CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF CIVIL ENGINEERING


# STRATEGY FOR A WIDER MARKET ADOPTION OF GREYWATER REUSE SYSTEMS IN THE US

MASTER'S THESIS


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Prohlašuji, že jsem předloženou práci vypracoval samostatně a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o etické přípravě vysokoškolských závěrečných prací.

Místo vypracování, datum: podpis:

**English Annotation:**

This paper is the outcome of an international program of Czech Technical University in Prague, Czech Republic and Texas Tech University in Lubbock, TX, United States. The work is focused on market research of existing manufactured on-site greywater reuse systems in the US market context. A qualitative research method was applied with emphasis on interviews with experts from business, academic and administrative sectors. Data was collected from earlier studies from various online sources, academic papers, journals, companies and industry conferences.

Market research of this early stage market is performed and underlying opportunities and threats are identified. Available technologies are evaluated from technical and business point of view. Recommendations are provided for both businesses and regulatory bodies in the sense of overcoming common barriers. The intent is to give an overview of residential water recycling in the US and highlight present-day obstacles.

**Key words:**

Water security, Decentralization, Alternative water supply, Rainwater harvesting, Greywater recycling, Renewable energy

**Česká anotace:**

Práce je výsledkem mezinárodního programu Českého vysokého učení v Praze a Texas Tech University v Lubbocku. Práce je zaměřena na průzkum amerického trhu s výrobky pro recyklaci šedých vod v rezidenčním a komerčním odvětví. Zdrojem pro průzkum jsou rozhovory se zástupci podnikatelského, akademického a veřejného sektoru a také autorův průzkum vědecké literatury a veřejně dostupných zdrojů.

Práce zahrnuje průzkum trhu a identifikuje příležitosti a překážky v tomto rozvíjejícím se průmyslu. Dostupné technologie a komerční výrobky jsou vyhodnoceny z hlediska jejich technologie a šanci úspěchu na trhu. Autor v závěru práce doporučuje řešení pro překonání tržních překážek a navrhuje strategii pro aspirující podnikatelské subjekty. Záměrem je poskytnout komplexní přehled o aktuálním tržním prostředí v oblasti rezidenční recyklace vod ve Spojených státech amerických.

**Klíčová slova:**

Zásobování vodou, Decentralizace, Alternativní vodní zdroje, Využití deštových vod, Recyklace šedých vod

# List of definitions

**Greywater**

Greywater is water generated from washing foods, clothes and dishware, as well as bathing. Greywater accounts for approximately 65% of the wastewater produced in households with flush toilets. (Tilley et al. 2014)

**Blackwater**

Blackwater is the mixture of urine, faeces, flush water and/or dry cleansing materials. Blackwater contains both pathogens and nutrients from feces and urine that are diluted in the flush water from toilets. (Tilley et al. 2014)

**Rainwater**

Rainwater is rain that has not collected soluble matter from the soil and is therefore soft and absent of minerals. Rainwater is typically harvested only from the rooftops.

**Stormwater**

Stormwater is rainwater that meet the ground and can be contaminated (oil, soil).

**Membrane bioreactor**

A Membrane bioreactor (MBR) is a combination of a membrane process like microfiltration or ultrafiltration with a biological wastewater treatment process, the activated sludge process. It is widely used for municipal and industrial wastewater treatment (Judd 2006).

**Ultrafiltration**

Ultrafiltration is a type of membrane processes. It uses water filtration to separate particles when the solution passes through the bulkhead - membrane. Ultrafiltration has typical porosity in the order of tens to hundreds of nanometers.

## Laundry to Landscape

Simple greywater system without any treatment and storage. Water goes directly from source to subsurface irrigation.

# List of abbreviations

| | |
|---|---|
| BW | Blackwater |
| GW | Greywater |
| RW | Rainwater |
| SW | Stormwater |
| L2L | Laundry to Landscape |
| WWTP | Wastewater treatment plant |
| MBR | Membrane bioreactor |
| WBBR | Water budget based rate |
| NSF | National Sanitation Foundation |
| LEED | Leadership in Energy and Environmental Design |
| LBC | Living Building Challenge |
| P2P | Peer to Peer |
| ROI | Return on Investment |
| CBA | Cost benefit Analysis |

# Table of contents

# 1. Introduction

Introduction section consists of 5 subsections. The first subsection explains the reason and motivation behind this work. The history is wastewater treatment is briefly explained and author explains his inclinations to study this particular topic.

The second section defines the objective of this work followed by section 3, where author explains why is it necessary to address the issue.

Section 4 explains the purpose of the work and defines the specific goals of this research.

In the last subsection, author describes how he approached the work from methodic point of view.

## 1.1. Background and motivation

This master's thesis is focused on determining an ideal strategy for wider market implementation of systems for decentralized onsite wastewater recycling, also called greywater systems. To understand the motives for this particular research, we first need to understand the author's background and the brief history of water treatment.

The author has a Bachelor’s degree with a specialization in water treatment and water management. He has remained in the water industry since graduation. One reason why he finds water engineering and industry so fascinating is the astonishing underestimation of the real price of water. Fresh water is a vital resource for the survival of our population. Despite that, quality drinking water in western societies have become something so abundant, people take it for granted and fail to realize its real value.

Less than two centuries ago, cholera outbreaks and water related diseases were so common, the only truly safe way of drinking safe water was in the form of processed beverages like beer or from high mountain streams. The water industry has advanced significantly since then and people have forgotten the real price of potable water. As a consequence, we are wasting this resource like never before. Drinking quality water is used to flush our toilets and irrigate gardens. Not only is this unsustainable, but in some cases also undesirable.

The author's motivation is to combine his background in engineering, business and entrepreneurship to address the current market situation of domestic wastewater recycling. The objective is to identify barriers and propose solutions for overcoming them. The author wants to implement his knowledge from the European market and learn from the US market experience.

This author has decided to focus on a specific geographic region of United States. Currently, the largest incentive to saving water is to reduce water bills. The United States is in a unique position because they can already feel the effects of the drought in some states and have effectively started changing regulations and legislations. The United States have a higher purchasing power, compared to other drought affected areas in the world, and therefore provides an ideal environment for the generation of various water recycling technology startups.

## 1.2. Objective

The main objective of this work is to determine why the current market for domestic systems for the recycling of greywater is not more developed. The intent is to identify technical, legislative and business barriers and propose the most suitable technology and business model for a wider implementation of these systems in the United States. In other words, what does one need to know in order to start a GW business in the US?

## 1.3. Problem statement

The United Nations has addressed the global water crisis and have prioritized water and sanitation as goal number six of its sustainable goals (United Nations 2015).

Estimates indicate that world demand for fresh water will exceed supplies by 40 percent by 2030. In this year, 3.9 billion people — almost half the world population — may live in areas of "severe water stress" (Agency 2013).

According to the World resources institute, there are 7 reasons why the world is facing a global water crisis (Schleifer 2017).

1. Climate change has made dry areas drier and precipitation more variable and extreme
2. A growth in the human population results in increased demand
3. Groundwater is being depleted
4. Water infrastructure is in a dismal state of despair
5. Nature infrastructure is being ignored
6. Water is wasted
7. The price of water is low, water is seriously undervalued

Domestic greywater recycling is not a solution that would solve all water crisis problems, but will certainly help to achieve more sustainable water management and the reduction of potable water wasting. Greywater directly addresses problem of increasing demand, aging water infrastructure, water wastage and respects the nature infrastructure and environment. It can also help to slow down groundwater depletion and thus effectively fight with US drought problems and water crisis.

While the biggest water users are the agricultural and industrial sector (see Figure 1) this paper is going to focus on the domestic/residential/municipal sector. There are three main arguments why municipal sector is worth our attention.(Mohsenin 2016)

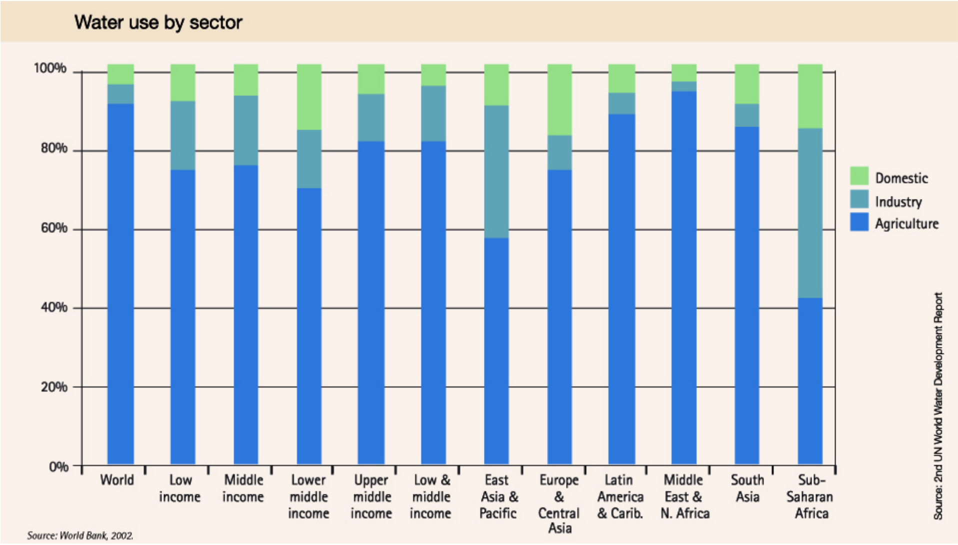



Figure 1: Water use by sector and location (Parker 2010)

Municipal water demand, unlike other water demand is projected to increase. Agricultural, industrial and livestock industry are taking steps to reduce their water consumption, however we do not see similar steps in the case of municipal sector. Water demand projections for the state of Texas show clearly how substantial problem is this becoming (figure 2).

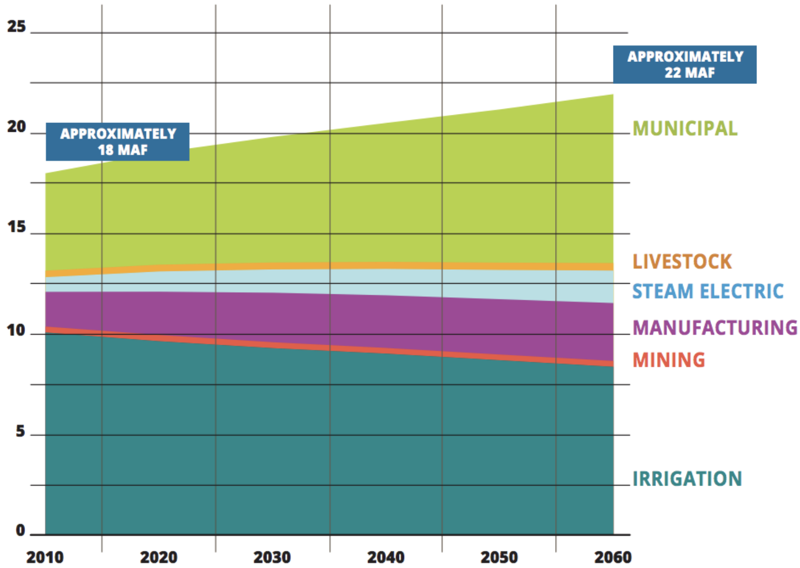



Figure 2: Texas water demand projections, 2010-2060 (Combs 2014)

Other species rely on freshwater besides humans as a vital component to their survival. Overuse of freshwater in household settings result in less fresh water for agricultural use (this affects humans on a food scarcity level), but many livestock species rely on freshwater.

From an ecological point of view, increasing our demand for water (as population and standards of living increase globally), means that we need to supplement for this lack of freshwater by pulling it out of aquifers or groundwater supplies in which their regeneration rate is lower than the extraction rate. This unsustainable practice decreases long-term water security and availability.

From an energy point of view, wastewater takes a lot of energy, time and money to make it drinkable again. Wasting water means wasting energy need for this intensive process of treatment and distribution. The many steps of this process—extraction, transportation, filtration, etc.—require non-renewable fossil fuels and as these resources become depleted, their dangerous by-products such as carbon dioxide build up in the Earth's atmosphere, contributing to your carbon footprint and the Earth's rising temperature.

The points above demonstrate the need for addressing the residential sector and its increasing role in sustainable water management. The approach how to address this problem are is further discussed in the following section. (section 1.4.)

## 1.4. Purpose

The most efficient and fastest way to adopt domestic household recycling systems is through economic, market and public incentive. If society starts perceiving water recycling not only as environmentally friendly technology, but also as economically friendly, the use of these systems will increase dramatically.

Therefore, the purpose of this paper is to explore the market environment and opportunities for innovation in the field of domestic wastewater recycling. The author compared existing technologies on the market and evaluated them from a technical and business point of view.

The big picture of this thesis is to contribute to a solution of water crisis by gathering data and suggesting a "blueprint" model for existing and aspiring companies in the greywater field.

Specific goals of this research can be defined as:

1. Evaluation and comparison of available domestic greywater systems on the US market

   There are various technologies available for GW treatment. Companies have number of approaches which one to choose depending on their target sector. The objective is to give a reader overview of the technologies available on the market as well as systems which are commercially available. Each system has some advantage and disadvantage. Author will summarize features of the systems and practical experience using them.

2. Identification of market barriers and suggestion of a business model for a wider market adoption

   GW industry is faced with many challenges and market barriers for implementation. The author will identify both barriers and drivers to this market and will provide his opinion on how to take advantage of them. The business model is created with business perspective in mind. However, the paper provides suggestion for administrative and academic sector as well. The summary of the suggestions ranked according to the specific areas can be found in section 3.4.

## 1.5. Methodical approach

The work is based on author's observations, literature research and experience with working in the wastewater industry. Based on the observations, several research questions came to surface. Why are we still using potable water for non-potable purposes? Why are people generally not keen to on-point water reuse and management? And why are companies struggling to install water reuse systems in new households?

Author had an idea how to address this questions from the European perspective but wanted to research the situation in the US and the practical experience of professionals working in this industry. To the best of authors knowledge, there is not any comprehensive overview of this particular industry and thus the reason for creating this paper.

A questionnaire was developed to test if certain predictions are correct. The questionnaire consists of rank scale questions, binary questions and open-ended questions and is explained in detail in section 3.1. The objective is to gather data from businesses, non-profit organizations, academic figures and public authorities and to confirm or reject the hypothesis. A general theory of the best approach to the market and recommendation will be the outcome of this work.

# 2. Theory & Current state of art

Section two explores the literature and the current stage of knowledge on GW system. In the first section GW is defined, categorized depending on their complexness and its use is demonstrated in form of example. Section 2 gives overview of the most used technologies for the treatment and identifies their advantages and disadvantages. Centralized vs decentralized approach to water and wastewater management is discussed in the section 3. Section 4 summarizes legislation and regulations that have a direct impact on residential wastewater recycling.

## 2.1. Greywater system

Greywater (GW) is untreated wastewater that has not been contaminated by feces. In the household scale, it means wastewater from bathtubs, showers, bathroom washbasins, clothes washing machines and laundry tubs.(Alexander & Clark 2016)

Studies (D. Butler 2006) (Pidou 2007) (Donner et al. 2010)   show that between 50-70% of total wastewater produced in households can be treated and reused for irrigation, or toilet flushing. (see Figure 3) The remaining 30-50% is defined as Black water - water containing fecal matter and urine, also known as foul water or sewage.

