependence on the central grid. Similarly, majority of the treated water will be discharged into Yamuna River, while a part of it will be used in power plants in the city to reduce their dependence on ground water. Commercially, if the plant were to sell the produced electricity and treated water, it would generate revenue to the tune of INR 550 lakh (€ 0.7 million) per year (at a unit cost of INR 6 per kWh) and INR 547,400 lakh (€ 657 million) per year (at a unit cost of INR 0.3 per liter).

8.3 Combustion

About technology: Combustion of sludge is similar to that of other solid fuels. The process involves oxidation of fuels at high temperature leading to generation of heat, carbon dioxide, water vapor, and other trace gases. The use of combustion technology can be done for generation of heat (conventional combustion) or for reduction of volume of waste materials (incineration). The heat generated from conventional systems could be used for consumption or for power generation through allied mechanisms. The incineration based systems however may not utilize the heat generated as the main purpose for such systems is to burn off harmful elements from waste before final disposal or reuse as residual ash. Incineration reduces 90% of the sludge volume while terminating pathogens. Unlike anaerobic digestion, where the dewatered sludge could be used directly, combustion technology requires further drying of dewatered sludge to reduce moisture content to less than 50% before transmission into the reactor. A schematic detailing the entire combustion process has been provided in the figure below:

Figure 18: Schematic representation of combustion of sludge

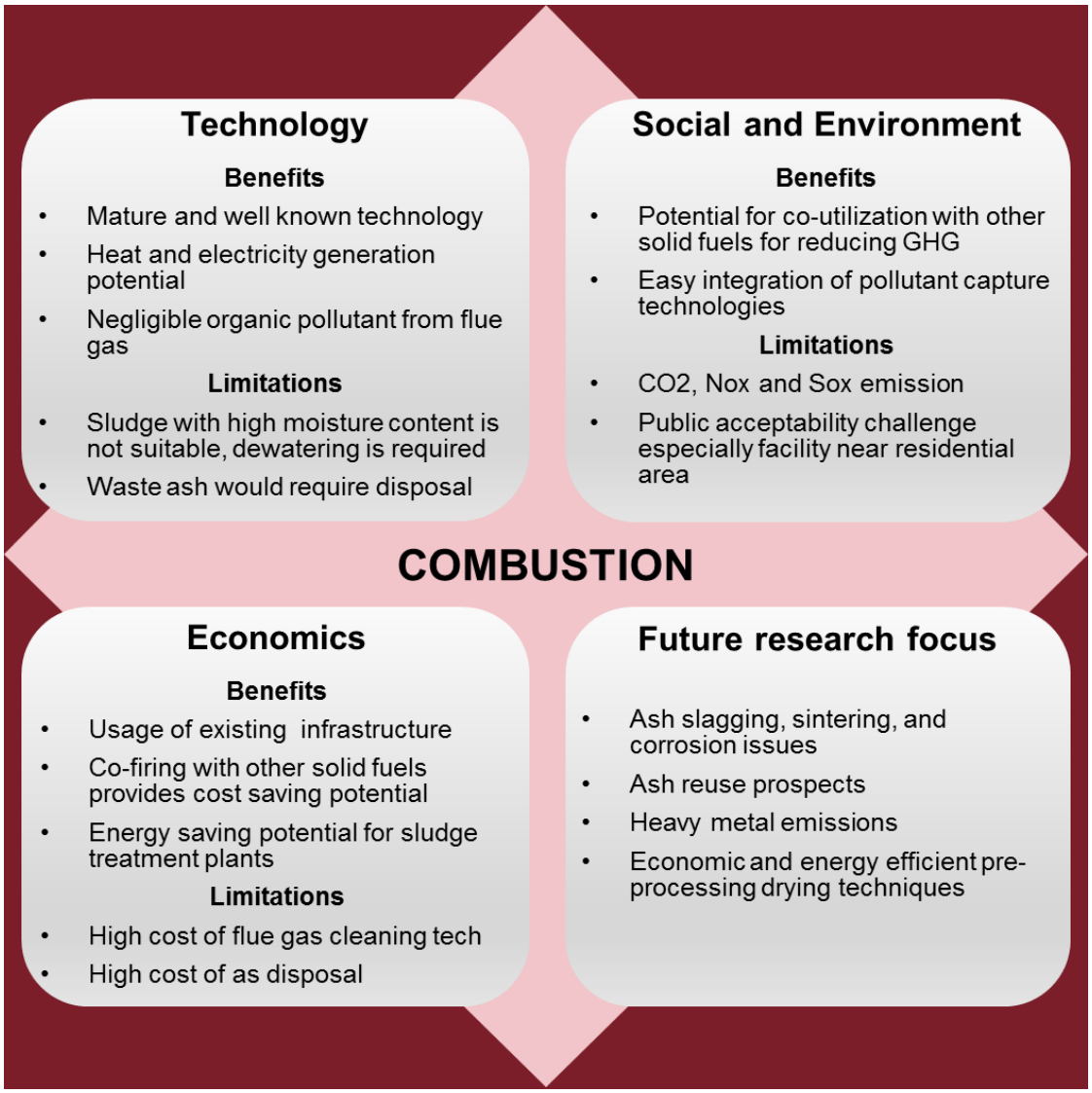


Source: Energies 2019, 12, 60

Technology assessment: The major challenge with combustion technology is the requirement of adapting the combustor design requirement as per the sewage sludge components. High moisture and ash contents in

the sewage sludge increase the bulk density of fuel, lowers energy content and reduces the complete oxidation. It further leads to additional time, energy and oxidants for drying the sludge and can also lead to the formation of erosive sulphuric compounds. Finally, the ash generated through the process is associated with heavy metals emission and can have adverse effect on health and environment. A brief technological, socio-environmental and economic assessment of the technology has been presented in the figure below.

