Life Cycle Assessment of Hemodialysis Treatments

A Thesis submitted by

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ABSTRACT

Close to 400,000 people in the US suffer from end stage renal disease and require regular HD treatments as a life sustaining therapy. HD consumes high amounts of energy, water, and disposables, but the environmental impacts of the treatment has only begun to be characterized in the literature. A life cycle assessment (LCA) methodology is used to determine the impacts of HD treatments in the scenarios where:

- dialyzers are used once and then thrown away.
- dialyzers are reused, reprocessed between uses, and then thrown away after about 20 uses.
- dialyzers are recycled by recovering materials from the dialyzer cartridge housing.

Environmental impacts are calculated across the nine impact categories in the TRACI2 LCIA method. This study demonstrates that reusing and recycling dialyzers creates substantial reductions in the life cycle impacts of individual dialyzers, but offers only modest benefits when put in context of the entire HD treatment.

Table of Contents

LIST OF FIGURES

LIST OF FIGURES

List of Tables

ACRONYMS

Acronym	Meaning
AP	Acidification Potential
CP	Carcinogen Production
EP	Eutrophication Potential
ET	Ecotoxicity
FU	Functional Unit
GHG	Green House Gas
GWP	Global Warming Potential
HD	Hemodialysis
LCA	Life Cycle Assessment
NCP	Non-Carcinogen Production
OD	Ozone Depletion
PAA	Peracetic Acid
PCR	Product Category Rule
RC	Recycle
RE	Respiratory Effects
RU	Reuse
SC	Smog Creation
SGD	Sector Guidance Document
SU	Single Use

1 OVERVIEW

Dialyzers are the critical component for hemodialysis therapy, a life-sustaining medical treatment for individuals with kidney failure that is used by almost 400,000 people in the US (USRDS 2012). The goal of this thesis is to use life cycle assessment methods to quantify environmental impacts of dialyzer choice and place them into context with the rest of the hemodialysis treatment. This comparative Life Cycle Assessment (LCA) of dialyzer utilization and end-of-life strategies is being conducted in conjunction with a medical and economic study of single use and reusable dialyzers funded by a grant from the American Society of Nephrology.

LCA is a method that calculates a product's or service's environmental impact using a model that accounts for all the material and energy that go into and come out of the product. To generate useful and insightful results, LCA requires extensive data collection, research on industrial processes and materials, modular model formulation, and detailed result interpretation. Data must be collected on a variety of materials and processes. Some data may require estimation and carry a large amount of uncertainty because there is limited information on proprietary processes and high tech materials used in medical applications. Accordingly, uncertainty and variability in this model are carefully analyzed, including an uncertainty analysis via a Monte Carlo simulation and a sensitivity analysis to determine how changes in data and model formulation affect the results.

The key results of this study are:

- Most Consumptive Phase – As an energy consuming medical treatment, the highest impacts are seen in the use phase.
- Main Contributor – As an energy consuming medical treatment, electricity consumption is the majority contributor to GWP, and the highest contributor in all other impact categories, with the exception of human toxicity impacts.

1 OVERVIEW

- Secondary Contributor – Patient and staff commuting is shown to be a significant contributor in many impact categories. It contributes about 20% of the GWP in the single use scenarios.
- Tertiary Contributor – Disposable fittings and dialyzers are the majority contributors to human toxicity impacts and a significant contributor to ecotoxicity, smog, and eutrophication.
- Differences in Scenarios – Reusing and recycling creates substantial reductions in the life cycle impacts of the dialyzers, but offers only modest benefits when put in context of the entire HD treatment.
- Differences in Scenarios – If commuting distances for reuse techs are too high – reusing dialyzers no longer has a lower GWP burden than single use. If material recovery rates are very low in dialyzer recycling processes, recycling is no longer more beneficial than single use.
- Primary Recommendation – To reduce the overall impact of HD treatments, reduce power consumption in the use phase.
- Secondary Recommendation – There is no clear cut results on which dialyzer use methods – single use, reuse, or recycling – could minimize environmental impact for US dialysis clinics.