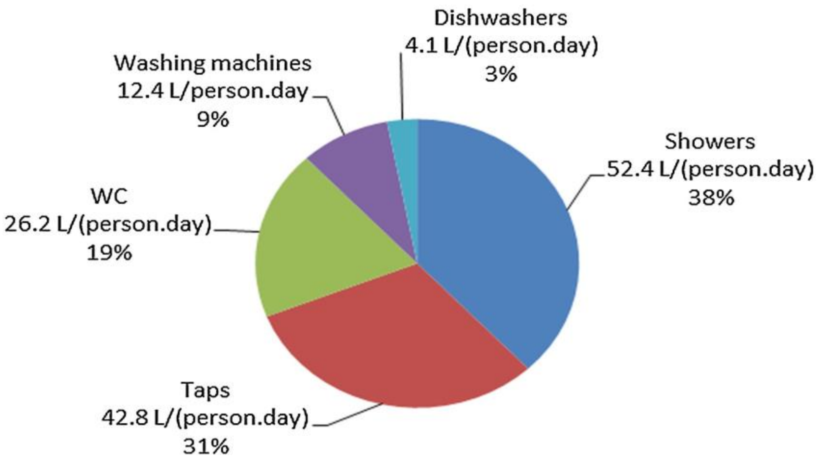



Figure 3: Average household water consumption (Vieira et al. 2017)

In a typical US household of 3-4 inhabitants GW is treated as wastewater and goes straight into the sewer system. The tenants are then being charged for it in the form of the sewer charge. Figure 4 depicts the water consumption in a household for 1 showers and 11 uses of toilet.

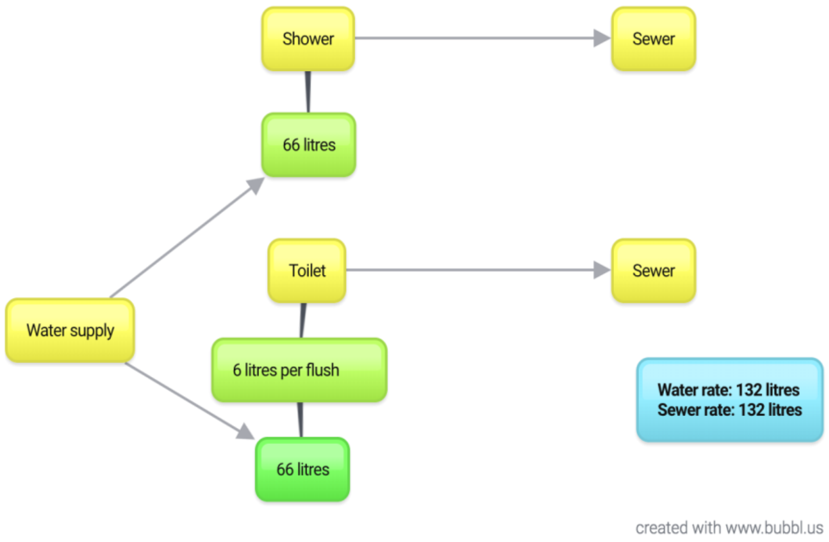



Figure 4: Toilet and shower consumption - without GW system

Typical shower water consumption for an average American is 17.2 gallon (66 litres). (NFP 2017) Modern US toilets use typically around 1.6 gallons per flush (6 litres).(NFP 2017) That means that that one shower can provide enough greywater for six toilet flushings. Figure 5 shows the same scenario but with the use of GW system.

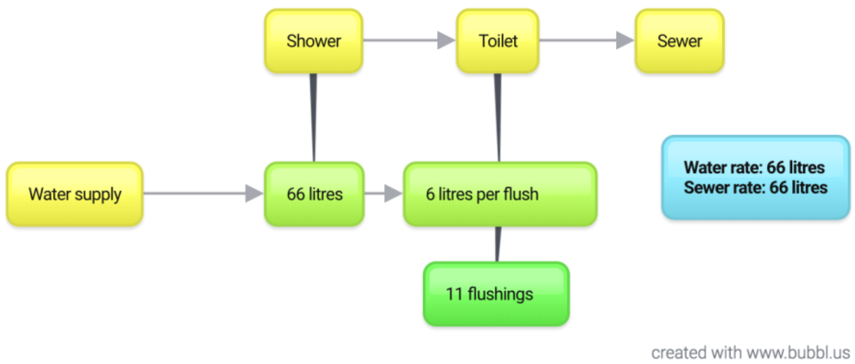



Figure 5: Toilet and shower water consumption - with GW system

There are ways how to recycle GW and thus save for both water and sewer rates (as depicted in figures 4 and 5). GW is very lightly contaminated and if used straight away, does not pose any health danger. The problem is with storing such water. Storage causes bacterial growth which makes water potentially dangerous if exposed to human contact.  Since typical household water use requires certain periods of water storage, treatment systems are usually required to treat the water. The quality is usually determined by the following criteria:

- Biochemical Oxygen Demand (BOD)
- Total Suspended Solids (TSS)
- Turbidity
- Fecal Coliform
- E. Coli
- Chlorine Residual

The contamination is highly case specific and depends on many factors such as water source, water usage patterns or detergents used. A good working GW system treats water to a quality perfectly acceptable for non-potable use. More about required parameters in section 2.4.

There is a variety of technologies that can be used for greywater recycling, ranging from very primitive to sophisticated systems. GW systems can be divided into three categories.

### 2.1.1. Laundry to landscape systems

Simple systems, that do not use any storage and diverts water straight to the irrigation system. This system cannot be used for different purpose than subsurface irrigation. A schematic picture of this system is depicted in figure 6.

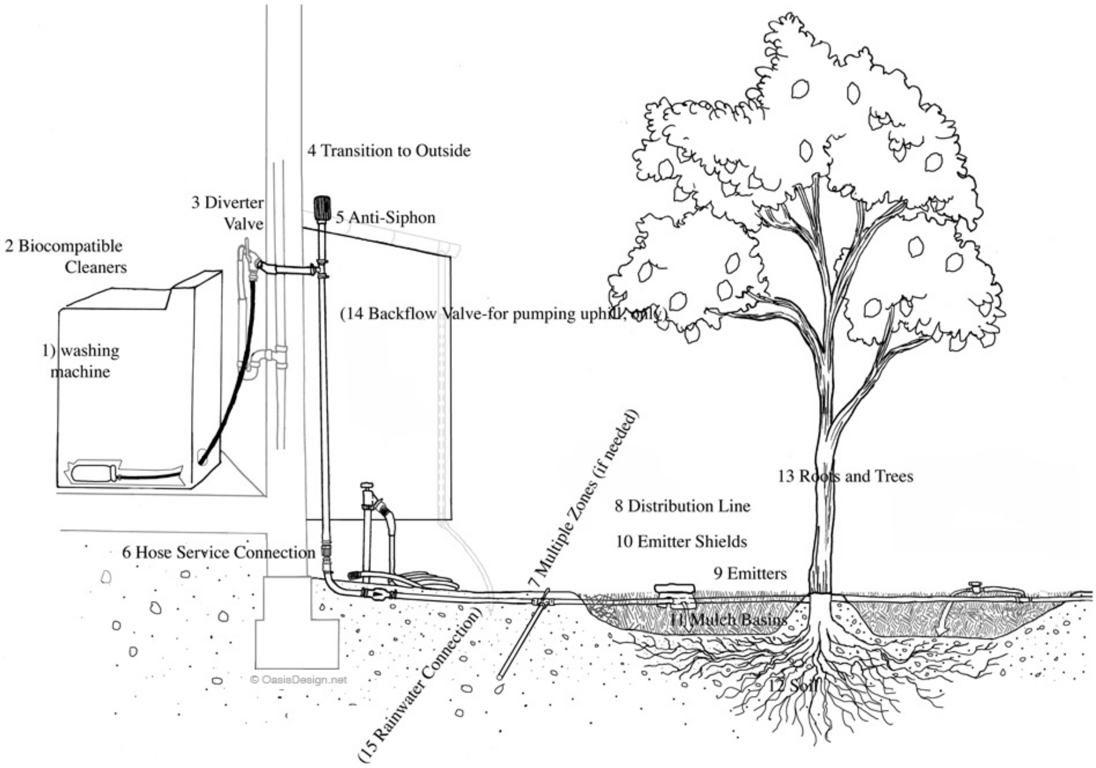



Figure 6: Laundry to Landscape system (Ludwig 1999)

Such systems have been called “Laundry to Landscape systems” are the least expensive, lowest effort kind of GW systems. This particular system diverts water from washing machine to subsurface irrigation system.

### 2.1.2. Simple systems with storage and basic treatment

These systems usually utilize basic coarse filters and chemicals. The filter can be a combination of coarse sand, gravel filter or reed bed (see figure 7). Chlorine tablets or UV disinfection is sometimes used for additional disinfection.

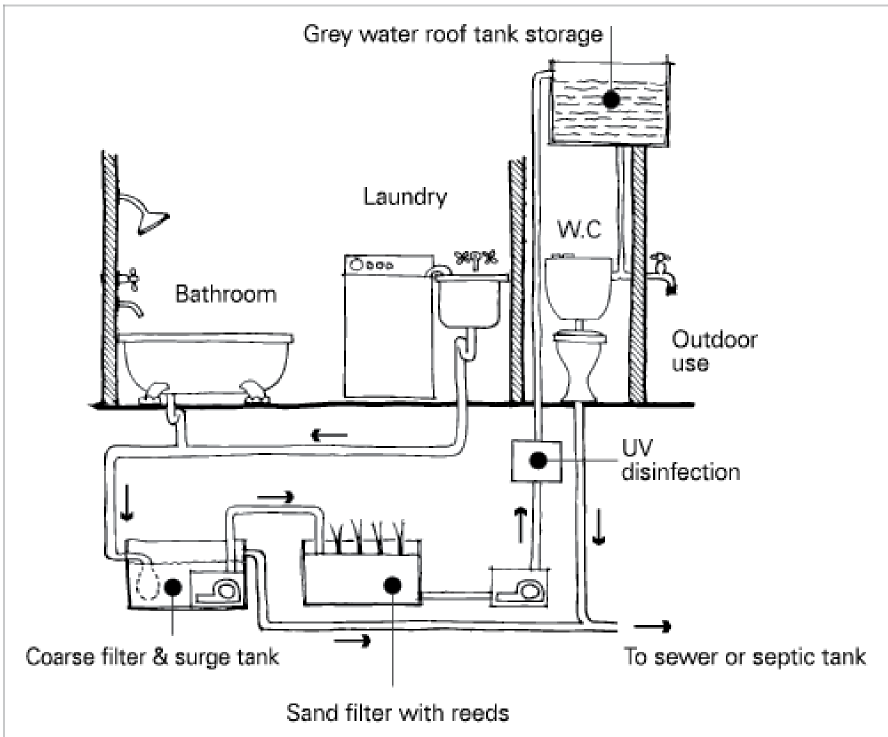



Figure 7: Simple GW system with storage

Simple systems are a good solution for subsurface irrigation purposes but should not be used for surface irrigation or inhouse water use. The long-term use of such systems usually leads to variety of quality problems like water coloration, unpleasant odor or slimy appealing water (Bill Kuru 2012). System shown in figure 7 is using simple coarse and sand filter followed by UV disinfection. The water is later pumped and stored in a designated container. In this case on the roof.

Systems above are usually installed without any permission and belong into do it yourself category (DIY). If precautions are taken, these systems are perfectly fine for subsurface irrigation but are not safe when exposed to human contact. According to Laura Allen, the state of California alone has around 1.7 million systems installed without permission.(Allen 2015)

### 2.1.3. High-end treatment technologies

The third category are high tech manufactured GW recycling products. These products are usually certified and use combination of treatment processes that treat the water to a level at which it is safe for any non-potable water reuse.

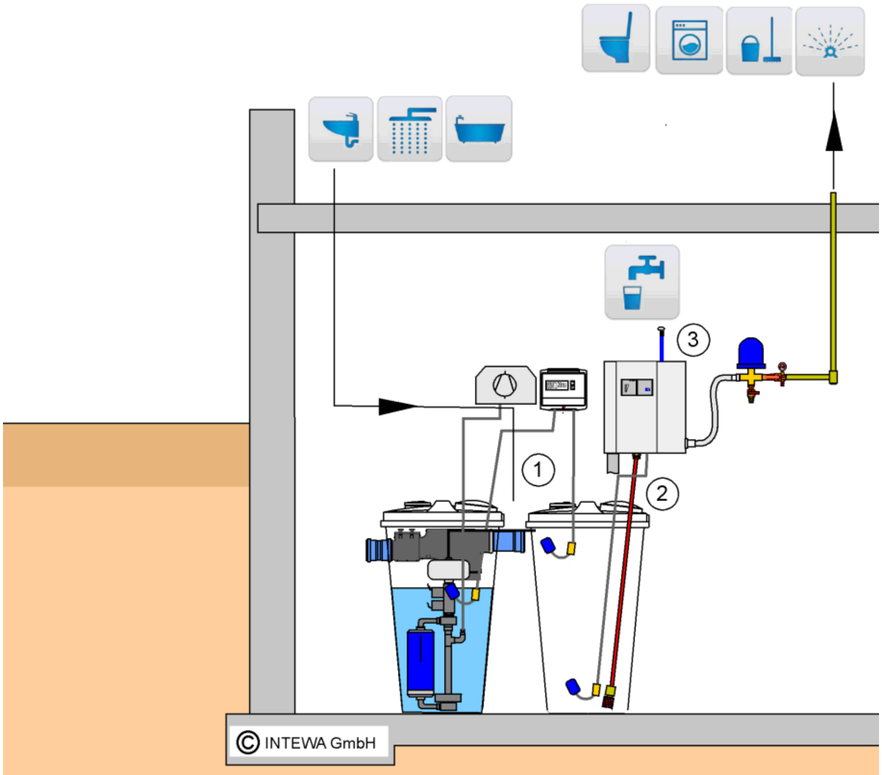



Figure 8: High-Tec treatment system with biological treatment and membrane filters (Ringelstein 2017)

The system shown is figure 8 is an example of a MBR system. Water undergoes biological treatment and passes through microfiltration membrane. Treated water is then stored in the collection tank from which it is pumped for further use.

Manufactured GW products approached the US market with various degrees of success. According to Laura Allen, author of The Water-Wise Home (Allen 2015), the greatest challenge is that greywater systems differ depending on use and there is not one-size-fits-all solution. In the case of commercial construction, each system needs to be engineered for a specific situation. In smaller residential sectors, treatment systems can be universal, but the installation due to the duo plumbing requirements is again highly individual.

It is clear, that a major part of a typical household water use can be reused and there are number of options available. In this work author will focus only on more sophisticated methods (i.e. category 3 systems) that can be used in applications where human exposure is likely, such as in case of flushing toilets or spray irrigation systems.