Figure 19: Technological, socio-environmental and economic assessment of combustion



Source: Energies 2019, 12, 60

Case study for cost benchmarking:

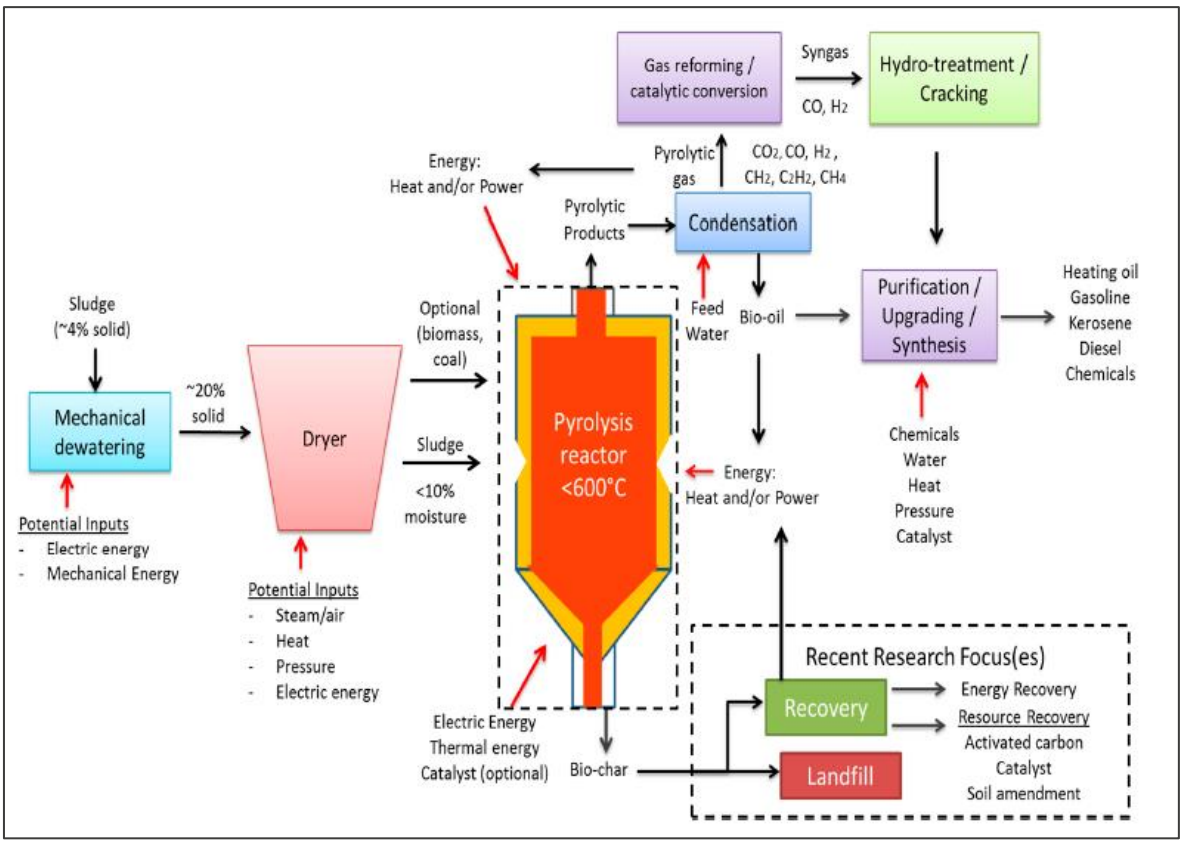
- Introduction - Ankur Scientific Energy Technologies Pvt Ltd has commissioned India's first FSTP plant incorporating the omni-processor technology. The technology has been patented by BMGF and further improved by Ankur Scientific. The plant uses an integrated approach for converting sludge to energy. It separates the solid and liquid part of the sludge using a volute press. The liquid part is then treated using the MBBR technique while the solid part is treated using the combustion process. The plant has a capacity to treat 200 KLD of faecal sludge and has been developed over an area of 4,000 m^2. The responsibility of O&M of the FSTP has also been given to Ankur Scientific Energy Technologies Pvt Ltd for a period of 10 years.

- Cost benchmarking and outputs – The capex incurred for the development of the plant was USD 5.5 million (€ 4.6 million) and the annual O&M expense has been pegged at USD 100,000 (€ 84,260). The plant generates 130 KLD of industrial grade water, 14 KLD of distilled water and electricity to the tune of 1,000 KwH per day. Commercially, the cumulative yearly revenue generating potential from the sale of industrial grade water, distilled water and electricity produced by the plant is INR 215.4 lakh (€ 0.29 million).

8.4 Pyrolysis

About technology: Pyrolysis is the thermal decomposition of matter in a non-reactive, oxygen deficient environment. The process is used for producing bio-oil, solid char and gaseous fuel and referred to as incomplete gasification. The process involves conversion of sludge at operating temperatures of 350-600°C, however some reactors also function at temperatures of up to 900°C. The output product during pyrolysis depends on the process temperature, low temperature heating promotes char production while high temperature promoted production of liquid and gas. The technology however is aimed at maximizing generation of the liquid fluid yield. The pyrolysis of sludge takes place in an inert environment and thus requires an external heat source to reach the required high temperatures for pyrolysis. The utilization of heat sourced from partial combustion of bio gas or bio oil derived from the process itself has been explored, however, the commercial scale expansion of such an arrangement requires significant interventions during the process. Further, the efficiency and cost-effectiveness of sludge pyrolysis is skewed towards dried resources rather than primary sludge. The maximization of bio-oil yield is the primary motive of the entire process as the heating value of such a yield is slightly higher than that generated by bio-oil from bio-mass. However, the bio-oil generated from sewage sludge has greater than 23% moisture content which, as compared to biomass derived bio-oil, leads to lower fuel quality and flame temperature as well as causes deterrence in combustion properties when used in engines. A schematic detailing the entire pyrolysis process has been provided in the figure below:

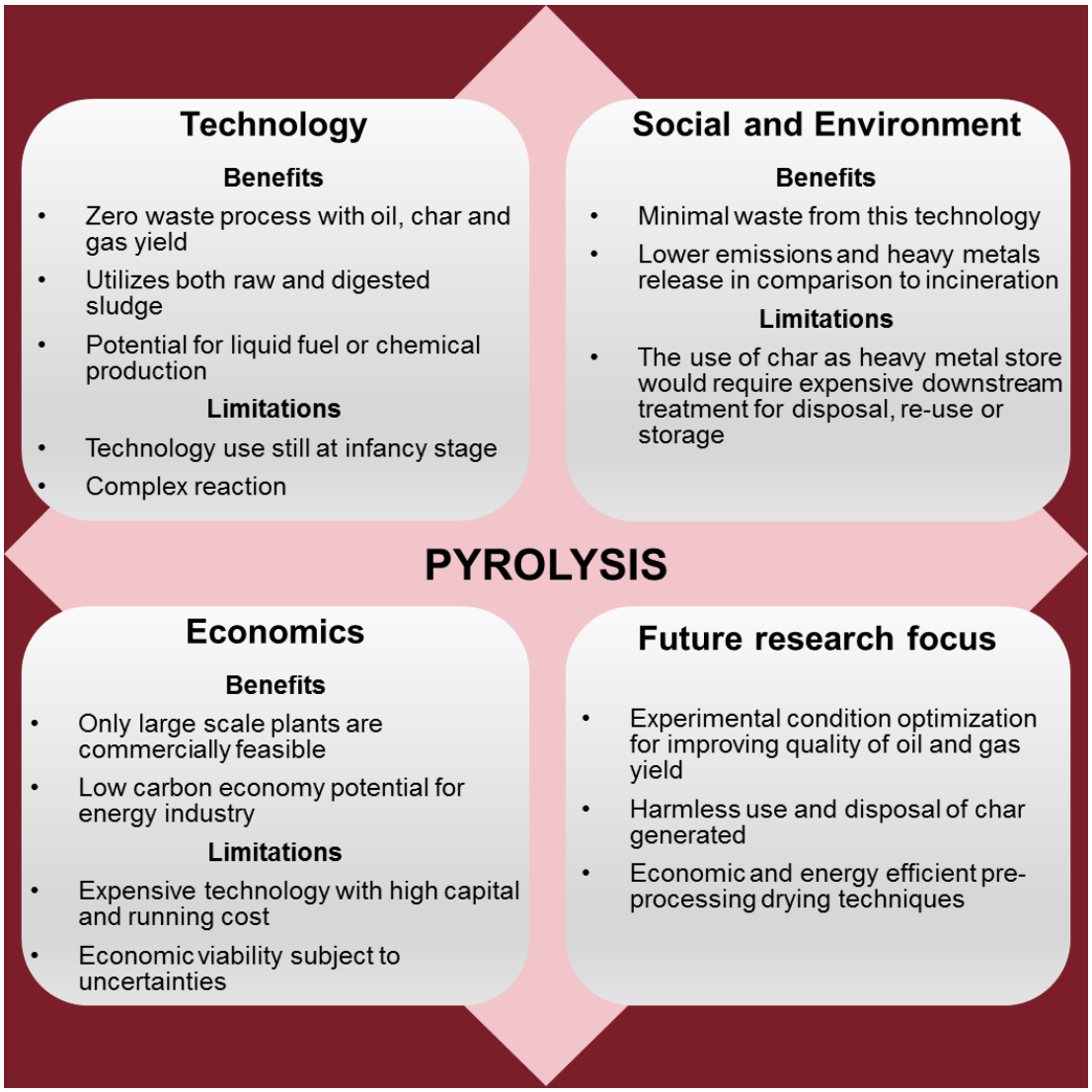
Figure 20: Schematic representation of pyrolysis of sludge



Source: Energies 2019, 12, 60

Technology assessment: Pyrolysis is considered a zero waste technology and has high potential as a sustainable energy source, the flue gas generated from the process requires less processing as compared to anaerobic digestion and incineration processes. However, the use of the technology for conversion of sewage sludge is not well established considering that the economic viability of the process is dependent on ability to maximize efficiency, produce high quality oil, gas and char which can be further used for other processes. A brief snapshot of the technological, socio-environmental and economic assessment of the technology has been presented in the figure below:

Figure 21: Technological, socio-environmental and economic assessment of pyrolysis



Source: Energies 2019, 12, 60

Case study for cost benchmarking:

- Introduction – KORE infrastructure, USA is in the process of commissioning[28] its patented pyrolysis technology to generate renewable natural gas (RNG) from treated sewage sludge[29] (bio solids). KORE's patented thermal process consists of five stages: 1) material handling; 2) drying; 3) pyrolysis; 4) pyrolysis gas conversion to RNG; and 5) compression. Pyrolysis and gas conversion produce an RNG equivalent

[28] *https://koreinfrastructure.com/*
[29] *https://www.waterworld.com/home/article/16205628/kore-infrastructure-receives-25-million-grant-from-the-south-coast-air-quality-management-district*

that can be turned into variety of energy products. This will be Kore's first commercial-scale facility, located in Rialto, California. The company had previously design, built and operated a pilot facility at the Los Angeles County Sanitation Districts' (LACSD) Joint Water Pollution Control Plant in Carson, California. This facility was operated for over five years and was the testing ground for designing, integrating, and optimizing the pyrolysis system and liquefaction of KORE's thermochemical process[30]. The techniques will use an independent approach for sludge to energy recovery and will use treated sewage sludge from nearby facilities.

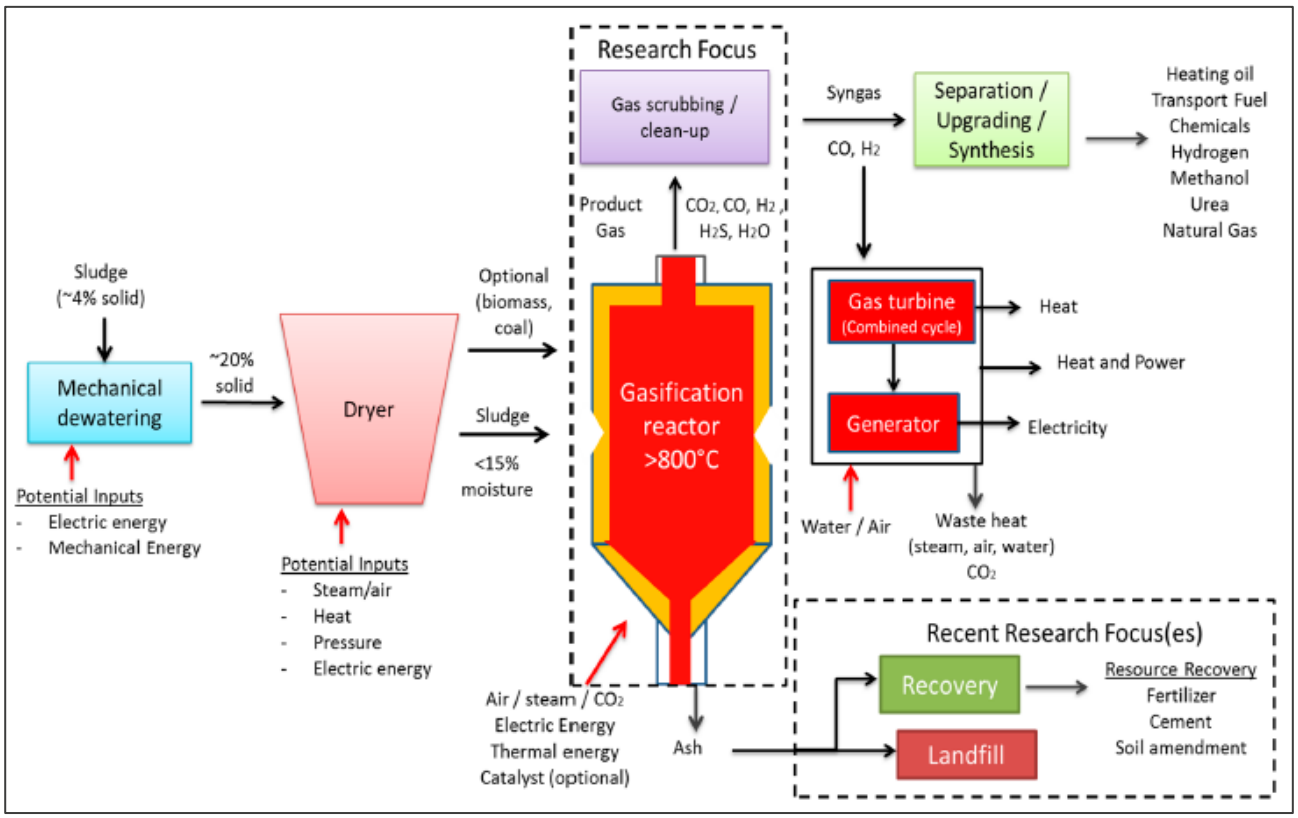
- Cost benchmarking and output - The facility will be developed at a cost of over USD 25 million (€ 21 million) with a capacity to treat 300 TPD (tons per day) of bio solids and RNG production rate of 1,000 – 1, 200 gge/d (gasoline gallon equivalent per day)[31] or 125-150 MMBTU (million British thermal unit) per day. The plan is to use the produced RNG to power vehicles fitted with Cummins Westport's 8.9-liter near-zero-NOx natural gas engine. If KORE infrastructure were to sell the produced RNG, commercially, it would generate an annual revenue to the tune of USD 182,500 to USD 219,000 (€ 154,692 to € 185,630).