2 BACKGROUND

2.1 HEMODIALYSIS AND DIALYZER TYPES

Dialyzers are the cornerstone technology for hemodialysis, a life-sustaining therapy for individuals with kidney failure. Dialyzers consist of plastic fibers spun into thin tubes that function as a semipermeable membrane, permitting the transit of small and medium size molecules based on size and charge characteristics Cycling through one side of the membrane is pure fluid with specific electrolyte, chemical and acid-base concentrations; across the membrane, blood is pumped counter current through the tubes by the hemodialysis machine. Urea, metabolic products, salts, and water are removed from the blood via osmotic and hydrostatic forces across the semipermeable dialysis membrane. Back-diffusion can also occur, such that components of the dialysate enter the blood. This process simulates the natural function of the kidneys, providing kidney function roughly akin to about 25% of normal, and must be repeated often to maintain a healthy blood composition. Typical in-center hemodialysis occurs thrice weekly while home hemodialysis may occur up to 6 times each week.

This study explores three different types of dialyzer use strategies: single use, reprocessing (also called reuse), and recycling. The difference between these strategies is primarily in their usage patterns but also to a smaller extent in the material composition of the dialyzers. Single use dialyzers are used for a single dialysis session and then discarded as medical waste. Reusable dialyzers are used for a patient's multiple dialysis and are disinfected and stored between sessions. When a maximum number of uses is reached (there is no industry standard for this number) or the functionality of the dialyzer has diminished, they are then discarded as medical waste and replaced by a new reusable dialyzer. Recyclable dialyzers are used for a single session and then discarded as recyclable medical waste, after which they are sterilized, disassembled, and the materials are reclaimed. Both reusable and single use dialyzers are used today in the US, and there is debate over which strategy is safer and more cost effective (Lacson, Upadhyay, Lazarus). One large US hemodialysis provider - Fresenius Medical Care, which treats approximately 35% of dialysis patients - has shifted entirely away from reusable dialyzers (Lacson), while the other large chain - DaVita, which treats approximately 33% of dialysis patients - is moving back toward reusable dialyzers. Dialyzer recycling is a new initiative, with a pilot recycling program launched in 2011 by WasteManagement with several DaVita hemodialysis centers in Southern California.

2.2 HEMODIALYSIS IN THE US

More than 610,000 people in the US suffer from end stage renal disease, with close to 400,000 requiring regular hemodialysis as a life sustaining therapy (USRDS 2012). Estimates predict this number could double within thirty years (Stevens). Hemodialysis can simulate sufficient kidney function to extend life for many years in otherwise healthy individuals. However, hemodialysis expenses add up quickly; in the US, average per patient per year Medicare costs exceed $82,000for ESRD patients, with the cost specifically for outpatient hemodialysis costs of $31,415 (USRDS 2012).

2.3 HEMODIALYSIS GLOBALLY

In many developing nations, hemodialysis is considered as a short-term treatment for acute kidney failure, with chronic maintenance therapy available only to the wealthy (Jha, Nayak, Li, Carter). The difficulties delivering kidney replacement therapies, including hemodialysis, peritoneal dialysis and kidney transplantation, is an ongoing challenge in regions where chronic diseases like cardiovascular disease, obesity, and diabetes are becoming as relevant as infectious disease. Accordingly, resource conserving therapies have considerable importance, both in developed and developing nations.

2.4 POTENTIAL ENVIRONMENTAL IMPACTS OF HD

Dialysis treatments generate a number of environmental burdens. For example, thrice weekly hemodialysis regimens use about 1500 liters of water per week per patient (Agar 2009) To give a sense of scale of the amount of water consumed by renal hemodialysis in the US, consider that if an the amount of water used in hemodialysis for one patient for one year is 60% of the amount of water consumed per capita in the average American home (EPA WaterSense).

The suspected impacts of hemodialysis treatments include:

- Water consumption, especially in municipality facing droughts or other water constraints.
- GHGs and other environmentally harmful emissions to the atmosphere from combustion processes required for equipment production, patient transportation, and water processing.
- Carcinogenic and toxic hazards to human health from the life cycle of plastic medical accessories used each session, such as packaging, needles, and tubing.