## 2.2. Greywater treatment

A good GW system need to remove potentially harmful elements in water as well as removing contaminants encouraging biological growth or causing odor issues. The typical system consists of collection tank, treatment technology, treated water collector and pump (see figure 9)

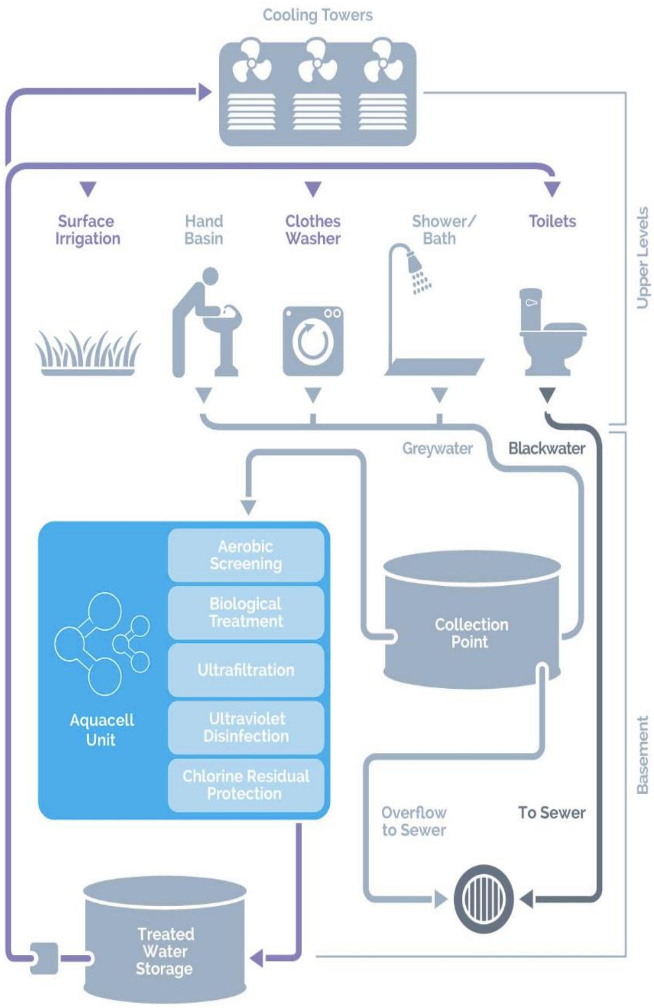



Figure 9: Scheme of a typical GW recycling system (Phoenix 2009)

The best performance is achieved by combination of different technologies to ensure effective treatment of all fractions. The most common combination of technologies is shown in table 1.

| Technology | Description |
| --- | --- |
| SYSTEM 1<br><br>Filtration and Chlorination<br><br>Most simple system; a similar process to the process used in swimming pools.<br><br>PRICE: ~$2,600 | + Suitable for low strength water<br>+ Single collection tank<br>- Residual chlorine in effluent<br>- Monthly consumables<br>- Physical treatment demonstrates poor removal of organics and solids |
| SYSTEM 2<br><br>Advance oxidation $H_2O_2$ + UV<br><br>Hydrogen peroxide in introduced, final product goes through ultraviolet radiation<br><br>PRICE: ~ $4,500 | + Effective removal of chlorine resistant Cryptosporidium to prevent biological growth<br>+ Single collection tank<br>+ Almost no maintenance<br>- Monthly consumables<br>- Does not remove organic matter sufficiently |
| SYSTEM 3<br><br>Chemical reactor + UV<br><br>PRICE: ~ $6,000 | + Effectively removes solids, organics and surfactants in light greywater<br>- Poor performance with mixed and dark greywater with high organic content<br>- Residual chemicals<br>- Maintenance<br>- Price of chemicals<br>- Ventilation and storage of chemicals needed |
| SYSTEM 4<br><br>Biological with media filter<br><br>Same as MBR but replaces expensive membrane filter with sand and granulated carbon. Final step remains UV radiation.<br><br>PRICE: ~ $5,000 | + Non-expensive<br>- Does not satisfy quality requirements - does not remove suspended solids completely<br>- UV bulb replacements<br>- Multiple tanks |
| SYSTEM 5<br><br>Membrane Bioreactor (MBR) | + Natural based system<br>+ Biological treatment - not expensive |

| | |
|---|---|
| Bacteria growth in aerated environment and consume pollutants. Effluent is filtered through ultrafiltration membrane. The final step is UV light radiation.<br><br>MBRs are widely adopted in other application in wastewater industry.<br><br>PRICE: ~ $7,500 | + Aerobic treatment is recommended for high organic matter<br>+ Small footprint<br>- Maintenance issues<br>- Expensive membrane replacement<br>- Complicated membrane regeneration<br>- Temperature dependent<br>- Occupancy dependent<br>- Sensitive to influent changes<br>- Multiple collection tanks<br>- UV bulb replacements |
| SYSTEM 6<br><br>Hybrid MBR system (Mix of rainwater and greywater)<br><br>PRICE:~ $10,000 | + Present the highest water saving potential<br>+ Shortest payback period<br>+ Offsets the seasonal nature of rainfall<br>+ May extend life of filter media and membranes<br>+ Less sensitive to occupancy<br>+ Reduction<br>- Larger collection tanks |

Table 1: Overview of systems for greywater treatment

There has been a number of studies that have evaluated performances of different technologies for long-term use. For example, Kohler has conducted a study on residential greywater systems for indoor use and how they impact toilets over time (Bill Kuru 2012). The team operated four different greywater systems, namely systems 1,2,4,5 (Table 1) over a one-year period and measured water quality, user experience, function and costs. The test reported that more simple systems have maintenance issues and performance problems, while better functioning ones are too expensive. The most suitable system in terms of water quality, operation costs and maintenance was MBR reactor (Bill Kuru 2012).

The biggest factor influencing price are membrane, sizing of tanks, UV bulbs and equipment (such as pumps and control panels). The highest price is typically the treatment system followed by the costs for installation and eventually permission costs. The price shown in table 1 does not include the price of installation, piping and permissions which is further discussed in section 3.4.5. The price information is based on the prices of the commercially available systems (section 3.2.5.). Author has decided not to perform economic evaluation of the investments because it is highly case specific.

In terms of water quality, simple technologies (Systems 1-4) achieve only a limited treatment whereas use of submicron membranes shows a good removal of the solids but poor results with organic fraction.

Biological treatment (Systems 5,6) achieve generally good results, particularly great removal of organic matter.

Chemical systems (System 3) show promising results when treating water with shorter retentions times. The system is not able to achieve sufficient micro-organism removal without a disinfection stage.

Information on Life Cycle costs and Total Energy requirements is scarce. CBA (Cost benefit analysis) analysis for residential systems was previously studied by (Yu et al. 2015). In the case of larger applications, MBR is the most favored due to its smaller footprint, lower energy consumption and good treatment results. Commercial buildings also have facility personnel to take care of maintenance tasks including: monitoring, UV bulb replacements, chemical refilling, media filter replacement or membrane regeneration.

In case of residential application, MBR has its place as well, but faces several problems (table 1). Mechanical and chemical based systems could be an alternative choice. These systems are generally cheaper, require less maintenance and are not sensitive to changes in influent, compared to biological based systems. However, the quality of the treated water does not currently comply with the requirements of national standards (more discussed in section 3.4).

The consensus in the literature and case studies is that MBR based systems are the only kind of GW systems in terms of water quality over long time use.

## 2.3. Centralized vs decentralized system

Decentralization is a big topic in wastewater treatment because of aging infrastructure and the costs associated with it. Before 1850, there were decentralized systems or no fluid system at all. Water “treatment” of that time was dilution into receiving waters. In many countries, this procedure is still typical. Centralization was a sensible choice to protect the health of the people, especially with rapid population growth. But with aging infrastructure and related costs there is a need to start looking for alternative solution. In the past the goal, was to divert as much water from the household as possible. Now, we see a trend towards water detention and local water management.

There have been a number of studies comparing conventional centralized water treatment with a decentralized one. (Roefs et al. 2017) shows that greywater separation, treatment and usage can be competitive to conventional systems even on district level. Centralized systems benefit from the economies of scale, however the transport and aging infrastructure begin to show as a problem. Ariamalar Selvakumar in his technical paper (Selvakumar & Tafuri 2012) states that “the average rate of system rehabilitation and upgrading is not adequate to keep pace with increasing needs, quality demands, and continually deteriorating systems”. Furthermore, studies (Maurer 2009; Wang 2014) show that under uncertainty and urban growth, the idle capacity and costs of traditionally designed wastewater treatment plants are higher than those of decentralized systems, which can grow incrementally. Therefore, by designing in smaller units the financial risk can be significantly reduced.

Greywater recycling itself also is not anything new. Archaeologists have discovered Greywater reclamation used over 3,000 years ago in Babylon, other Mid-Eastern regions, and some Asian communities for extending crop growth and drought mitigation(Sedlak 2014) . We do not have to go that far into the history. In Europe, people often enjoy their vacations in cottages built in the woods with no access to engineering networks. We can see very simple GW recycling solutions in these cases. Water is usually diverted from showers and sinks and is used for toilet flushing or irrigation. Usually a simple bucket serves this purpose.

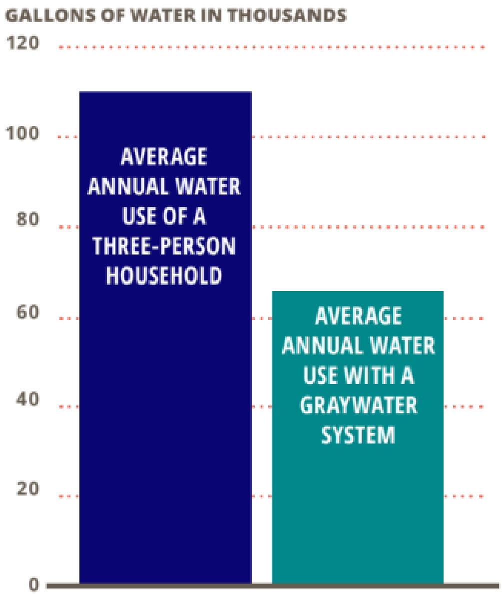



Figure 10: Comparison of water usage with and without greywater system in the US (Combs 2014)

By incorporating source separation and a local greywater treatment and reuse, we can limit the wastewater outflow to only 20% and thus design smaller diameter long distance piping. (Combs 2014)

Already existing infrastructure needs to be taken into consideration. One of the most common arguments against wider implementation of GW systems is that if greywater is eliminated from the sewer systems, sewer plants might not be able to handle the more concentrated product. Sewers are already flowing at a lower level than they were designed for and the metropolitan areas are experiencing issues with a lack of carry because of the lower volume flowing through the channels.

However, there are studies that claim that this is an unfounded concern. The excess rainwater is a problem because it can cause an overflowing sewer plan. There is a study (Eran Friedler 2011) that found out sewer plants function with two large peaks of flows. The large morning flow represents when everyone is getting up, showering, making breakfast, and using the restroom. During the day, the flow drops to relatively low levels and in the evening, another large peak appears. This sinks down to almost no flow in the evening. Sewer plans are working on daily basis with these low flows. If there would be 100% adoption of greywater recycling, the consequence would be the lowering of these peak flows. It would have almost no impact on the current low flow of the day and night.

The bigger problem is connected to the centralization. The sizing of pipes is based on outdated flow predictions and do not reflect the current situation. Residential water in the US has lowered since 80's but the sewer system is still being sized on the same calculations. The problem is thus the pipe size and lack of planning and updating of procedures for planning sewer systems.

There is currently an ambitious project in Australia (PowerLedger 2017) that wants to achieve decentralization of energy and water management. The project, which involves academic, infrastructure and technology partners, will assess how cities can use blockchain technology and data analytics to integrate distributed energy and water systems.

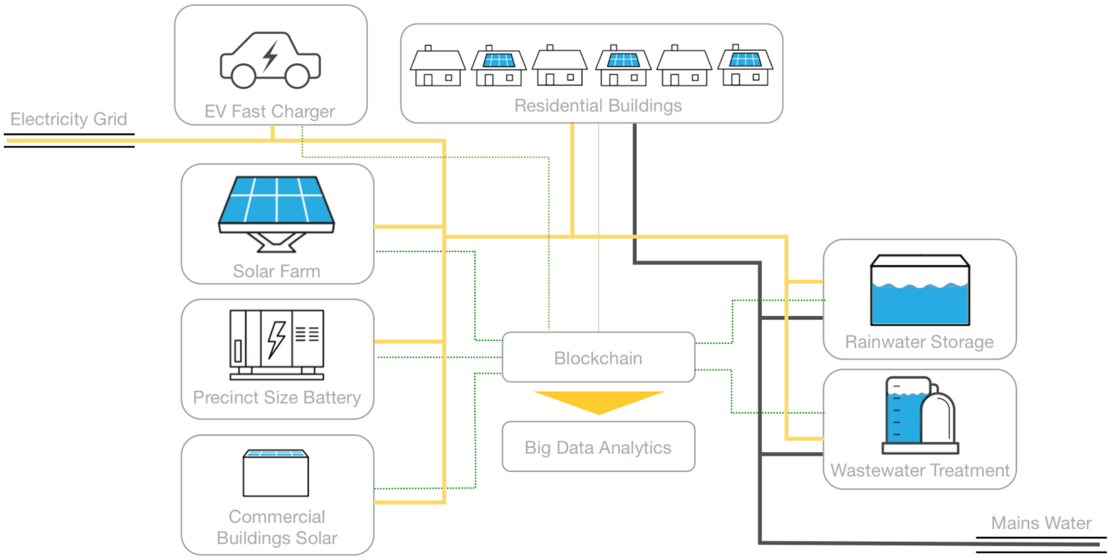



Figure 11: The City of Fremantle project (PowerLedger 2017)

The trial will involve highly resilient, low-carbon and low-cost systems installed and connected using blockchain technology. A large solar photovoltaic (PV) plant, rooftop solar PV panels, a precinct sized battery, an electric vehicle charge station and precinct water treatment and capture systems will be orchestrated using blockchain technology and data analytics, and demonstrate the interconnected infrastructure of future smart cities. Onsite energy generation at water treatment systems will also circumvent the need for costly distribution overhauls. The project will provide the community with financial and service sustainability while still engaging the private sector.(PowerLedger 2017)

From the literature, it can be concluded that the source separated on a point system is viable and suitable from an environmental and energetic point of view and also an economic one.

## 2.4. US Legislation

Two American standards have been developed to address residential wastewater reuse. These are NSF/ANSI 350 and NSF/ANSI 350-1. The NSF determines the water quality results that needs to be satisfied in order to have a safe greywater system.

### 2.4.1. NSF/ANSI 350

Full name: NSF/ANSI 350: Onsite Residential and Commercial Water Reuse Treatment Systems. This option deals with residential (up to 1500 gallons per day) or commercial (more than 1500 gallons per day) sector and was originally adopted in 2011. It covers four different types of influent water - combined black and gray water, gray water only, bathing water only and laundry water only. It covers general non-potable reuse, including toilet and urinal flushing and surface and subsurface irrigation. The standard includes methodology and requirements for testing reuse systems for efficacy. There are two classifications which differs slightly in the quality of the effluent. Class R is supposed to be used for single-family residential application and Class C for multifamily and commercial one (see table 3).

The protocol testing takes 26 weeks involving typical daily loads as well as various stress events (vacations or power failures).(LEED 2017.)