8.5 Gasification

About technology: Gasification is the thermochemical conversion of sewage sludge's organic content into gases such as hydrogen, carbon monoxide as well as carbon dioxide, methane, water and other hydrocarbons. The process can be completed using air, carbon dioxide, oxygen, steam, or mixture of similar gases, leading to an output of syngas. The syngas can be used directly used for heating or electricity generation or can be used for further processing as chemicals or liquid fuel synthesis. The process is similar to that of combustion but has lower moisture acceptability (less than 15% of total waste). The gasification process results in output in the form of gases and ash. The output gases generated during the process require further processing and cleaning for use in both heat and electricity generation as well as to be upgraded as liquid fuel and for use in chemical synthesis. The gasification process can also be termed as incomplete combustion or extended pyrolysis in which gas-solid, gas-gas and liquid cracking reactions are required to maximize the gaseous product yield. A schematic detailing the entire combustion process has been provided in the figure below:

[30] *https://www.waterrf.org/news/kore-infrastructure*
[31] *https://escholarship.org/content/qt0055g3kb/qt0055g3kb.pdf?t=q16ebg*

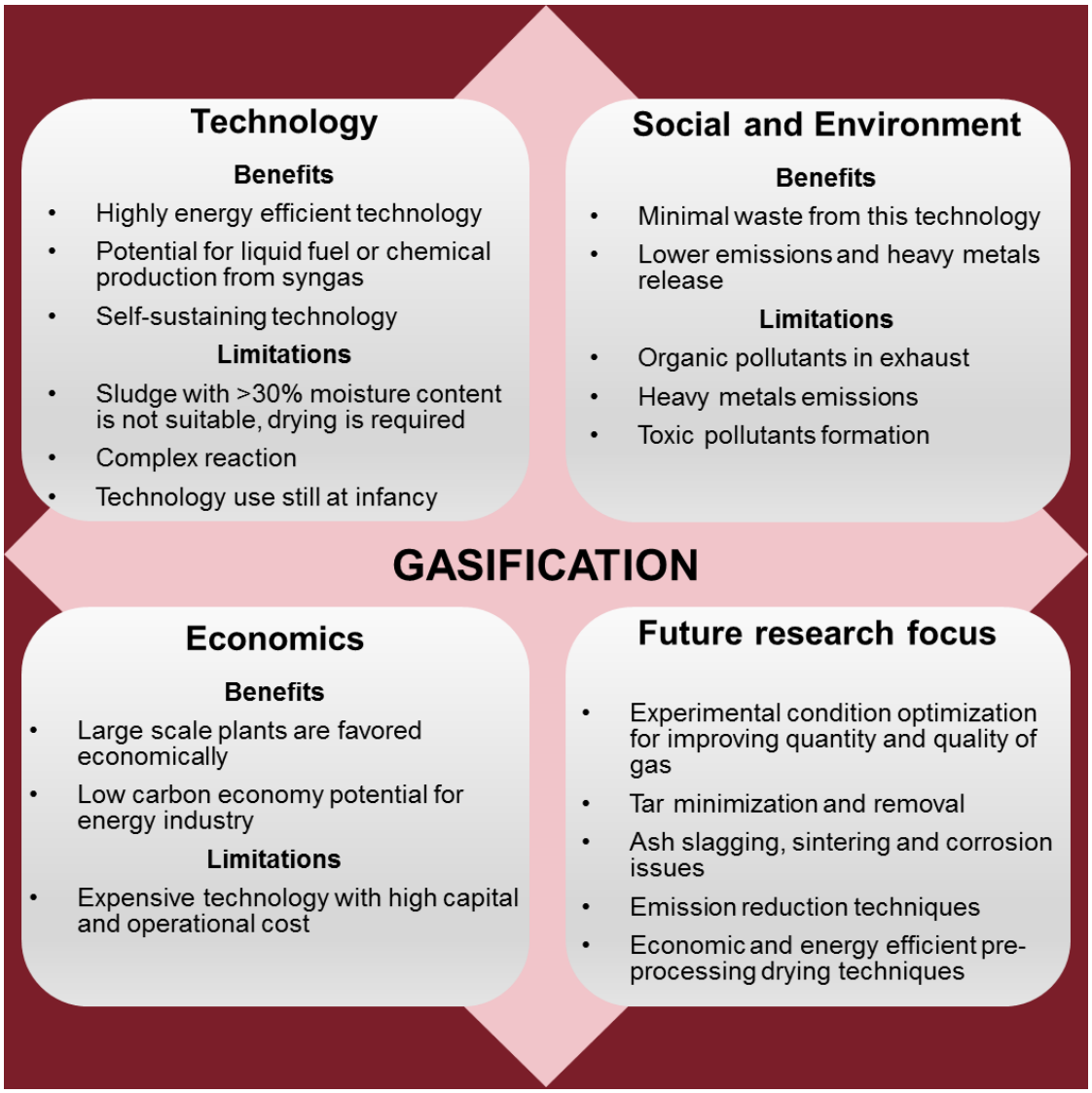
Figure 22: Schematic representation of the gasification of sludge