2.5 EXISTING LITERATURE

There have been few thorough sustainability studies of hemodialysis technologies. This topic is addressed by three papers in the literature. The first is Hanson's "Towards Sustainable Design for Single-use Medical Devices" (2009) which measures the mass, strength, and plastic type of dialyzer component. Hanson's paper shows us three things: a first order approximation of GHG impact of dialyzers; the impact ratio of different types of plastics; and what portions of the dialyzer are recyclable. The second is Connor's "The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom" which compares hemodialysis regimens conducted in centers against at hemodialysis done at home. It shows us that hemodialysis treatments are sensitive to hemodialysis machine technology, hemodialysis prescription and duration, and patient travel. The third is Lacson's "Dialyzer Best Practice: Single Use or Reuse?" which examines the medical, economical, legal, and environmental repercussions of the disinfectants used in the reprocessing of reusable dialyzers between sessions.

2.6 LIFE CYCLE ASSESSMENT

A complete LCA has four basic components, (1) definition of the goal and scope, (2) inventory and data collection, (3) life cycle impact analysis, and (4) interpretation.

The first stage of an LCA is setting goals and defining the scope. Goals act as guidelines for the development of the study and to clearly define the intent of the study. The scope defines a specific set of rules that dictate how the model is built. A well-defined scope supports the goals of the study and reduces ambiguity in the model formulation. The scope defines the boundaries of what inputs are included, the rules for model formulation, allocation rules, impact categories considered, and how data quality is evaluated.

The second phase is inventory data collection. Data is collected on the processes of interest, as defined by the scope. Important data definitions include:

- Foreground data: Models of processes that do not yet exist in an LCI database and represent processes of interest.
- Background data: processes already in the LCA database that support the rest of the model .
- Primary data: data gathered by the researchers for this study.
- Secondary data: data from the literature or other sources.

In the third phase, impact assessment, the impact indicators are calculated. The LCIA method multiplies the model inputs and emissions by characterization factors to produce the impact indicators. There are two types of indicators:

- midpoint indicators – indicators which correspond to environmental phenomena
- endpoint indicators – indicators that use cultural assumptions and evaluation to combine multiple midpoint indicators into categories.

For example, human toxicity is an midpoint, but it could be aggregated with other midpoints that have human health impacts into a health endpoint.

The last phase in an LCA is interpretation. The interpretation phase addresses the study goals and draws conclusions, discusses limitations, and makes recommendations.

In the phases of LCA, there is quite a bit of room for ambiguity, misrepresentation, and error. In general, there are three important tools LCA's use to remain valid and scientific: transparency, consistency, and adherence to standards.

A fully transparency applies transparency to all phases of the LCA; goals and scope, inventory, impact assessment, and interpretation. This allows the audience to draw conclusions for themselves and avoid hidden biases and unexpected limitations.

The concept of consistency in LCA means that the scope is applied in a consistent way to the data and results. For example, a consistent LCA does not use different background database for different processes without reason, nor does it compare two products with difference scopes.

Standards in LCA are necessary in order to build a literature base where data can be compared across studies. Standards, like the ones discussed in section 2.7 LCA STANDARDS, help standardize the phases of LCA so that products can be more comparable across studies.

2.7 LCA STANDARDS

There are a growing number of standards for LCAs. This study employs many of the ISO 14040 standards. The ISO 14040 series is intended to provide information on how to conduct, review, present, and use an LCA. The standards define terminology, prescribe data quality guidelines, and aide contextually appropriate interpretation of results. They also carefully examine the limitations of LCA. There exist a number of more specific guidelines, some of which are also ISO14040 compliant, but they will not necessarily be adhered to for this study.

Since I am using the ecoinvent database as a background data, ecoinvent standards should be adhered to when incorporating new data to preserve consistency and comparability within the model (more about ecoinvent can be found in Section 4.8 DATA QUALITY ANALYSIS). These standards are outlined in the ecoinvent Overview and Methodology document (ecoinvent Methodology).

A standard transportation value will be used when there is not data on material transportation.

The GHG protocols are standards developed for carbon footprinting by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI).The GHG Protocol has very recently released a draft of a Sector Guidance Document (SGD) for Pharmaceuticals and Medical Devices (GHG Protocol). The draft addresses important issues in the definition of scope for medical devices, but is incomplete in its recommendations for later phases of the LCA. The SGD draft has only examined issues concerning GHG impacts so far, and provides limited guidance for LCAs hoping to examine the full spectrum of potential environmental impacts of a medical device. This LCA does not strive to conform to recommendations from the SGD draft.