### 2.4.2. NSF 350-1

Full name: NSF 350-1 Onsite Residential and Commercial Greywater Treatment Systems for Subsurface Discharge. The second option is less strict on effluent parameters but can be used only for subsurface irrigation i.e. human contact on any kind must be avoided. It was also adopted in 2011 and was developed with similar approach as NSF/ANSI 350.

| Parameter | Class R | | Class C | |
|---|---|---|---|---|
| | Overall test average | Single sample maximum | Overall test average | Single sample maximum |
| $CBOD_5$ (mg/L) | 10 | 25 | 10 | 25 |
| TSS (mg/L) | 10 | 30 | 10 | 30 |
| Turbidity (NTU) | 5 | 10 | 2 | 5 |
| E. coli[2] (MPN/100 mL) | 14 | 240 | 2.2 | 200 |
| pH (SU) | 6–9 | NA[1] | 6–9 | NA |
| Storage vessel disinfection (mg/L)[3] | ≥0.5–≤2.5 | NA | ≥0.5–≤2.5 | NA |
| Color | MR[4] | NA | MR | NA |
| Odor | Non-offensive | NA | Non-offensive | NA |
| Oily film and foam | Non-detectable | Non-detectable | Non-detectable | Non-detectable |
| Energy consumption | MR | NA | MR | NA |

[1] NA = Not applicable
[2] Calculated as geometric mean
[3] As chlorine. Other disinfectants can be used.
[4] MR = Measured and reported only

Table 3: NSF 350 requirements of effluent quality parameters (Bruursema 2011)

NSF/ANSI 350-1 also distinguish between commercial and residential use and covers the same spectrum of input waters as NSF/ANSI 350. The protocol, test water and water quality criteria are similar as well.

### 2.4.3. Regulation

Regulation regarding reuse can be divided into two categories: Regulations and plumbing codes. Besides keeping with regulation, installing greywater systems typically requires a permit from a county. Uniform Plumbing Code and the International Plumbing Code have adopted reference NSF/ANSI 350.

The state of Washington has adopted NSF/ANSI 350-1. Numerous other states (see figure 12) have adopted or proposed various requirements for the quality of treated reuse water. These requirements vary in scope and cover areas like subsurface irrigation, surface irrigation, toilet/urinal flushing, laundry uses or car washing. (LEED 2017a)

These states are Arizona, California, Florida, Georgia, Hawaii, Illinois, Massachusetts, New Jersey, Oregon, Texas, Washington, and Wisconsin.

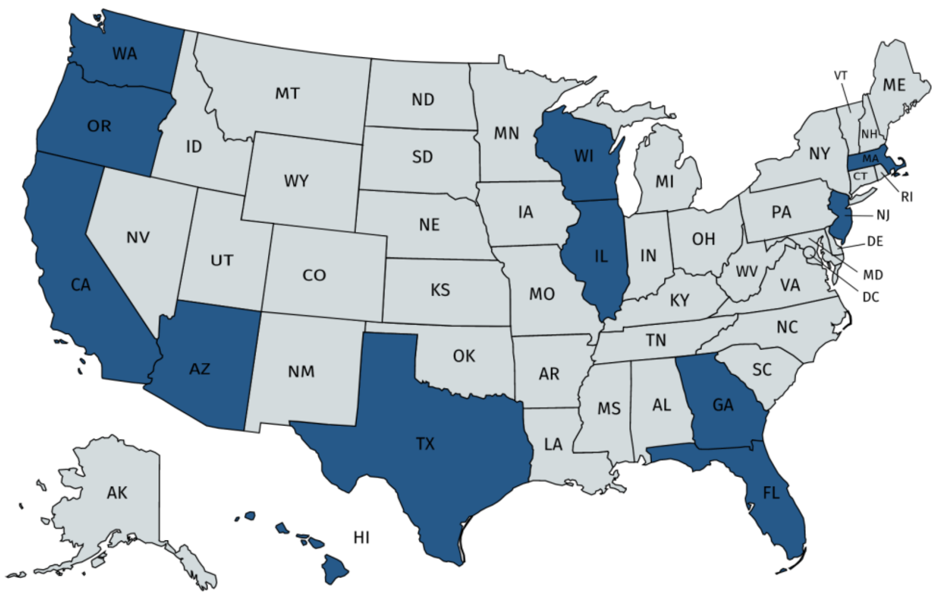



Figure 12: States that have adopted NSF/ANSI 350/350-1 or it's variations

Other states generally follow the U.S. EPA guidelines on wastewater. These guidelines cover toilet/urinal flushing, car washing, surface and subsurface irrigation.

### 2.4.4. NSF Criticism & Regulation compliance

In practice, the approval of GW systems depends on the city and the individuals reviewing the permit. San Francisco, for example, requires the NSF and is tightening their regulations overall. (Yu et al. 2015) However, there is still a possibility of permit even without being in compliance with NSF standards. The system needs to be proven that the system is capable of treating water to a level which is safe for human exposure. Companies try to convince governing authorities - specifically department of health and department of building. This is becoming more and more difficult and for that reason most companies in the industry are working towards getting NSF certification. As for now, there are only three NSF certified GW systems which is giving them a significant competitive advantage. (see section 3.2.5)

Individual jurisdictions can make it extremely difficult even for the simplest systems we encounter extreme difficulties. It is a lack of education and lack of desire to change. (Allen 2017)

# 3. Research

The research section consists of five sections. Overview of each section is shown is table 3.

| Sections | Content |
|---|---|
| 1. Market research method | Description of the research method |
| 2. Market report | |
| a. Market adoption | Market business cycle |
| b. Market size | Description of the market and estimation of its size |
| c. Market Geographics | Describes most attractive US states for GW industry |
| d. Market Segments | Customer segments |
| e. Key Players overview | Profile of the following companies: Nexus-e-Water, Ecovie, Wahaso, Phoenix, Flotender, Greyter Water systems, Biomicrobics |
| 3. Interviews - infographics | Sums up interviews and present results in a form of graphs |
| 4. Discussion of influencing factors | Discusses barriers and opportunities |
| 5. Proposal of business strategy for a wider market adoption | Business strategy for a company interested in engaging in this market |

Table 3: Research section overview

The first section describes the research method used for this work, sources that were used for completion of the research and defines objective of the report.

Section two is the market report which is divided into 5 subsections (content discussed in subsection 3.2). Section three analyses interview results and put them into a graphic representation.

section four discusses important influencing factors. Present market movers and barriers are identified and the author's opinion on how to handle these factors is presented.

The final section (section five) proposes a business strategy for a company who would be interested entering the GW market. This business strategy is based on the all previous sections and data collected.

## 3.1. Market research method

Market analysis is an effective tool for evaluation of the potential of a market. There are many approaches for the research, but a combination of primary and secondary market research technique will be used for this work.

Primary research included interviews with companies and institutions involved in the greywater business. Secondary research approach is used data already analysed by credible sources.  The figure 13 depicts schematic diagram of the data collection for this work.

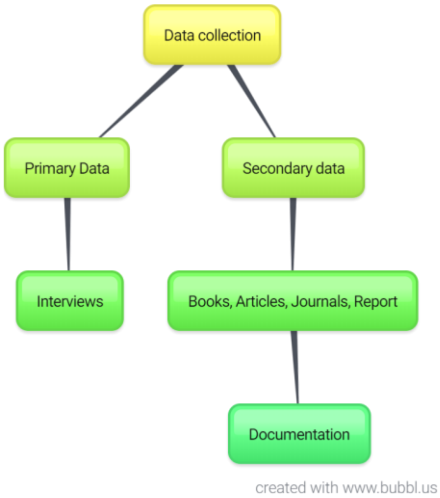



Figure 13: Methods of data collection

This thesis follows a qualitative research approach, which is suitable for business related studies. Qualitative can be described as an "array of interpretative techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency of certain more or less naturally occurring phenomena in the social world" (Cooper & Schindler 2013)

Different forms of techniques are used during the data collection stage such as individual interviews, focus groups or case studies. During the subsequent stages the author analyzed interviews in form of written transcription from previous interviews. This method enables the interviewee to freely express his opinion, ideas and professional experience directly related to the researched topic. The goal of qualitative analysis is deep understanding of the study topic.

Qualitative research draws data from several sources, namely “people (individuals or group); organizations or institutions; texts (published, including virtual ones); settings and environments (visual/sensory and virtual material); objects, artifacts, media products (textual/visual/sensory and visual material); events and happenings.”(Cooper & Schindler 2013)

The objective for my research was to provide a comprehensive view of the current situation in the US GW industry with focus on on-site technologies.

Interviews were conducted via phone and participants were asked industry related questions to evaluate and compare their views of the market. The questionnaire used to conduct these interviews can be found in the in the list of attachments. The list of respondents is included in the list of attachments as well.

## 3.2. Market report

The market reports consist of subsection market adoption, market size and characteristics, market geographics, market segments and key players overview. The first subsection describes the market environment, business cycle of the technology and its parallels to other environmentally focused markets. In subsection two, market size is estimated with emphasis on water recycle industry as a whole. Market geographics will be discussed in terms of legislation, water reuse potential and market environment in subsection three. Subsection three identified market segments and explores them in terms of suitable GW configurations. The last subsection of the market report gives an overview of key players on the US market and their products on the US market.

### 3.2.1. Market adoption

The greywater market is still a very early market (Hitchner 2017). At the moment, no US state can be described as a fast-growing greywater market. Even though the technology is available market acceptability remains low mostly due to number of market barriers. Current companies operating on this market can be described as "early adopters" in the technology market (see figure 14).

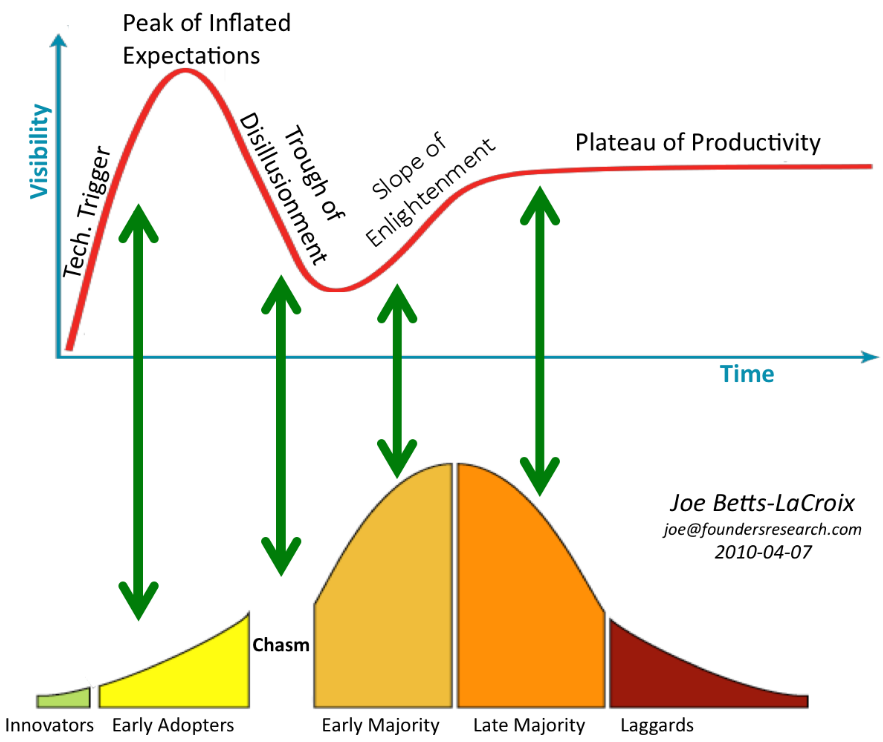



Figure 14: Technology adoption life cycle(Betts-Lacroix 2010)

The market still needs to cross the chasm[1]. In the case of greywater, it would mean acceptance of health community and recycle friendly regulation and legislation. The biggest barrier, however, remains the low price of water and thus non-attractive return on investment. The barriers are discussed more in detail in section 4.4.

[1] Chasm - The phrase comes from Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers (Moore 2014) , It refers to the chasm between the early adopters of the product (the technology enthusiasts and visionaries) and the early majority (the pragmatists). The challenges of this stage include choosing a target market, understanding the whole product concept, positioning the product, building a marketing strategy, choosing the most appropriate distribution channel and pricing.

GW treatment market at this point can be best explained by looking at parallels with solar industry market in the 90s. Both solar panels and greywater treatment systems are onsite environmentally friendly products offering an alternative to centralized solution. In California, there was an active push to make builders to include solars in new homes and there were financial incentives to do so. The regulatory side is similar to GW, but the financial incentives do not yet exist. Solar power in California is a big prosperous market now and the reason is because of a policy that enabled it to grow. We are looking for similar policy in the case of greywater industry.

Air Conditioning in the 1950’s or 60’s is another analogy that can be made. Air Conditioning business is similar to GW in terms of use. In some geographic regions, AC has become a standard because of the climate conditions. In other areas, air conditioning is not needed and will never be needed. The same applies to GW treatment and residential water recycling in general, but the situation has not reached the tipping point yet. Consumers do not see the need for water recycling because potable water is cheap and more convenient. There however will be areas where potable water irrigation will not be permitted and GW and RW management will become a standard feature of houses.

### 3.2.2. Market size and characteristics

Water recycling and reuse marker keeps increasing. As reported by Zion Market Research (Zion 2015), the US has anticipated the highest growth owing to the niche advancements in water recycling technologies. Residential Water has an established position in the US, with expected CAGR[2] of 15% between 2016 and 2020. (Technavio 2016)

Residential reuse market is very competitive and fragmented. The total size of the market as of 2017 is estimated to be $20 million (Yates 2017). There is a space for development because of the availability of a wide scope of water reuse options with diverse treatment technologies or options with no treatment at all. This is encouraging for new players to enter the market. The technology is rather simple and does not need any extensive know-how. As a consequence, the water reuse market is currently

[2] Compounded annual growth rate

facing issues related to misleading claims and operating failures. Companies are working on improving their products in terms of user-friendliness and functionality and the market leaders invest in obtaining regulatory certificates to prove long-term functionality of their system. The main competing factors remain pricing, certification and long-term reliability.

We see a great increase of water reuse in public and industrial centralized sector. According to the Bluefield research (Reese Tisdale 2017) municipal wastewater reuse capacity is expected to increase 58% from 2016 through 2027. In terms of potable water reuse, which is the greywater sector, Mr. Tisdale claims that the sector will experience 98% increase. This would mean that by 2027, potable water is expected to account for 19% of total reuse, up from 15% in 2016.(Reese Tisdale 2017).

### 3.2.3. Market geographics

For the evaluated state to be attractive, we need to take in consideration factors like policy drivers, funding available, historical experience or threat of water scarcity. Bluefield in its webinar U.S. Municipal Wastewater and Reuse Market Trends, Opportunities, & Forecasts, 2015-2025 (Casey 2015) evaluates California, Florida and Texas as the most attractive states followed by Arizona, Colorado, Georgia and Oklahoma being less but still appealing. In the of first three states, attractiveness is defined mostly by reuse friendly regulations and available funding.

If we focus only on greywater treatment, results are very similar. West Coast states in general are the most attractive ones given the drought problems and forward-moving regulations. As for now, most of the business activities is taking place in California. Alaska and Hawaii are also perspective states because of a number of properties in remote locations without proper working engineering networks.

There are many factors why California is considered to be most attractive for GW systems. It has just emerged from a severe drought in 2017. Homes are often limited how often they can landscape with city water. The likelihood of policy support for using non-potable water is very high. More and more people are aware of the potential of for using greywater instead of drinking water for irrigation. Initially California had regulations only for non-treated greywater system, but in 2014 California also created regulations for treated greywater systems. Treated greywater is required for use in flushing toilets in the house or spraying irrigation.