Source: Energies 2019, 12, 60

Technology assessment: The major challenge of gasification lays with ash related issues leading from high inorganic content in the sludge. The high amount of ash has adverse influence on gasifier operation and may lead to frequent shutdowns and maintenance of the reactors. Further, the gasification also leads to generation of ammonia, hydrogen cyanide and hydrogen sulphide formation which are toxic pollutants. A brief snapshot of the technological, socio-environmental and economic assessment of the technology has been presented in the figure below:

Figure 23: Technological, socio-environmental and economic assessment of gasification



Source: Energies 2019, 12, 60

Cost benchmarking: As per a research report published by TruSense Consulting Services (Pty) Ltd for Water Research Commission of South Africa[32], the capital investment required for the development of a 50 tDs/d (tons of dry solids per day) gasification plant is pegged at USD 33 million (€ 27.8 million). The annual operations and maintenance cost of the same plant is pegged at USD 0.76 million (€ 0.64 million), while electricity produced for 85% availability of the plant (310 days) is estimated at 21 million kWh/year. Considering a rate of € 0.072 per unit of electricity sold, the plant has a revenue generating potential of € 1.5 million/year. These estimates consider the independent approach for setting up a gasification plant for treating bio-solids from waste activated sludge. Further breakup of the cost has been provided in table 17 below. Indirect costs include engineering and supervision costs, construction expenses, legal expenses, contractor's fee, and contingency.

Table 17: Cost estimate of a 50 tDs/d (45 KLD) gasification plant

Equipment and installation	Cost
Pre-dewatering	USD 9.8 million (€ 8.3 million)

[32] *http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20752-18.pdf*

Equipment and installation	Cost
Dryer, gasification plant and gas cleaning	USD 10.8 million (€ 9.1 million)
Gas engine	USD 3.0 million (€ 2.5 million)
Sub-total (1)	**USD 23.6 million (€ 19.9 million)**
Indirect costs (40% of sub-total)	USD 9.4 million (€ 7.9 million)
Total capital investment	**USD 33.0 million (€ 27.8 million)**

Source: http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20752-18.pdf

8.6 Key findings

The key findings from the analyses of cost benchmarking undertaken for various sludge to energy recovery methods have been presented below:

Key comparative points for the recovery techniques evaluated: The four types of sludge to energy recovery methods discussed above are anaerobic digestion, combustion, pyrolysis and gasification. The cost benchmarking for STPs using these techniques has been done using actual cases from around the world or through estimations provided in research reports and the findings have been presented in Table 18. These techniques either use biological or chemical processes to treat sludge. The cases discussed for anaerobic digestion and combustion techniques are based on the integrated approach for sludge to energy conversion and since they treat the entire incoming wastewater/fecal sludge, their capacity has been measure in KLD. The cases discussed for pyrolysis and gasification techniques, on the other hand, are based on independent approach for sludge to energy conversion and since they treat only bio-solids, their capacity has been measured in TPD or tDs/d. The table below presents a comparative analysis of the cost benchmarking undertaken for these techniques along with the estimated revenue generating potential. The plant using anaerobic digestion for sludge to energy conversion has a capacity of 564,000 KLD and will be constructed at a cost of € 139 million, bringing per unit cost of construction to € 246/KLD. Similarly per unit cost of constructing the FSTP using combustion technique for sludge to energy conversion comes out to be € 23,000/KLD. The sludge to energy plant using pyrolysis as the energy recovery technique will have a capacity of 300 TPD and will be constructed at a cost of € 21 million, bringing per unit cost of construction to € 70,000/TPD. Similarly, the estimated per unit cost of constructing a sludge gasification plant with a capacity to treat 50 tDs/d of dry solid per day comes out to be € 0.6 million/tDs/d.

Table 18: Cost comparison of plants employing different sludge to energy techniques

Parameter	Anaerobic digestion	Combustion	Pyrolysis	Gasification
Capacity of plant	564,000 KLD	200 KLD	300 TPD	50 tDs/d
Capex	€ 139 million	€ 4.6 million	€ 21 million	€ 27.8 million
Unit cost	€ 246/KLD	€ 23,000/KLD	€ 70,000/TPD	€ 0.6 million/tDs/d
Revenue generating output	Electricity and industrial grade water	Industrial grade water, distilled water and electricity	Renewable natural gas (vehicular fuel)	Electricity
Revenue generating potential	€ 658 million/year	€ 0.3 million/year	€ 0.2 million/year	€ 1.5 million/year
Opex	Not available	€ 84,260/year	Not available	€ 0.6 million/year

Parameter	Anaerobic digestion	Combustion	Pyrolysis	Gasification
Land Requirement (m^2)	Not available	4,000 m^2	Not available	Not available

Note: The cost analysis indicated above is only a preliminary estimate to give the reader an idea about the indicative costs to implement these technologies in order to generate energy from sludge. A detailed financial analysis will need to be undertaken at the feasibility stage for all the four technologies including all parameters in order to arrive at the final cost. These parameter include but are not limited to area of land required, location of plant, man-power related costs, capacity of the plant, contingencies, etc.

9 Conclusion & Way Forward

This chapter summarizes the findings of the study in brief and lists out important points as a way forward for relevant stakeholders.

Need for a sludge-to-energy project: Given the international and national precedent set by the WWTPs plants in Aarhus, Copenhagen and Vadodara, it is evident that energy generated from wastewater/sludge not only helps in making the STPs self-sufficient in terms of energy, the electricity and heat produced can be used for various commercial purposes as well. The setup of sludge to energy plant will also lead to odor reduction thereby increasing the quality of life of the city's citizens. Additionally, the plant will utilize the methane generated from sludge leading to a better CO2 footprint for the city. Further to the aforementioned points, the sludge to energy will have significant environmental benefits such as reduction in soil and water pollution, significant reduction in the landfilled area, and improvement in the overall hygiene and health of the areas surrounding the landfill. Since the sludge generated from the commissioned STPs in Udaipur is not put to any productive use and is directly dumped into the landfill site without using any scientific method for its treatment, there is an imminent need for a sludge-to-energy project in the city.

Next steps/way forward: Having established the need for a sludge-to-energy plant in Udaipur through this baseline study, the UMC should undertake a detailed feasibility study in this regards. The baseline study prepared as a part of this assignment should feed in to the feasibility study. In addition to the points mentioned below, the feasibility study may also undertake a detailed analysis of the sludge to energy plant in Vadodara to understand the specific advantages and challenges in implementing such projects.