3 GOALS

The first step of an LCA is setting goals. These goals were developed with Dr. Daniel Weiner (Assistant Professor of Medicine at Tufts University School of Medicine) and Dr. Stephen Levine (Professor of Civil and Environmental Engineering at Tufts University). These goals will act as guidelines for the development of the study and clearly define the intend of the study.

This LCA study has the following objectives:

1. Document the materials and energy that go into dialyzer use strategies and hemodialysis treatments. Making this data available for hemodialysis can help technology providers identify areas for potential environmental and economic improvement, inform patients' and doctors' search for their optimal modality, and could influence policy makers to investigate hidden costs and impacts.
2. Identify environmental "hotspots", processes with particularly significant environmental impacts in the life cycle. The identification of hotspots can spur industry to develop and implement improvements, especially if such improvements are inexpensive or "low hanging fruit."
3. Confirm or challenge the environmental claims made in the literature of the environmental impact of HD treatments.
4. Contribute to the generation of data on medical technologies, which is critical to carbon regulations and the potential for green medical technology initiatives.
5. Further inform the holistic comparison of single use, reusable, and recyclable dialyzer strategies.

One of intended applications of this study is to augment a project by Dr Weiner on the financial and medical performance of reused and single-use dialyzers. This study is funded by Dr Weiner's grant from the American Society of Nephrology. The study itself is a master thesis at the Tufts University and may be the basis of a paper on the environmental performance of reused and single-use dialyzers. This LCA is written for an audience specifically for LCA practitioners, those interested medical device design, and HD providers, but may also be of interest to other types of engineers and medical professionals. This study strives for ISO 14040 conformity, although it is not critical to the intended use of the results.

This study is intended to be used to guide the development of products and procedures in this field. Neither this study nor it's associated publications are intended to be the basis of any environmental product declarations nor of any comparative assertion regarding the environmental performance of one product over another. While some types of dialyzer’s and related products may be made exclusively for one type of use pattern (single-use, reuse, or recycle) this study is an analysis of a generic product with different use patterns rather than a comparison of two different products. This distinction is important in determining the type of critical review recommended by the ISO standards and this statement relating to the intended purpose is required for ISO 14040 conformity (ISO 14040, Lichenvort, Klopffer).

4 SCOPE

The scope defines a specific set of rules that dictate how the model is built. A well-defined scope reduces ambiguity in the model formulation and eases comparison across studies. This study examines the cradle-to-grave life cycle of the hemodialysis process rather than just parts of the dialyzer manufacture and use because dialyzer use and disposal choices have impacts that change the footprint of the entire hemodialysis procedure. Additionally, knowing the overall impact of hemodialysis treatments creates a more contextualized interpretation of dialyzer use and disposal choices.

4.1 SYSTEM DESCRIPTION

This LCA is a cradle-to-cradle analysis of the hemodialysis treatments. The study examines the following components though all their life cycle phases:

- Dialyzers (manufacture, reuse, and disposal)
- Dialysate (manufacture and disposal)
- Hemodialysis Water Requirements
- Hemodialysis Power Requirements
- Hemodialysis Supplies (fittings, tubing, and sanitary equipment for dialysis, and facility power and water requirements)
- Commuting (of patients, doctors, and staff)

Figure 1 gives a visual representation of how the system is organized.

4.2 FUNCTION AND FUNCTIONAL UNIT

As previously described, hemodialysis is a life sustaining medical treatment for people with kidney failure. Hemodialysis uses a medical device, a dialyzer, to administer a pharmaceutical, a dialysate, via an energy consuming machine, a hemodialysis machine.

4 SCOPE

The functional unit (FU) defines the quantity of the product that analysis considers. Appropriate functional unit selection allows for comparison between systems. For example, the functional unit for an LCA of concrete as a building material could use an FU either of mass of concrete or a FU of strength. Using a more complicated unit like strength, rather than just mass, allows for an easier comparison against other materials, in this case like wood or steel, but also requires more assumptions about the materials and how they are used in a building. Our functional unit will be a US standard hemodialysis session of about 3.5 hours in length, in sufficient quality and quantity to be used in a thrice weekly hemodialysis regimen. While this choice of FU may seem distinctly non-quantitative, the GHG Protocol's SGD supports a defining FUs on a per treatment basis for energy using medical devices, citing the importance of “focusing on the quantitative and qualitative aspects of the function (what, how much, how well and for how long” (GHG Protocol).