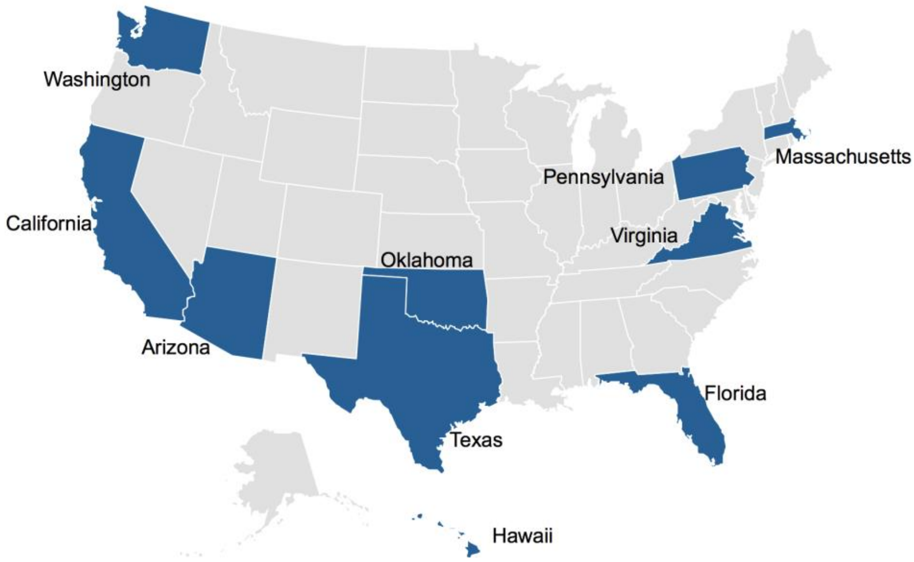



Figure 15: States with greywater recycling potential

Individual counties have implemented regulations that drives GW business. Los Angeles requires dual plumbing in all of its buildings. Extra piping needs to go into new homes so in future they can be upgraded. When developers want to build new construction, city now requires taking measures to effectively use water. In this case, it is not incentive but a mandate. The city and county of San Francisco require that all new commercial development reuse as much water as they can. This has a direct impact on commercial turnkey GW business. (Yu et al. 2015)

More states are starting to implement stormwater regulations in newly built buildings. The infrastructure is getting old and cannot handle the rate of new construction and the green spaces infiltration places are replaced by impermeable surfaces. In a lot of areas, we see rainwater harvesting as an add to stormwater management. Detention tanks are being turned into retention tanks and water is reused. But in California they do not have a lot of rain and GW is very important, especially for those buildings that do have a residential component to them. Then water saving requirements can be met without relying on steady source of water. Greywater is ideal for that purpose since it provides daily inflow.

California is also a good prospect from investment point of view because there is a lot of capital going into new development. State code is also relatively friendly, and regulators are relatively progressive. Same case with Arizona and New Mexico but they are not as perspective from the economic side as California.

### 3.2.4. Market segments

There are a few ways how the overall market can be divided and how demographics of each market varies significantly.

From application point of view, the market can be divided into

- Commercial sector - universities, gyms, hotels, malls
- Residential sector - Family houses, apartment complexes
- Industrial - Manufacturing plants, laboratories, warehouses

.


Figure 16: Market segments and GW usage

The biggest market lies within do-it-yourself greywater systems, where simple technologies with no or minimal treatment are used. Many systems are installed without permission to avoid expensive fees.

Commercial and industrial sector almost exclusively employs high-tech engineered treatment systems while the residential sector is divided in terms of technology use. Industrial and commercial building require a turnkey engineered solution whereas residential sectors, under certain circumstances, can adopt manufactured package solutions

A lot of customers are people who just need to relieve the load on their septic system customers owning “tiny houses”.

### 3.2.5. Key players overview

The current GW industry is made from mostly small companies and startups with less than 10 employees. Following companies either manufacture their own product or import overseas products. The list of GW system installers can be found in the list of attachments.

#### 3.2.5.1. Nexus-e-water

***Estimated turnover:*** $7 million

***Headquarters:*** San Diego, California USA

Nexus is based in San Diego California and manufactures and resells GW recycling systems together with heat recuperation solutions. It is one of three providers on the US market that has NSF/ANSI 350 certification. It is also the only company that is not using biological based with NSF certification. Nexus focuses primarily on family houses, specifically custom house builders and custom house owners. The company’s products include water treatment devices, water heaters, and water collection systems. It serves homeowners, builders, architects, and developers. The company was founded in 2009 and incorporated in 2014.

***Technology:*** Coarse filter, Aeration chamber, Carbon filter, Pleated filter, UV light

***Maintenance***: Coarse filter, pleated filter replacements, UV bulb (once per year), Carbon replacement (every 5 years)

***Price:*** Complete installation costs ranges from $10 000 to $15 000.

### 3.2.5.2. Ecovie

***Estimated turnover:*** $700k

***Headquarters:*** Miami, Florida USA

Ecovie is a company that is exclusive distributor of the Aqualoop system by a German company, INTEWA. Aqualoop systems are MBR based systems and are also NSF certified. Ecovie focuses on both residential and commercial GW and RW systems

***Technology:*** MBR + UV

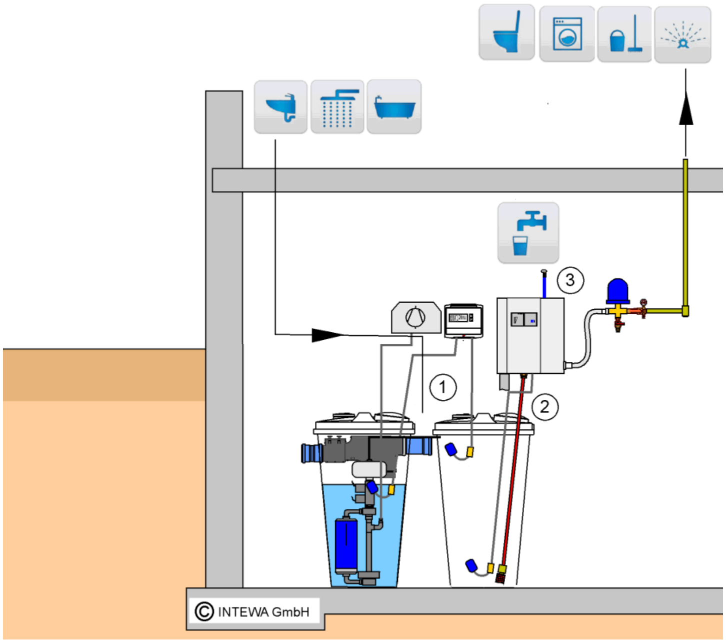



Figure 17: Aqualoop system schematic

***Maintenance:*** Membrane regeneration, UV bulb replacement

***Price:*** System cost about $6000 for a single family house (6 people), in case of commercial installation, the cost is case specific.

### 3.2.5.3. Wahaso

***Estimated Turnover:*** $1-$7 million

***Headquaters:*** Hinsdalle, Illinois, USA

Wahaso is an integrated solutions provider of systems for harvesting and recycling rainwater and greywater in commercial and institutional buildings. Such solutions may include rainwater sourced from rooftops and parking lots, greywater sourced from showers and sinks, groundwater from sump pits or even condensate from cooling systems.

***Technology:*** Collection tank (chlorine disinfection), settling tank, thin filter, multimedia filter, activated carbon filter, process water holding tank (chlorine or UV disinfection)

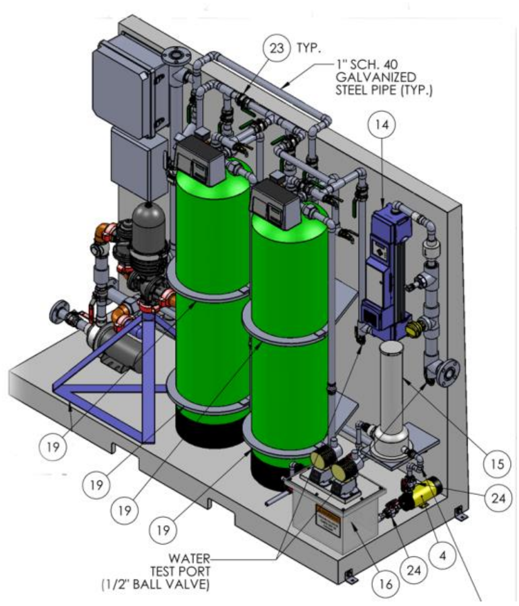



Figure 18: Wahaso technology schematic

***Maintenance:*** Chlorine replacement, UV replacement, Filter replacement, Monitoring

***Price:*** Case-specific (turnkey)

### 3.2.5.4. Phoenix

***Estimated Turnover:*** $34.3 million

***Headquarters***: Louisville, Kentucky, USA

Phoenix is a distributor of Australian brand Aquacell. Aquacell also focuses on larger commercial and multi residential engineered solutions. Company has NSF 350 certification but for blackwater, not greywater.

***Technology:*** MBR + UV + Chlorine

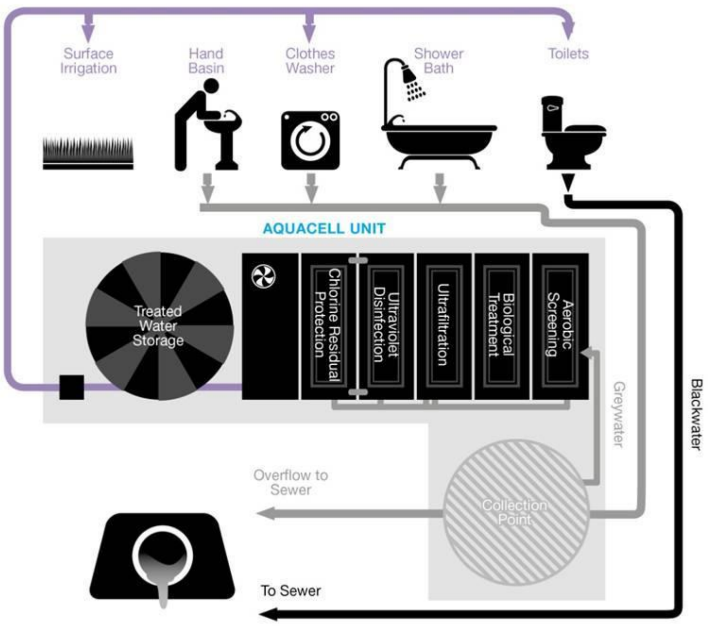



Figure 19: Aquacell technology schematic

***Maintenance:*** Membrane regeneration, UV bulb replacement, Chlorine refill

***Price:*** Case-specific (turnkey)

### 3.2.5.5. Flotender

***Estimated turnover:*** $694k

***Headquarters:*** Bellevue, WA

Flotender is a division of the Filtrific, a company that has been manufacturing water feature equipment since 2002. Filtrific is providing water systems residential and commercial applications through recycling greywater in landscape irrigation.

***Technology:*** Filtration, Ozone & UV Treatment (optional), Primary Filter

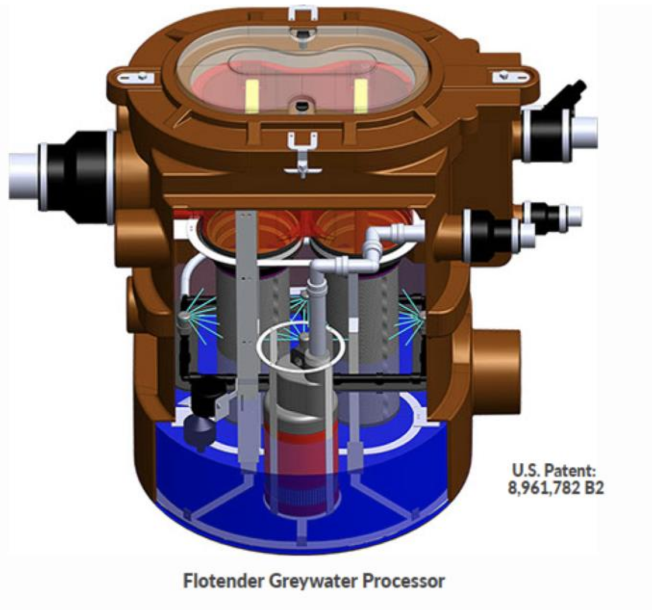



Figure 20: Flotender system

***Maintenance:*** Chlorine replacement, UV replacement, Filter replacement, Monitoring

***Price:*** $3,700 - $23,246

### 3.2.5.6. Biomicrobics

***Estimated turnover:*** $10 - $100 million

***Headquarters:*** Kansas City, Kansas

Biomicrobics manufactures and resells its own solution for GW treatment. They are worldwide. In the US, they operate mostly on west coast. They have over 60000 operating systems, all manufactured in the US. Their primary focus is residential sector GW reuse for irrigation purposes.

***Technology:*** Cleanscreen technology - simple chemical & mechanical based system - silica sand

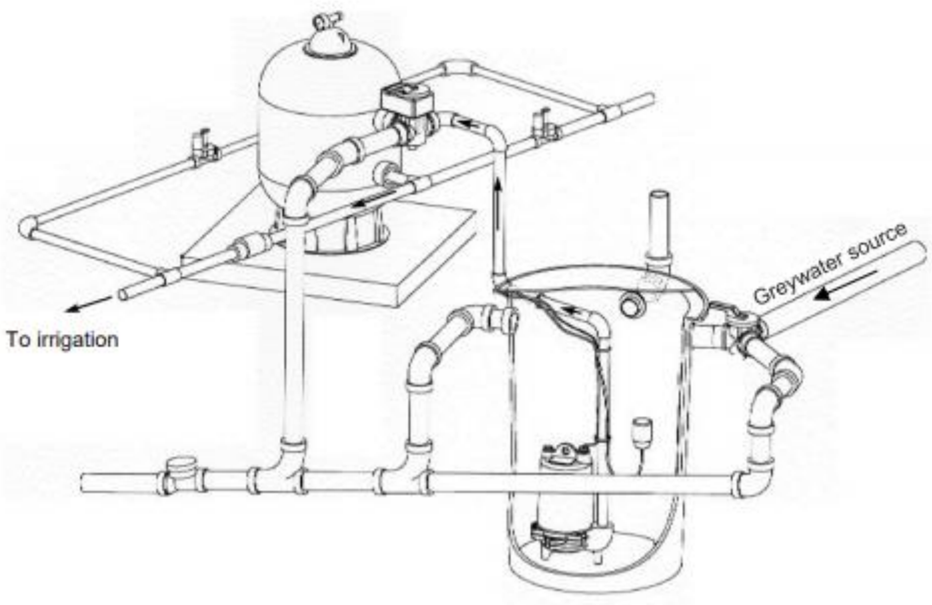



Figure 21: Recover technology

**Maintenance:** Silica sand replacement

**Price:** $1,114 - $3,358

### 3.2.5.7. Waterwise group

***Estimated turnover:*** $145k

***Headquarters:*** Leesburg, Florida

Waterwise groups focuses only on greywater for irrigation purposes. The sole sector they work on is residential and they are focusing on end-user only. They are a distributor of Australian brand Aqua2use. They have both simple on-point systems as well as more sophisticated mechanically based systems for larger residential applications. Most of their uses are not authorized because people and that is also part of the reason why are they focused on end-user customer.