- Sewage and sludge monitoring program: The Aarhus city team in collaboration with UMC is also planning to undertake a sewage monitoring program to evaluate the quality of sewage in Udaipur and the consequent sludge generated from the sewage treatment plants. The findings of the monitoring program will feed into the feasibility report.
- Technical feasibility – This part of the feasibility report should cover all the technical aspects in detail, including but not limited to selection and assessment of all technologies available for sludge-to-energy conversion and their comparison with omni-processor technology employed at the Vadodara sludge to energy plant, costs related with each technology and their feasibility, availability of encumbrance free and suitable land (proximity to source of sludge and size), potential users of energy generated in terms of heat and electricity, input and output specifications of the project along with its performance standards, legal and regulatory assessment, social and environmental assessment, risk assessment along with mitigation and allocation of risks to different parties.
- Financial feasibility – The feasibility study should also undertake a detailed financial assessment of the project covering detailed estimation of capital expenditure, operational expenditure and revenues, quantum of electricity to be generated; electricity tariff; subsidies required, sensitivity analysis and value for money analysis. Although a preliminary cost benchmarking has been undertaken for various sludge to energy recovery methods, it is recommended that a detailed financial feasibility of these technologies is undertaken at the feasibility stage including various parameters such as required capacity, location of project, land required, associated man-power costs, overheads, etc., so as to select the most efficient and affordable technology to be implemented at the Udaipur sludge to energy plant.
- Project structure – This includes roles and responsibilities of various stakeholders, particularly that of the private developer and the implementing agencies, possibility of integration with existing STPs by increasing HZL's scope of work, mode of contracting such as PPP or EPC, mode of payment and contract duration.

- Bid-process management – The feasibility study should also provide details regarding the next steps in project preparation and execution, i.e., bid-process management. This part should explain in detail the number of stages that will be employed for the procurement process, bidding parameters including technical and financial parameters, appointment of transaction advisors, and formation of data rooms and customisation of bidding documents.

10 References

The chapter lists the links to various news articles, publications, policy documents, research papers, company reports, and case studies that were referred to during the preparation of this study.

The following table provides a list of all reference used during the preparation of this report:

Table 19: Table of references

Date	Title	Author	Link
Case Studies			
-	Sewage Treatment Plant – Hindustan Zinc Limited	India Sanitation Coalition	http://www.indiasanitationcoalition.org/resources/Case-Study-Hindustan-Zinc.pdf
-	Sewage Recycle Plant at Hindustan Zinc Limited	Thermax	-
Existing studies on Udaipur urban infrastructure			
-	DPR for sewerage work under AMRUT phase II and smart city mission of GOI in line with comprehensive DPR prepared by Nagar Nigam for Udaipur City	Exceltech Consultancy and Projects Pvt Ltd	http://www.udaipurmc.org/PDF/Others/Ud_Sewerage_DPR.pdf
February 19, 2015	City Development Plan for Udaipur	CRISIL	http://www.udaipurmc.org/PDF/Others/Ud_PPT_CDP.pdf
-	City Sanitation Plan	NF Infratech Service Pvt Ltd	http://www.udaipurmc.org/PDF/Others/Ud_CSP_DraftReport.pdf
News articles and other relevant publications			
July 8, 2019	India's largest sewage treatment plant to come up in Okhla	Roushan Ali	http://www.millenniumpost.in/delhi/indias-largest-sewage-treatment-plant-to-come-up-in-okhla-362330?infinitescroll=1
July 12, 2019	How India's biggest sewage treatment plant in Delhi is different from others	Telegraph India	https://www.telegraphindia.com/india/how-india-s-biggest-sewage-treatment-plant-in-delhi-is-different-from-others/cid/1694191
November 25, 2019	Okhla will soon have India's largest sewage treatment plant	Gajendra Goswami	https://www.whatshot.in/delhi-ncr/indias-largest-sewage-treatment-plant-in-okhla-c-15603
May 29, 2019	India's largest sewage treatment plant to come up at Okhla: DJB	Economic Times	https://economictimes.indiatimes.com/news/politics-and-nation/indias-largest-sewage-treatment-plant-to-come-up-at-okhla-djb/articleshow/69565260.cms?from=mdr
September 14, 2016	Kore Infrastructure receives $2.5 million grant from the South Coast Air Quality Management District	Water World	https://www.waterworld.com/home/article/16205628/kore-infrastructure-receives-25-million-

Date	Title	Author	Link
			grant-from-the-south-coast-air-quality-management-district
June 17, 2019	Kore Infrastructure	The Water Research Foundation	https://www.waterrf.org/news/kore-infrastructure
July, 2019	Renewable Natural Gas Project Economics	M.J. Bradley & Associates	https://www.mjbradley.com/sites/default/files/RNGEconomics07152019.pdf
-	Ankur Omni-Processor	Steps for sanitation	https://techdirectory.stepsforsanitation.org/systems/3/
December 25, 2018	Oladejo, J.; Shi, K.; Luo, X.; Yang, G.; Wu, T. A Review of Sludge-to-Energy Recovery Methods. Energies 2019, 12, 60.	Jumoke Oladejo, Kaiqi Shi, Xiang Luo, Gang Yang and Tao Wu	https://www.mdpi.com/1996-1073/12/1/60
December 25, 2018	A Review of Sludge to Energy Recovery Methods	Jumoke Oladejo, Kaiqi Shi, Xiang Luo, Gang Yang and Tao Wu	https://www.mdpi.com/1996-1073/12/1/60/pdf
April 6, 2017	From waste to energy: Danish plant flexes the power of wastewater	Magdalen Mis	https://www.reuters.com/article/us-denmark-wastewater-power/from-waste-to-energy-danish-plant-flexes-the-power-of-wastewater-idUSKBN1782BN
-	MBBR	Sandeep Joshi	https://sswm.info/step-nawatech/module-1-nawatech-basics/appropriate-technologies-0/mbbr
-	From Wastewater Plant to Power Plant	State of Green	https://stateofgreen.com/en/partners/aarhus-vand/solutions/marselisborg-wwtp-energy-neutral-water-management/
-	OECD (2019), Making Blended Finance Work for Water and Sanitation: Unlocking Commercial Finance for SDG 6, OECD Studies on Water, OECD Publishing, Paris, https://doi.org/10.1787/5efc8950-en.	OECD Environmental Directorate	https://www.caidp-rpcdi.ca/sites/caidp-rpcdi.ca/files/conferences/2019_Conference/OECD%282019%29Making-Blended-Finance-Work-for-Water-and-Sanitation.pdf
August 16, 2016	Every time we consume 100 units of energy, we send back 260	State of Green	https://stateofgreen.com/en/partners/state-of-green/news/every-time-we-consume-100-units-of-energy-we-send-back-260/
January 2, 2019	Copenhagen opts for performance-based sludge to energy treatment model	Kemira Oyj	https://www.kemira.com/insights/copenhagen-opts-for-performance-based-sludge-treatment-model/
October 2018	Understanding Water Flows in Udaipur	Heinrich Böll Foundation-India and Development	https://www.devalt.org/images/L2_ProjectPdfs/Understanding_Wat