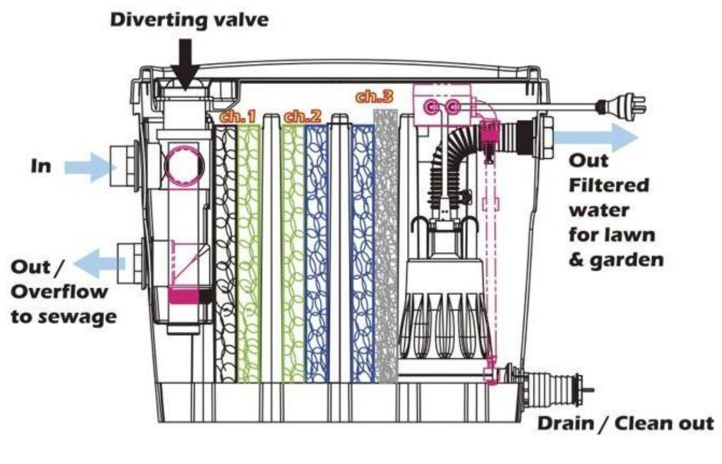



Figure 22: Water2use technology

***Maintenance:*** Filter cleaning and replacement

***Price:*** $400 - $12,900

### 3.2.5.8. Greyter Water Systems

***Estimated turnover:*** $12 million

***Headquarters:*** Mississauga, Ontario, Canada

Greyter offers water reuse management solutions for commercial and residential buildings. Greyter was founded in 2012. The company manufactures its own product and specializes on out-of-the-box-water reuse technology.

***Technology***: Coarse filter, membrane filtration, chlorination, activated carbon

Figure 23: Greyter system

***Maintenance:*** Chlorine refill, Activated carbon filter replacement

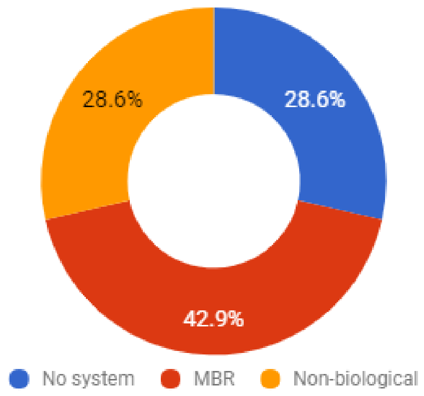
***Price:*** Complete installation costs ranges from $10,000 to $15,000.

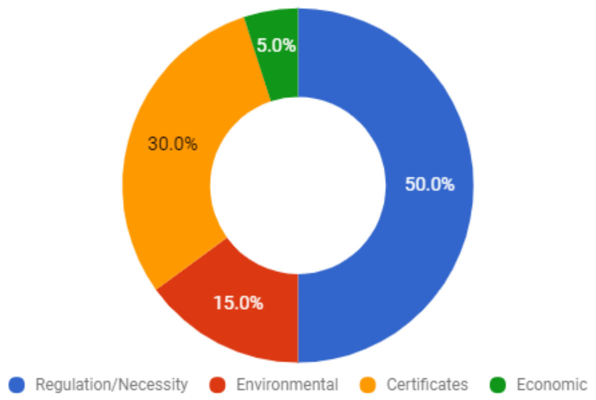
## 3.3. Interviews - evaluation

In total 18 interviews were conducted. 13 interviews from business sector, 3 from academic or non-profit sector and 2 from authority figures. List of participants can be found as an attachment.

In general, the participant agreed to base points such as problematic return on investment, water price, retrofitting problems and regulatory issues.

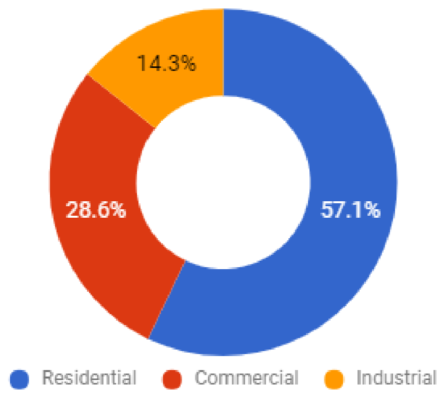
However, interviewees could not agree on what the future of this industry looks like and what systems are most perspective. About 43% agreed that the NSF certification and high-tech treatment systems are the most potential in the future but 29% thought that simple laundry to landscape systems with no treatment or very limited treatment have the most potential on market.

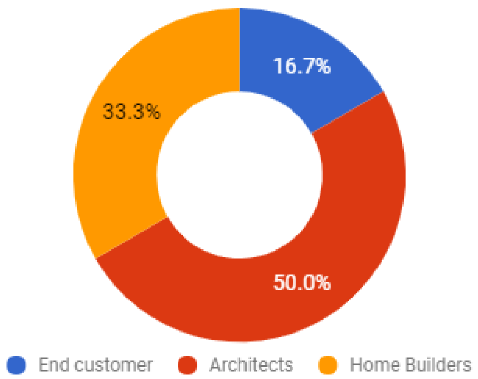



Concerning the drive that makes customer to invest into recycling system, only 5% agreed the that primary reason is economic benefit. About half of participant expressed the regulation or necessity as the main reason for purchasing GW system. Green certificates have also their position but in commercial sector or multi residential dwellings. Environmental factor is important to only 15% of the customers.

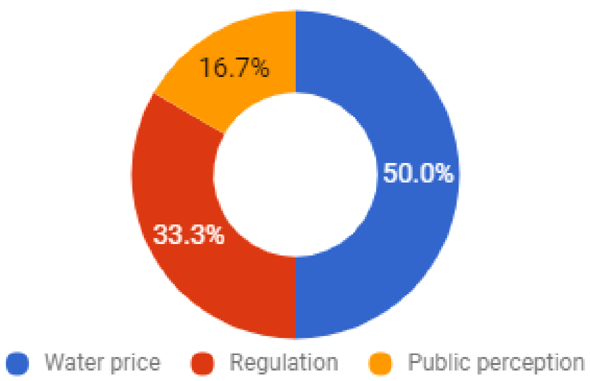
Residential sector remains to be the most attractive sector. Residential complexes or single-family houses are the usual target groups. Some companies are focusing only on single houses because of possibility of using modular scalable solution instead of turnkey project.




The target customer for most companies are businesses. The reason is that GW system needs to be considered from very early stages of the construction because of duo-plumbing requirements. Companies usually spend of the time with architects and home builders and focus their marketing activities in the same direction.

The biggest perceived barrier is the water price and regulations. We can talk about return on investments (ROI) only in the case of commercial and multi residential construction. ROI in a family house is typically between 10-20 years, which is the average durability of the system itself.




The market barriers and opportunities are further discussed in the following section.

## 3.4. Discussion of influencing factors

### 3.4.1. Legislation & Regulation

Legislation and regulation is the single biggest driver of this market. It is important to realize that regulation has both positive and negative impact on the market.

NSF became a standard in the United States and is now required for indoor use of greywater in several states. There has been a discussion whether the limits are not too strict for water used only for non-potable purposes. This might be taken into consideration for the future regulatory adjustments, but at the moment it is the only standard that ensures safe and non-problematic use of greywater.

Before the NSF 350 option was available, it was even harder to get GW systems approved because it required each permitting agency to decide whether the system was good enough. Because authorities don't usually have experience with GW systems, they were unwilling to be allow new systems. Consequently, there were fewer systems installed. Having an industrial standard makes agencies more comfortable permitting it.

On the other hand, there are other issues linked with NSF 350. Permissions issued by local councils are a problem because of the costs associated with engineering drawings that are required for these permissions. Simple installation with L2L system cost about $2000 in permission but more complex installation with toilet flushing and surface irrigation climbs up to $10000 in costs.  The price for the permit can be the same as the system itself. State regulation is administered by local regulators and local regulators are usually not familiar with it. Even though NSF is in place, regulation is still new. During the projects it is usually the first time the regulators and inspectors are dealing with it. (Hitchner 2017)They are now trying to setup a model for regulation at a state level to show that it is acceptable and that the other regulators handled it successfully. More support from the policy standpoint is needed.

Having a standard is a good idea but as indicated above, the cost benefit of NSF 350 remains a problem. Standard is needed for the reason that the agencies feel comfortable accepting these solutions. They do not feel that they are putting anybody in a risk because of a system that they don't understand or don't have experience with.

There also needs to be a much stronger consensus in the public health community regarding the relative risk of non-potable water for certain uses. As for now, any kind of risk is unacceptable.

Legislation needs to be actively required or incentivized and only after that will GW treatment become a significant market place. Without legislative support, this market does not have a chance to succeed. The problem is that there is currently nobody lobbying or advocating for the industry.

California has done it on the power side very effectively with solar systems and energy providers. However, in water industry, water agencies still have very little incentive to support on-site recycling solutions. They are still managing their own businesses based on revenue and cost of selling water and don't see value in incorporating greywater systems into individual homes and properties. It is understandable since this does not bring any advantage to their business.

The mission of water agencies should be changed from being sellers of water to being suppliers of water. They need to be a social corporation that have as their mission making certain that their users always have the amount of water they need and that they are doing it in an environmentally sustainable way. General population need to be incentivized to use water use efficiency. Most water agencies don't perceive that as part of their mission. For that reason we don’t see any support these kinds of the systems.

There also need to be much stronger consensus in the public health community about the relative risk of non-potable water for certain uses. For many public health professionals any kind of risk is unacceptable, so they don't support it. The mission of public health community is to protect health, but it is also providing potable water for population. By misusing and wasting potable water, the whole community can face serious challenger in the long-term. There already are communities they don't have sufficient access to potable water it is also a big problem for the state. Public health community needs to take much more responsibility for public water than they have so far in terms of availability and quality.

Specific steps that can be considered is to prohibit potable irrigation and setting up on-site reuse statewide goals by 2030. For example, set a goal of 20 percent water reused on site. Not centralized, but onsite water reuse. This would be creating a new drive to encourage these projects. As for now, there are no framework, no targets so everybody is working just with people who are interested. Larger unified goal as a state or as a country is missing.

### 3.4.2. Water price

The price of water is undervalued worldwide, and it remains a very politically delicate topic. Most water districts in the US are managed by elected public officials so they are very sensitive to their public perception. If it is a private water district, that's a different situation. For that reason, we can see much higher rise of the rates in the privately owned water systems. On average, privately owned systems charge 59% more than publicly owned systems. Tables 4 – 8 shows average expected annual water bills based on 500 largest community water systems in the US and assumption of 60000 gallons a year per household.

| **Region and State** | **System Ownership** | |
|---|---|---|
| | **Public** | **Private** |
| **Midwest** | **$305.48** | **$511.05** |
| Illinois | $300.31 | 586.33 |
| Indiana | $267.04 | 407.67 |
| Iowa | $270.87 | $468.75 |
| Kansas | $364.50 | |
| Michigan | $324.10 | |
| Minnesota | $236.49 | |
| Missouri | $357.76 | $422.41 |
| Nebraska | $224.32 | |
| North Dakota | $255.00 | |
| Ohio | $302.81 | 519.52 |
| South Dakota | $320.34 | |
| Wisconsin | $246.45 | |

Table 4: Expected annual water bills Midwest region (Watch 2016)

| Region and State | System Ownership | |
|---|---|---|
| | **Public** | **Private** |
| **Northeast** | **$313.12** | **$569.35** |
| Connecticut | $343.02 | $459.27 |
| Maine | $246.12 | |
| Massachusetts | $297.28 | |
| New Hampshire | $358.59 | |
| New Jersey | $290.01 | $519.92 |
| New York | $251.05 | $510.56 |
| Pennsylvania | $382.31 | $705.00 |
| Rhode Island | $371.78 | |

Table 5: Expected annual water bills Northeast region (Watch 2016)

| Region and State | System Ownership | |
|---|---|---|
| | **Public** | **Private** |
| **West** | **$356.25** | **$433.06** |
| Alaska | $606.48 | |
| Arizona | $247.45 | 285.23 |
| California | $385.50 | $452.25 |
| Colorado | $301.41 | |
| Hawaii | $343.08 | |
| Idaho | | 254.78 |
| Montana | $273.26 | |
| Nevada | $428.22 | |
| New Mexico | $261.94 | |
| Oregon | $298.15 | |
| Utah | $231.50 | |
| Washington | $380.45 | |

Table 6: Expected annual water bills West region (Watch 2016)

| Region and State | System Ownership | |
|---|---|---|
| | Public | Private |
| **South** | **$288.89** | **$461.71** |
| Alabama | $284.87 | |
| Arkansas | $265.70 | |
| Delaware | $375.42 | $542.85 |
| District of Columbia | $420.12 | |
| Florida | $292.44 | |
| Georgia | $306.27 | |
| Kentucky | $365.06 | $478.71 |
| Louisiana | $187.39 | $277.85 |
| Maryland | $228.73 | |
| Mississippi | $257.47 | |
| North Carolina | $287.71 | |
| Oklahoma | $296.94 | |
| South Carolina | $203.16 | |
| Tennessee | $303.65 | $316.57 |
| Texas | $290.04 | |
| Virginia | $317.89 | $297.48 |
| West Virginia | | $710.63 |

Table 7: Expected annual water bills South region (Watch 2016)

| Region and State | System Ownership | |
|---|---|---|
| | Public | Private |
| Midwest | $305.48 | $511.05 |
| Northeast | $313.12 | $569.35 |
| West | $356.25 | $433.06 |
| South | $288.89 | $461.71 |
| **Grand Total** | **$315.56** | **$500.96** |

Table 8: Grand total of expected annual water bills (Watch 2016)

From the data above, we can predict that the average price of water is around $0.0053 per gallon ($1.4 per cubic meter) for publicly owned systems and $0.0083 per gallon ($2.2 per cubic meter) for privately owned systems. Large cities have considerably higher rates but still remain one of the cheapest in spite of buying power per country see tables 4-8.

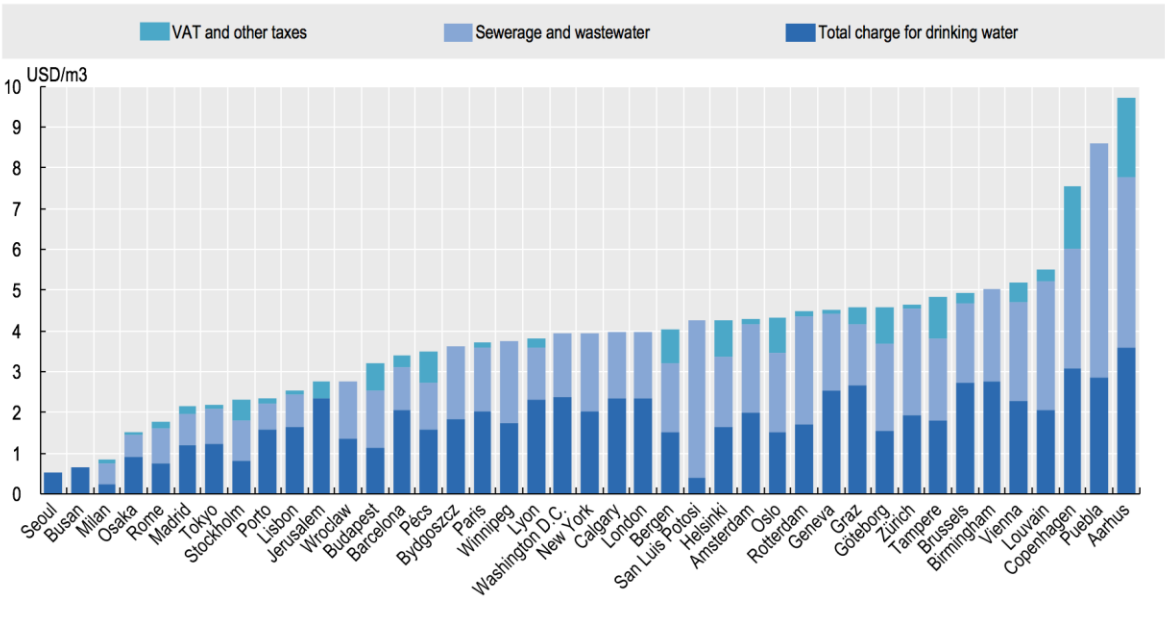



Figure 24: Water prices in selected major cities. 2013 (Organisation for Economic Co-operation and Development 2015)

Despite the US high undervaluation of water price, the study (Watch 2016) reveals that 12% of US households cannot afford their water bills and the outlook is pessimistic. The prediction for 2019 is that over third US households, i.e. 36% will be unable to pay their bills. The first thing people who can't afford their water is to stop watering their lawn and since the cheapest systems are the ones used for irrigation it would be a negative thing for GW business. Indoor water recycling would not be suitable either because of its capital costs.