Date	Title	Author	Link
		Alternatives Group	erflows_In_Udaipur_HBF.pdf?Oid=209
-	Sludge for energy at Copenhagen's Largest Wastewater Treatment Plant	Anders Dyrelund	https://stateofgreen.com/en/partners/ramboll/solutions/sludge-for-energy-in-copenhagen-biofos/
-	Moving Bed Biofilm Reactor	Ecologix	https://www.ecologixsystems.com/system-mbbr/
-	City Wide Decentralised Septage Treatment In Udaipur	Sneha Bhattacharyya	https://portfolio.cept.ac.in/2019/S/fp/city-wide-infrastructure-planning-for-udaipur-rajasthan-ui4000-spring-2019/city-wide-decentralised-septage-treatment-in-udaipur-spring-2019-pg181015
February 12, 2004	SMC installs 0.5 MW sewage power plant	Amarendra Jha	https://timesofindia.indiatimes.com/city/ahmedabad/SMC-installs-5-MW-sewage-power-plant/articleshow/493504.cms
-	Udaipur-City of Lakes	USAID	https://www.ircwash.org/sites/default/files/udaipur.pdf
June 09, 2018	Vadodara to get waste to power and waste water to usable/potable water plant	-	https://www.deshgujarat.com/2018/06/09/vadodara-to-get-waste-to-power-and-waste-water-to-usable-potable-water-plant/
May 17, 2018	Bill Gates foundation to fund sludge treatment	-	http://timesofindia.indiatimes.com/articleshow/64197063.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
July, 2018	Energy recovery from wastewater sludge – A review of appropriate emerging and established technologies for the south African industry	Eustina Musvoto, Nomvuselelo Mgwenya, Hazel Mangashena, Alexis Mackintosh, TruSense Consulting (Pty) Ltd	http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20752-18.pdf
Official websites of stakeholders and other government agencies			
-	Budget documents, balance sheets, etc.	UMC	http://www.udaipurmc.org/HomePage.aspx
2008	National Urban Sanitation Policy	Ministry of Urban Development, GOI	http://mohua.gov.in/cms/National-Urban-Sanitation-Policy.php
-	General documents and data	Aarhus Vand	www.aarhusvand.dk
-	General data	Ankur Scientific Energy Technologies Pvt Ltd	https://www.ankurscientific.com/

11 Annexure 1: STP performance data

This Annexure presents the data pertaining to the effluent parameters pertaining to 25 MLD and 20 MLD STPs, provided by UMC, as of July 22, 2020.

Effluent concentration of wastewater inlet and outlet: As per the data provided by UMC, the Biological Oxygen Demand (BOD) of incoming wastewater at both the STPs is 195 mg/ ltr and outgoing treated wastewater from the 25 MLD STP and 20 MLD STP is 6.6 mg/ liter and 8 mg/ liter, respectively. Chemical Oxygen Demand (COD) of incoming wastewater at both the STPs is 356 mg/ liter and outgoing treated wastewater from the 25 MLD STP and 20 MLD STP is 28 mg/ liter and 40 mg/ liter, respectively. Total Suspended Solids (TSS) of incoming wastewater is 212 mg/ liter while that of outgoing treated wastewater from the 25 MLD STP and 20 MLD STP is 3.8 mg/ liter and 4.6 mg/ liter, respectively. The effluent concentration of wastewater inlet and outlet for the 25 MLD STP, as on July 22, 2020, is in-line with the design parameters stipulated in the standard operating procedure document (SOP) shared by the UMC. Further, the effluent discharge standards of the operational STPs in Udaipur are in line with the standards stipulated by Ministry of Environment, Forest and Climate Change, India. The effluent discharge standards as mandated by the ministry have been provided in Annexure 2 of the document. Further details related to the chemical composition of the incoming and outgoing sewage, as per provided by UMC, have been provided in the table below:

Table 20: Effluent concentration of sewage inlet and outlet

Parameter	25 MLD STP		20 MLD STP
	Design parameters[33]	Actual value	Actual value
Wastewater inlet (flow proportional analysis for each of the STPs)			
Flow (seasonal)	As per sewage availability		
Biological oxygen demand (mg/liter)	250	195	195
Chemical oxygen demand (mg/liter)	400	356	356
Total nitrogen (mg/liter)	50	36	36
Total phosphorous (mg/liter)	10	4.5	4.5
Suspended solids (mg/liter)	250	212	212
Wastewater outlet (Flow proportional analysis for each of the STPs)			
Flow (seasonal)	As per sewerage availability		
Biological oxygen demand (mg/liter)	≤ 10	6.6	8
Chemical oxygen demand (mg/liter)	≤ 50	28	40
Total nitrogen (mg/liter)	≤ 20	8.6	18.1
Total phosphorous (mg/liter)	≤ 2	1.3	1.7
Suspended solids (mg/liter)	≤ 5	3.8	4.6

Source: UMC

[33] *As per the SOP document shared by UMC on July 22, 2020.*

12 Annexure 2: Data received from Aarhus

This Annexure highlights the important details of various documents shared by the officials of Aarhus City Council. These include land requirement (area) for setting up a sludge-to-energy plant, technical data required pertaining to the existing STPs in Udaipur, details related to Egaa WWTP, technologies for conversion of sludge to energy.

Land requirement: The Aarhus team provided a comprehensive note on the additional area that would be needed for construction and establishment of new buildings and unit operations on the existing STPs in Udaipur in connection with establishment of energy production. The estimates in the share note were based on various assumptions about sludge and hands on experience of Aarhus Vand. The following table provides the estimated area required for various components of a sludge to energy plant:

Table 21: Area required by various components and buildings for sludge to energy conversion

S.no	Component/building	Area/volume
1	Primary settling tank	486 m^2
2	Primary sludge concentration tank	16 m^2
3	Septic sludge concentration tank	82 m^2
4	Pre-dewatering unit	3 m^2
5	Digested sludge storage tank	87 m^3
6	Digester	3,300 m^3
7	Gas storage tanks	1,600 m^3
8	Gas engine	100 m^2
9	Torch	400 m^2
10	Side stream de-ammonification tank	400 m^3

Source: Aarhus City Council

List of data: The Aarhus City Council also provided a list of data that will form the technical basis for establishing a sludge-to-energy plant in Udaipur. This data should be gathered as a part of the detailed feasibility study to be conducted by the UMC. The list of important parameters has been provided in the table below:

Table 22: Data to be incorporated in detailed feasibility study

Media	Parameter
Wastewater inlet (Flow proportional analysis for each of the 4 STPs)	Flow (seasonal)
	BOD (in Denmark BOD5)
	COD
	Total nitrogen
	Total phosphorous
	Suspended solids
	Flow (seasonal)

Media	Parameter
Wastewater outlet (flow proportional analysis for each of the 4 STPs)	BOD (in Denmark BOD5)
	COD
	Total nitrogen
	Total Phosphorous
	Suspended solids
Sludge from STP	Volume (daily, monthly, yearly)
	Dry matter, %
	COD
	BOD (in Denmark BOD5)
	Biogas potential incl. methane, %
	Lower heating value (NHE)
Sludge from septic tanks	Volume (daily, monthly, yearly)
	Dry matter-%
	COD
	BOD (in Denmark BOD5)
	Biogas potential including methane, %
	Lower heating value (NHE)
Sewer catchment area	Mapping of sewer catchment areas for the four STPs
	Mapping of sewer pipelines connected to the four STPs
	Mapping of septic tanks (if available)

Source: Aarhus City Council

Sludge-to-energy conversion techniques: During our discussions with the officials of Aarhus City Council, Royal Danish Embassy and Aarhus Vand, it came to light that there are many technologies used for sludge-to-energy conversion. The advantages and disadvantages associated with these technologies have also been highlighted below:

- Decomposition: The technique requires the availability of large land for the activity to take place. It impacts the quality of groundwater. The technology has a high carbon footprint, as a significant amount of methane gas is released during the process.
- Combustion: The combustion technique involves high temperature oxidation of sludge to obtain heat, carbon dioxide, water vapour and other traces of gases. The heat generated can then be used for heating or generating electricity. The space requirement for the process is low. The process generates a high amount of ash and the management of this ash is difficult due to its light nature. The combustion process requires significant amount of energy for the process. Due to the increased energy requirement, the carbon footprint of the technology increases.
- Digestion (Biogas): Digestion is a biological conversion method, which is widely used due to its low cost and ability to utilise organic waste with high moisture content without reducing the high calorific value of the produced biogas (a combination of methane and carbon dioxide). The biogas obtained from the digester can be cleaned and further upgraded to produce bio-methane, which can be a direct substitute

for natural gas or the biogas can be converted to heat and electricity via cogeneration using thermal reactors. The process is technology intensive and requires technically trained staff for operation. The quality of sludge is important for the efficient operation of the process. The potential of biogas increases in case of fresh sludge. Further, the digestion (or biogas) process requires constant temperature monitoring for the energy conversion process to be effective.

13 Annexure 3: Effluent Discharge Standards - India

The Ministry of Environment, Forest and Climate Change, India as per gazette notification dated October 13, 2017 specified the effluent discharge standards for sewage treatment plants. These standards however were recently scrapped by the National Green Tribunal[34] and it ordered a reversal to stricter norms proposed by Central Pollution Control Board in 2015. These standards are now applicable for all existing and upcoming STPs in the country. The effluent discharge standards as per the November 2015 draft notification of Govt. of India are tabled below:

Table 23: Effluent Discharge Standards for Sewage Treatment Plants in India

Standards	Concentration not to exceed
pH	6.5-9.0
Bio-chemical oxygen demand (BOD)	10
Chemical oxygen demand (COD)	50
Total suspended solids	20
NH_4-N	5
N-Total	10
Faecal coliform (FC) **Most probable number per 100 millimetre, MPN/100ml**	<100

Source: www.indiaenvironmentportal.org.in/files/file/Draft%20notification%20of%20Sewage%20Treatment%20plan.pdf

[34] *https://www.downtoearth.org.in/news/waste/ngt-scraps-2017-ministry-note-easing-sewage-treatment-norms-64317*

14 Annexure 4: Technical components of STP

Technical components: The UMC shared a SOP document prepared by Thermax India, which is an engineering company involved in energy and environment projects. Thermax signed an agreement with Udaipur Smart City Limited in June 2017 to set up a 25 MLD STP. The SOP gives technical specification of the components that should constitute a STP based on the MBBR technology, which have been provided in the table below:

Table 24: Technical components of Udaipur STP

Components	Capacity (in side water depth, SWD)	Description
Receiving chamber	3.4m*3m*1.2m	Collects raw sewage from the sewage system
Raw sewage collection sump	12.6m*2.8m	Mixes organic particles in raw sewage sump
Stilling chamber	4m*4m*4.5m	Settles big grit using water turbulence and pressure control
Step fine screens and manual screen	1.3m*5m*1.5m	Removes grit particles which are more than 6mm in size
Grit separator channel	7.4m*7.4m*0.7m	Removes silt and add backs organic particles
Flow division box	4.2m*2.5m*2.5m	Maintains flow of discharged water for normal plant operations and sends excess water in buffer tank
Oil and grease chamber	8.4m*4.4m*2.5m	Traps free floating oil in raw sewage
Anoxic tank	23.7m*5.6m	Helps in biological reduction of nitrate to nitrogen gas and organic carbon to CO2
MBBR	26.8m*5.6m	As described in previous section
Flash mixer	2.7m*2.7m*2.8m	Chemicals such as Ferric chloride and poly electrolyte are mixed
Recirculation pump	-	Provided for recalculating the flow from the recirculation sump to anoxic tank
Clarifier tube flocculator	22.4m*3.75m	Removes suspended solids and sludge are separated
Sludge sump	11.5m*2.2m	Sludge is received from clarifier using two pumps and is fed to a centrifuge
Rapid gravity sand filter	-	The function of rapid sand filter is to remove floc and suspended substances contained in settled water. Filtration is the final treatment process to gain drinking water quality by removing impurities and suspended particles.

Source: UMC

Chemical dosage calculation: As per the SOP document of the 25 MLD STP, submitted by the UMC, following chemicals are used in daily operations of the STP. These chemical are added during the treatment process for various reasons such as pH correction, absorbing finely divided solids and colloids, etc. The chemicals with their dosage have been provided in the table below:

Table 25: Chemical dosage calculation for STP operation

Chemical	Nature of chemical	Capacity of tank	Chemical concentration	Chemical consumption	Chemical dosage (PPM[35])
Lime	pH correction	1,500 liters*2	5%	200 kg/day	5
Ferric Chloride	Coagulant	2,500 liter*2	10%	687.5 kg/day	20-25
Poly electrolyte	Flocculent	2,150*2	0.5%	27.5 kg/day	1
HCL	pH correction	500 liter*2	100%	416 kg/day	5
Chlorine gas	-	-	2.5%	5-6 kg/hour	5

Source: UMC

[35] *PPM-parts per million*