There is an incentive to educating the public on the real price of water and the rates are growing at a faster pace than inflation. The price however, still does not reflect the real value. Policy objectives are in place in order to use water more efficiently because there is a worry of lack of potable water. But at the same time policy makers didn't give people a reason to comply with the objectives. It that sense price of water is the most important issue which has not been properly addressed yet.

A good way how to minimize water wasting, reflect real price of water and at the same time not affect lower income population is so called water budget based rate (WBBR). With WBBR every resident is given their water budget based on the size of their property and landscape size. This water budget is based on climate, so it is known how much water is needed both for household use and irrigation. For the consumption within the determined water budget, water rates remain standard.  But if the water budget is overdrawn, the rates rise extensively.

Such policy incentives would encourage people not to use potable water for non-potable uses and to look for alternative water sources. Many districts are now considering this model. This is the first step that should be taken, following steps would be potable irrigation ban and sustainable landscaping rules adjusted to specific regions.

### 3.4.3. Technology

The GW treatment technology is available, but the price of it remains high. There is also a bad experience with high-tech indoor systems. Systems often break down, don't work as intended or require excessive maintenance.

As for now there are non-biological based treatment systems, but none of them have proven satisfy effluent water quality criteria in long-term so far. There is one exception in the residential sector of a system that consists of coarse sand filter, aeration chamber, carbon filter, pleated filter and UV disinfection (nexus e-water).

The use of the biological based system is viable for larger commercial applications when there is a dedicated person to take care of the system. Return on investment of these technologies is highly case specific and depends on volume of treated water. For low scale residential application, it is important to use a technology, which does not require complicated maintenance. For that reason, there is a need for further development and testing of options which do not involve biological treatment. Biological treatment is problematic from maintenance point of view. Also, it requires at least room temperature in order to work properly.

Installation can be as high as the systems itself for that reason retrofitting is a very problematic issue and is not feasible in most cases. Solutions that don't use treatment are not acceptable for new home builders now.

### 3.4.4. Capital & Operational costs

Price remains a big barrier for a wider scale adoption of such systems and will remain so in the upcoming years. There are currently only two commercial technologies on the US market which can satisfy NSF 350 requirements and both are in the upper scale price level.

Financing models that help customers, homeowners help to pay it slowly over time, are needed. There is a call for different financing mechanisms which would be supported by water agency or city.

The solution for the price barrier could be a lease model similar to SolarCity. SolarCity is a solar-panel installation company which leases solar panels over a 20-year period, covering installation costs. The client never owns the panels, but instead rent them and use the energy they capture. The second option is called PPA (Power Purchase Agreement) agreement. In this case, SolarCity owns their product as well and sells the power it generates to a customer. The rate they charge is typically lower compared to the utilities charge.

We can apply the similar model to greywater treatment. However, a system like this comes with large upfront costs. There would be a need for major investment. Also, this model will only work under presumption that the technology will pay for itself. For that reason, the financial model would need to be developed in coordination with water agencies and authorities.

In commercial construction, problems arise when projects go over budget. Designers start looking for places to reduce costs and GW systems are usually the first place they look into. Water is still relatively cheap, and not only does it cut down the price of the system, but also the plumbing costs. Companies in the commercial sector report 90% of the projects are not executed because GW recycling was removed from the project.

### 3.4.5. Retrofitting vs New Technology

Installing greywater into an existing construction is not feasible from economic point of view. The ROI (return of investment) for a house is between 5-10 years. The reason are the expenses connected with duo-plumbing installation. Plumbing is usually the second highest expenses after the treatment system itself.

The great inhibitor for greywater systems would be regulation requiring duo-plumbing systems being standardly installed into new construction. This is a standard in Asian countries, where sea or brackish water is used for toilet flushing purposes. We can see progress in case of United States as well, specifically the new code requiring all the new constructions in the Los Angeles county to be duo plumbed. Every home should be built recycle ready. This does not mean that every house will require greywater reuse, but it will provide a clear pathway for future house conversion. For that reason, we need mandates for houses to be built recycle ready in the areas that are fighting with drought.

### 3.4.6. Public aversion

A big barrier to a wider public implementation seems to be the lack of public knowledge and so-called “yuck” factor.

The “Yuck” factor remains to be a major roadblock to wider water recycling implementation. People don’t like the idea of reusing their wastewater in the house and have an emotional response to it, despite the fact that the water has been highly treated, and it is perfectly safe for them.

It is important to understand that these emotional responses are often in contrast with the rational thinking. The fact that somebody understands that treated greywater does not pose any kind of danger to him may not be enough to stop the emotional response.

The anthropologist Mary Douglas defines this phenomenon by term “matter out of place” and refers to things, that do not easily fit into our known systems of classification and thus often come to be thought as dangerous. Greywater is a matter out of place since it hedges our conceptions of clean and polluted. The lack of experience of people with the relatively new concept of water recycling only causes them to classify it into categories they do know about.

For that reason, simple education about scientific case for these technologies is not enough because we need to also change social and cultural values towards them. There are communities who have successfully adopted recycled water and embraced it into their culture. The example is widely accepted Singaporean NEWater.

The recent study conducted by K. Hyde (Hyde et al. 2016) demonstrated that a lack of aversion for using treated greywater for number of non-potable and potable uses provided that it is safe to use. This study was conducted on MBR GW system which operates at the University of Reading, UK since 2012 and shows that the perception of people can be changed if they are familiar with the technology and its functionality.

### 3.4.7. Custom build houses

Smart, prefabricated and off grid homes and getting a lot of market traction in the recent years. Tiny houses are often off grid and put emphasis into energy efficiency and savings and for that reason are a good sector for greywater systems to be implemented as a part of a design. They can be installed together with the rainwater system in order to achieve complete water independence and market the home as such. In general, remote areas without engineering networks are suitable for GW application.

There are homebuilders who are interested to install GW systems in their projects, so they can upsell the home. It is another feature of the home that can be used for it to seem more “high end”. Custom built houses are a rising market because there is a certain number of customers who enjoy having the latest technology in their household. But the main reason for people buying these systems is necessity because they have no other source of water, or they don't want to pump out their holding tank as often.(Rebori 2017)

In the long run, there would be opportunity for a greywater system that captures GW from a single pipe, does not capture black water and treats the GW while sending BW to the sewer. This would eliminate need for duo-pluming. This is currently not allowed from a public health perspective, but may be changed in the future (Hitchner 2017).

### 3.4.8. Sustainable housing, certificates

Green certificates are having a great impact on implementation of GW technologies into commercial and residential sector. LEED (Leadership in Energy and Environmental design) certificate is prominent in the US and GW systems contribute in the Water Efficiency credit category of the LEED for New Construction (NC) rating system. There are several credits that GW systems directly contribute to.

Water efficiency (WE) prerequisite requires that the project uses 20% less water that the baseline calculation. Since the GW reuse water for toilet and irrigation self alone can usually satisfy this criterium.

WE Credit 1: Water Efficient Landscaping requires 50% reduction (2 points) or 100% elimination (4 points) of potable water used for irrigation. Depends on the amount of GW used in the object usually full credit can be accredited.

WE Credit 2: Innovative Wastewater Technologies credit to reduce wastewater and potable water demand. Two points are awarded for reducing potable water use for sewage by 50% or by treating 20% of wastewater on-site to tertiary standards.

WE Credit 3: Water use reduction is the same as WE prerequisite 1, but the required percentage of water reduction is higher. Projects are awarded 2 points for 30% reduction, 3 points for 35% or 4 points for 40%.

Installation of GW system can therefore grant up to 10 out of 12 points in case of BD+C and 10 out of 11 points in case of Homes design and construction. Furthermore, it can satisfy one of the prerequisites of the certification. The complete credit system can be found in the report LEED v4 for Building Design and Construction (LEED 2017b) and LEED v4 for Homes Design and Construction (LEED 2017a)

When LEED first came out, they did a couple of projects around the world.  Now a lot of people design according to the lead standard, but they don't pay for the lead certification. The problem with LEED certification is that the water goal can be met by RW system and GW system is not necessary. In the state like California, where rain is very seasonal. this does not apply. It is one of the reasons why California is the biggest GW market for greywater both residentially and commercially.

LEED certification faces the same challenges as public sector. Certifying agents tend to stick to solutions they are familiar with. It is not a really cutting-edge tool in terms of using the best sustainable technology.

There is another certificate which might become more significant for GW system - Living building challenge (LBC). LEED is based on what is installed in the building, it does not track the actual performance of the systems in the building. LBC is the quite the opposite. The building cannot get certified if it does not meet performance after a year since the construction completion. LBC requires that 100% of the project's water needs must be supplied by captured precipitation or other natural closed-loop water systems, and/or by recycling used project water, and must be purified as needed without the use of chemicals. All stormwater and water discharge, including grey and black water, must be treated onsite and managed either through reuse, a closed loop system, or infiltration.

## 3.5. Proposal of business strategy for a wider market adoption

In can be concluded that the regulation and water price remain two most important factors which are making the industry non-attractive for potential investors (section 3.4.). Financing schemes helping distribute the high investment costs would push this industry forward but at this moment are not viable as a business model. There are, however, certain aspects that can be exploited. Based on the authors findings, the following approach is recommended.

### 3.5.1. Market outlook

For the companies interested entering this market, it is recommended to take GW recycling as a part of their portfolio combined with other sustainable technologies. There is not much opportunity on the market before we see substantial changes in legislation or water rates. There is definitely place for this technology, but the timing is not right yet. The market is too young and not ready to implement this solution.

### 3.5.2. Portfolio

The company should profile itself as a upscale custom house solutions and take advantage of the currently booming markets.

Such portfolio would include:

- Solar panels,
- Energy storage,
- RW and GW management,
- Heat recovery solutions
- Household wastewater treatment plant

The product needs to be scalable, compact and interconnectable with other systems i.e. irrigation. There should also be minimal maintenance requirements.

### 3.5.3. Sectors

For the GW systems, it is recommended focusing on the residential sector and having the commercial sector as a side business. The problem with the commercial sector is that it requires a lot of man hours to design a system and then often happens from the system is dropped out of the project. Companies should actively seek LEED or LBD projects nevertheless and try to engage with the architects and engineers very early in the process. It is important because of the duo-plumbing aspect. However, it is advised to put bids only if the contractor is willing pay for the bid. The price would be deducted from the final price after realization.

The value proposition in the case of commercial LEED or LBD installations should be a complex water and energy management solutions.

For the residential sector, it is suggested to focus only on the treatment solution itself and develop strategic partnerships with GW installers over the country. The treatment system needs to be plug-in modular system with active monitoring.

### 3.5.4. Marketing

The recommended marketing strategy would be pull marketing method as described in (Dowling 2004). Current motivation of people to buy the product is primarily because of their necessity or environmental reasons (section 3.3). Pushing products on general population at this market stage would not be price effective form of marketing. Instead, the goal should be to take advantage of the currently trending markets (as described in section 3.5.2) and to "pull" interested customers into water recycling systems as well. The focus should be on creating brand loyalty and long-term customer relations especially with GW installers and custom house builders.

It is also advisable to get involved with the new technologies that helps decentralization of water and energy distribution, so called p2p networks (as discussed in section 2.3). Partnership is recommended in a form that one company provides the networks and physical solutions and the other ones provides the communication and payments solutions. This still remains a futuristic approach but it will draw a lot of publicity and will serve as a marketing tool. It will also give an opportunity to the companies to be the first movers on the new market.

### 3.5.5. Technology

Concerning the technology, MBR reactor with remote online monitoring is recommended both for residential and commercial applications. However, a working system without expensive membrane would be highly desirable.

## 3.6. Recommendations for city officials

There are multiple ways that the counties and municipalities can lower financial barriers and help with adoption of GW recycling:

1. providing rebates to lower the upfront system and retrofit cost
2. providing low or zero interest financing for system purchase and installation to property owners and allow them to repay through their utility bills
3. providing financing incentives to attract investors or developers to provide onsite GW recycling services through a third-party ownership model.
4. amending local building codes to require new constructions to include plumbing to divert

# 4. Conclusion

The work gives the reader complex view of the current situation of the residential water recycling market. A questionnaire was used to get a better insight into the industry and quantitatively evaluate current focus of the industry. As such the market was analyzed from aspects like business, technology or public perception.

Residential greywater recycling is still in its very early stages and faces major barriers which makes the industry barely profitable. The GW market would not be able to take off without significant changes to water pricing, permission costs and public acceptance.

Key players on the US market has been interviewed and the main issues and barriers identified. Even with the simplest system with the absence of treatment, the piping and extra construction work makes water reuse unattractive for the single family houses. Commercial building can achieve a certain level of economic benefit but the process of obtaining permit, rate of dropout from projects and personnel capital necessary makes the sector unattractive. Financing schemes are necessary but currently not manageable from business point of view.

The work also gives an evaluation of the most common technologies used for GW recycling and highlights their advantages and disadvantages in different sectors. Subsequently a complete market research is performed.

The specific goals of this work i.e. evaluation of available domestic greywater systems and identification of market barriers have been met and suitable business model was proposed.

The author suggested that aspiring companies should focus on the niche markets such as off-grid houses, custom build houses, tiny houses or modular constructions and include GW treatment as a part of their portfolio. It is however not recommended to engage solely in the GW industry.

The main contribution of this work can be seen in analysis of this small developing market which was not performed before. This gives aspiring companies a better information to decide whether or not to engage in the industry.

# 5. Discussion

The work was performed in period August - December 2017 at Texas Tech University in Lubbock Texas. Author spoke with 18 representatives from different fields. Thanks to a variety of sources and independent research author believe that was able to provide an objective insight into this small developing market.

Author's presumption was that the US, especially California was currently a "booming" GW market however that has confirmed no to be true. It is true that California due to its drought problems and matching regulation makes it more attractive than other states or countries but it is far from being a thriving and growing market. When dealing with a cheap media that water is, excessive regulation can actually become a market barrier on its own.

Authors did not discuss in detail other ways of residential recycling besides on-site reuse, such as decentralized solutions for neighborhoods or residential areas. It can be a way how to address non-viable ROI and it is a topic worth of an independent report.

Further research should focus on integration greywater, rainwater and energy sources to make the whole system profitable and reasonable in terms of ROI. Case studies and decentralized projects such as Power Ledger projects in Australia are showing promising developments in this area and certainly worth attention for the future viability study of such solution.

# 6. Used literature & sources

Agency, D.I., 2013. *Global Water Security: Intelligence Community Assessment, ICA-February 2012*, Government Printing Office.

Alexander, S. & Clark, B.Y., 2016. The Benefits, Challenges, and Impediments of Greywater Use in EPA Region 5. *SSRN Electronic Journal*. Available at: http://dx.doi.org/10.2139/ssrn.2860254.

Allen, L., 2015. *The Water-Wise Home: How to Conserve, Capture, and Reuse Water in Your Home and Landscape*, Storey Publishing.

Allen, L., 2017. Interview Nov 11, 2017

Betts-Lacroix, J., 2010. Hype Chasm. *Evocatro*. Available at: http://blog.evocator.org/2010/04/hype-chasm.html [Accessed November 12, 2017].

Bill Kuru, M.L., 2012. IS GRAY-WATER REUSE READY FOR PRIME TIME? Available at: https://www.us.kohler.com/webassets/kpna/pressreleases/2012/KOHLER-GRAYWATER_111412.pdf.

Bruursema, T., 2011. *The New NSF 350 and 350-1*, NSF.

Casey, E.B., 2015. *U.S. Municipal Wastewater and Reuse Market Trends, Opportunities, & Forecasts, 2015-2025*, WateReuse.

Combs, S., 2014. *Texas Water Report: Going deeper for the solution*, Texas Comptroller of Public Accounts.

Cooper, D. & Schindler, P., 2013. *Business Research Methods: 12th Edition*, McGraw-Hill Higher Education.

D. Butler, F.A.M., 2006. Water consumption trends and demand forecasting techniques. *IWA Publishing*, pp.1–26.

Donner, E. et al., 2010. Presence and fate of priority substances in domestic greywater treatment and reuse systems. *The Science of the total environment*, 408(12), pp.2444–2451.

Dowling, G.R., 2004. *The Art and Science of Marketing: Marketing for Marketing Managers*, Oxford University Press, USA.

Eran Friedler, R.P., 2011. *Study of the effects of on-site greywater reuse on municipal sewer systems*, Available at: https://greywateraction.org/wp-content/uploads/2014/12/Israeli-study-gw-affects-sewers.pdf.

Hitchner, B., 2017. Interview Nov 5, 2017

Hyde, K., Smith, M.J. & Adeyeye, K., 2016. Developments in the quality of treated greywater supplies for buildings, and associated user perception and acceptance. *International Journal of Low-Carbon Technologies*, p.ctw006.

Judd, S., 2006. *The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment*,

LEED, Guide to LEED Certification: Commercial | USGBC. *usgbc.org*. Available at: https://new.usgbc.org/cert-guide/commercial [Accessed November 6, 2017].

LEED, 2017a. Guide to LEED Certification: Commercial | USGBC. *usgbc.org*. Available at: https://new.usgbc.org/cert-guide/commercial [Accessed December 6, 2017].

LEED, 2017b. *LEED v4 for Building Design and Construction*, LEED. Available at: https://www.usgbc.org/sites/default/files/LEED%20v4%20BDC_07.8.17_current.pdf.

Ludwig, A., 1999. *Builder's Greywater Guide: Installation of Greywater Systems in New Construction and Remodeling*,

Maurer, M., 2009. Specific net present value: an improved method for assessing modularisation costs in water services with growing demand. *Water research*, 43(8), pp.2121–2130.

Mohsenin, A., 2016. Is wasting water actually bad for the environment? Available at: https://www.quora.com/Is-wasting-water-actually-bad-for-the-environment-If-all-the-water-we-use-just-gets-recycled-anyway-what%E2%80%99s-the-point-of-not-keeping-the-faucet-running-when-brushing-your-teeth-or-taking-a-longer-shower-other-than-the-effects-to-your-water-bill [Accessed October 3, 2017].

Moore, G.A., 2014. *Crossing the Chasm, 3rd Edition: Marketing and Selling Disruptive Products to Mainstream Customers*, HarperBusiness.

NFP, 2017. *Alliance for Water Efficiency project*, AWE.

Organisation for Economic Co-operation and Development, 2015. *Environment at a Glance 2015: OECD Indicators*, OCDE.

Parker, E., 2010. Farming: Wasteful water use. Available at: http://wwf.panda.org/what_we_do/footprint/agriculture/impacts/water_use/ [Accessed October 3, 2017].

Phoenix, 2009. Greywater System & Greywater Recycling. *Phoenix*. Available at: http://www.dewater.com/water_recycling/greywater.html [Accessed November 17, 2017].

Pidou, M., 2007. Greywater recycling: treatment options and applications. *Proceedings of the Institution of Civil Engineers*, 160, pp.119–131.

PowerLedger, 2017. *Australian Government Awards Grant to $8 Million Project In The City Of Fremantle Using The Power Ledger Platform*, PowerLedger.

Rebori, B., 2017. Interview Oct 25, 2017

Reese Tisdale, B.T., 2017. Markets, Opportunities and Investment Scenarios.

Ringelstein, O., 2017. Greywater recycling for a single-family house, with RAINMASTER Eco (indoor tank). *Intewa.de*. Available at: https://us.intewa-store.com/us_en/aqualoop/aqualoop-system-6/wasseraufbereitung-und-grauwasserrecycling-fur-das-einfamilienhaus.html [Accessed December 2017].

Roefs, I. et al., 2017. Centralised, decentralised or hybrid sanitation systems? Economic evaluation under urban development uncertainty and phased expansion. *Water research*, 109, pp.274–286.

Schleifer, L., 2017. 7 Reasons We’re Facing a Global Water Crisis | World

Resources Institute. Available at: http://www.wri.org/blog/2017/08/7-reasons-were-facing-global-water-crisis [Accessed October 2, 2017].

Sedlak, D., 2014. *Water 4.0: The Past, Present, and Future of the World?s Most Vital Resource*, Yale University Press.

Selvakumar, A. & Tafuri, A.N., 2012. Rehabilitation of Aging Water Infrastructure Systems: Key Challenges and Issues. *Journal of Infrastructure Systems*, 18(3), pp.202–209.

Technavio, 2016. *Global Residential Water Treatment Equipment Market 2016-2020*,

Tilley, E. et al., 2014. *Compendium of Sanitation Systems and Technologies*,

United Nations, 2015. Water. Available at: http://www.un.org/en/sections/issues-depth/water/ [Accessed October 3, 2017].

Vieira, P., Jorge, C. & Covas, D., 2017. Assessment of household water use efficiency using performance indices. *Resources, Conservation and Recycling*, 116, pp.94–106.

Wang, S., 2014. Values of decentralized systems that avoid investments in idle capacity within the wastewater sector: a theoretical justification. *Journal of environmental management*, 136, pp.68–75.

Watch, F., 2016. *The State of Public Water in the United States*, Food & Water Watch.

Yates, J., 2017. Interview Nov 10, 2017

Yu, Z.L.T. et al., 2015. Cost-Benefit Analysis of Onsite Residential Graywater Recycling--A Case Study: The City of Los Angeles. *Journal - American Water Works Association*, 107, pp.E436–E444.

Zion, 2015. *Water Recycle and Reuse Market: Industry Perspective, Comprehensive Analysis and Forecast 2015 – 2021*, Zion Market Research.

# 7. List of tables and figures

# 8. List of attachments

## 8.1. Questionnaire

### Goal

The goal is to identify barriers and opportunities on the market from different points of view.

### Hypothesis

- The MBR system is currently the best possible technology to provide quality treatment of greywater. Yes/No/Why
- The demand for greywater systems is increasing .Yes/No/Why
- Can your system handle kitchen greywater? Yes/No
- The demand for greywater systems is increasing yearly? Yes/No
- Automatization is the key to the residential market adoption. Yes/No

### Why - questions (open ended)

- What are the maintenance requirements for your system?
- What is the ROI of your system for a typical family house?
- Which states of the US are the most perspective from business point of view and why do you think so? (Arizona, Mexico, California, Texas, Washington - updated codes)
- Who are you main competitors/what other systems are you aware of?
- What role plays legislation in your business and how do you see a future development of legislation?
- What is the role of legislation?
- Where do you see opportunities in the field of greywater treatment?
- Do you use your systems for both irrigations and toilet flushing?

- Where is your operation in the US?
- How do you view green certificates such as LEED, which are supporting water reuse. Did it have any influence on your business?
- Do you need to use bio-friendly detergents in order to function properly?
- If you have to name one problem, one migraine problem in the greywater business, what would it be?

## Rank order (scale questions - rank from lowest to highest)

What markets would you evaluate most perspective and which the least now vs future

- Commercial - Universities, offices, shopping malls, gyms, hotels, malls
- Residential - Family houses, apartment complexes,
- Industrial - manufacturing plants, laboratories, warehouses

Who is the target customer for you?

- Builders
- Architects
- Designer
- End user
- Real estate developer

The best business model

- Sell just the treatment system
- Sell treatment system and collection system
- Complete installation - i.e. treatment system, piping, collection system

What is the most important for a customer?

- No maintenance, automatization
- No operational issues
- Price

- Design
- Social prestige - environmental friendliness
- Other - define

Rank the cost from highest to lowest and give estimation

- Installation
- Piping
- Treatment system
- Collection tanks

Rate the technology from the worst one to the best one

- MBR
- Chlorination + disinfection
- Advance oxidation $H_2O_2$ + UV
- Membrane Chemical reactor
- Biological with media filter
- Other

What do you perceive as the biggest barrier to wider market implementation?

- Price of technology
- Low price of water
- “Yuck” factor
- Maintenance problems
- Not being trendy or “sexy”
- Legislative barriers

What greywater systems innovation do you consider as most viable?

- Iot implementation (smart homes)
- Online remote monitoring
- Using house wall as water storage

- Subscription based service providing bioproducts suitable to use with greywater systems
- SolarCity model - zero down payment, lease over 20 years period
- Window/wall skyscraper systems - UC Berkeley

## Other questions

- Are there any particular events you would recommend me visiting?
- Is there an organization which could help me with my research you would recommend me to contact?

## 8.2. US greywater Installers

| Company | Headquarers, Area of service | Sector | Website |
|---|---|---|---|
| Abundant Waters | Pasadena, Southern California | Consultation, L2L, Branched drain, High-End Residential, Rainwater harvesting | abundantwaters.net |
| Bay Maples Wild California Gardens | San Jose, San Francisco Bay | Consultation, L2L, Branched drain | baymaples.com |
| CalWater Solutions | San Francisco, San Francisco Bay | Consultation, L2L, Branched drain, High-End Residential, Commercial Scale | calwatersolutions.com |
| Catching H2O | San Diego, Southern California | Consultation, All types of Greywater Systems | catchingh2o.com |
| Colorado Greywater | Denver, Rocky Mountain | All types of Greywater Systems | coloradogreywater.com |
| Compostteana's Organic Landscape Design and Maintenance | Los Angeles, Southern California | Consultation, L2L, Branched drain, High-End Residential | Compostteana.com |
| Daniel Tran | Sacramento, Northern California | Consultation, L2L, Branched drain, High-End Residential,, Commercial Scale System | californiaclips.com |
| Dig Coop | Oakland, San Francisco Bay | All types of Greywater | dig.coop |

| | | | |
|---|---|---|---|
| | | Systems | |
| Double A Handywork | Oakland, San Francisco Bay | Consultation, L2L, Branched drain, High-End Residential, Commercial Scale System | doubleahandywork.com |
| EcoAssistant | Davis, Northern California | Consultation, L2L, Branched drain | ecoassistant.net |
| EnviroMeasures | Los Angeles, Southern California | Consultation, L2L, Branched drain | enviromeasures.com |
| Equinox Landscape | Petaluma, Northern California | All types of Greywater Systems | equinox-landscape.com |
| Go to the Garden | Petaluma, Northern California | All types of Greywater Systems | gotothegarden.com |
| Grey Water Green Landscapes | Palo Alto, San Francisco Bay | Consultation, L2L, Branched drain, High-End Residential | greywatergreenlandscapes.com |
| Grey Water Landscape Design | San Francisco, San Francisco Bay | All types of Greywater Systems | GreyWaterLandscapeDesign.com |
| Greywater Corps | Los Angeles, Southern California | Consultation, L2L, Branched drain, High-End Residential, All types of Greywater Systems, Commercial Scale System | greywatercorps.com |
| Herschy Environmental | Bakersfield- Fresno- Tulare- Merced Counties, Central Valley California | Consultation, L2L, Branched drain, High-End Residential, Commercial Scale System | herschyenviro.com |

| | | | |
|---|---|---|---|
| Isis Plumbing | Los Angeles, Southern California | Consultation, L2L, Branched drain, High-End Residential, All types of Greywater Systems | linkedin.com/in/mark-akers-0387a647/ |
| Lelands Plumbing/GrayWater Systems | San Francisco, San Francisco Bay | Consultation, L2L, Branched drain, High-End Residential | n/a |
| Love’s Gardens | Santa Cruz, Northern California | All types of Greywater Systems | lovesgardens.com |
| NS Johnson Co | Los Angeles, Southern California | Consultation, L2L, Branched drain, High-End Residential | houzz.com/pro/krissellmanjohnson/ns-johnson-co |
| Phil Gray Construction and landscaping | Solano County, San Francisco Bay | Consultation, L2L, Branched drain, High-End Residential,Commercial Scale System | philgraylandscaping.com |
| Planting Justice | Oakland, San Francisco Bay | All types of Greywater Systems | plantingjustice.org |
| Portland Earth Care | Portland, Pacific Northwest | Consultation, L2L, Branched drain, High-End Residential | n/a |
| Seattle Greywater Initiative | Seattle, Pacific Northwest | Consultation, L2L, Branched drain | facebook.com/SeattleGreywaterInitiative |
| Sierra Watershed Progressive | Northern California | All types of Greywater Systems | sierrawatershedprogressive.com |
| Soleil Design | Fresno, Central Valley California | Consultation, L2L, Branched drain, High-End Residential | n/a |

| | | | |
|---|---|---|---|
| Terrasophia LLC | Southwest | Consultation, L2L, Branched drain | terrasophia.com |
| Twin Home Experts | Los Angeles, Southern California | Consultation, L2L, Branched drain, High-End Residential | Twinhomeexperts.com |
| Ty Teissere | Long Beach, Southern California | Consultation, L2L, Branched drain | earthstewardecology.com |
| Water Sprout | San Francisco Bay | High-End Residential, Commercial Scale System | watersprout.org |
| Webber Plumbing | Orange County, Southern California | Consultation, L2L, Branched drain, High-End Residential | n/a |
| Wild Rose Gardens Sustainable Landscaping | San Francisco Bay | Consultation, L2L, Branched drain | wildrosegardens.com |

Source: Internet research, greywateraction.org

## 8.3. List of interview participants

| Name | Company/Institution |
|---|---|
| Oliver Ringelstein | INTEWA |
| Karel Plotěný | Asio |
| Leigh Jerrard | Greywater Corps |
| Paz Gutierrez | UC Berkeley |
| John Yates | Green Energy Group |
| Bob Rebori | Biomicrobics |
| Laura Allen | Greywater Action |
| Bob Hitchner | Nexus-e-water |
| Kim Seay | Wahaso |
| Remy Sabieani | WaterWise |
| Robert Drew | Eco Vie |
| Penny Falcon | Los Angeles department of water and power |
| Paula Kehoe | San Francisco non-potable water program |
| Michael Conciatore | Aquacell |
| Steve Bilson | ReWater |
| Kevin Kassel | Greyter Water Systems |
| Juston Berkey | Flotender |
| Trathen Heckman | Daily Acts |