4.3 SYSTEM BOUNDARIES

System boundaries dictate which processes related to the product will be included in the LCA. In a cradle-to-cradle analysis, this is the whole lifecycle of the product including:

- Raw material extraction
- Transport of raw material to manufacturing locations
- Manufacturing processes
- Later transport and storage
- The product in use
- Disposal and recycling

Our scope includes the following components of hemodialysis treatments:

- Dialyzers (manufacture, reuse, and disposal)
- Dialysate (manufacture and disposal)

- Hemodialysis Water Requirements
- Hemodialysis Power Requirements
- Hemodialysis Supplies (fittings, tubing, and sanitary equipment for dialysis, fittings, tunings, and sanitary equipment for dialysis, and miscellaneous office requirements)
- Commuting (of patients, doctors, and staff)

Boundaries also include the requirements for the location and time frame of data, if necessary. This study will limit its geographical boundaries to the United States (US) and it's temporal boundaries to 2002-2012, because these boundaries are important for the goal of the study and the larger analysis it will support. These boundaries may be relevant, for example, to determine an appropriate mix of energy source used for the electricity grid at a "typical" session location. The need for further geographic specification may emerge as the model forms, and grid specific to certain regions or states may be explored as a model scenario. The geographical boundaries are also important in evaluating the data from our secondary source, the ecoinvent database, as that database specializes in data from Europe, not the US. The impacts of this database choices is explored further in Section 5.5 UNCERTAINITY & SENSITIVITY ANALYSIS. Temporal boundaries are important in determining the type of technologies and products ed in the model.

4.4 ALLOCATION RULES

Allocation methods partition product flows as they move in or out of the study system. There are several situations that require allocation rules in LCA. If a single process produces multiple products, there must be a rule for how the impact of that process is divided among the products. Additionally, there must be rules for how recycled materials add value to the original product. This can be particularly significant for plastic products, like dialyzers, where one oil source produces many types of plastics and components are often recyclable.

The ISO 14040 standards are used in this model to determine the preferred allocation procedures, including allocation avoidance, technical based partitioning, economic based partitioning, and assignment of values for recycled products. This project did not have many difficulties with allocation. There are no allocation procedures for the most significant processes in electricity, commuting, or disposable manufacture. The most significant allocation is the evaluation of reclaimed plastics from recycled dialyzers. This was modeled by defining the recovered materials as “avoided products” so that the system receives credit for the impacts that would have been expended to create polycarbonate from raw materials.

4.5 CUT-OFF CRITERIA

Not all of the processes that occur in the real world can be included in the model. Cut off criteria set conditions upon which an input may be excluded based on its low relative contribution to the mass, energy, and environmental impact. Though few inputs are excluded in this analysis due to cut-off criteria, it is important to have them defined.

- Mass: 5%
- Energy: 5%
- GWP: 5%

If a process is thought to contribute less than the cut off percent to the cumulative model in all of these categories, then it may be excluded. Inputs excluded due to cut off criteria can be found in Table 1: Cut Off Inputs, and the effect of the cut off inputs is analyzed in the sensitivity analysis in UNCERTAINITY & SENSITIVITY ANALYSIS

4.6 IMPACT INDICATOR SELECTION

After building the model, aspects of environmental performance are evaluated.

Indicators are metrics that quantify how much the product contributed to a particular environmental condition. Indicators can be straightforward physical metrics that address a single impact category (midpoints), or weighted and normalized to make complicated, value-based composites that consider a number of environmental phenomena (endpoints).

Category selection should ultimately support that goals of the LCA, but also must consider the limitations of the study. Typically, a portfolio of categories is chosen from the same LCIA method. This LCA's main indicator will be GWP from TRACI2 as implemented in SimaPro 7, but it will also examine in less detail acidification (AP), eutrophication (EP), smog creation (SC), respiratory effects (RE), carcinogenicity production (CP), non-carcinogenicity (NCP), and ozone depletion (OD), from that LCIA method. TRACI2 is a midpoint oriented LCIA methodology developed by the U.S. Environmental Protection Agency specifically for the US using input parameters consistent with US locations (US EPA). TRACI 2 incorporates characterization factors from USEtox, a toxicity calculating method, into its calculations for human cancer toxicity, human non cancer toxicity, and ecotoxicity (PRe Methods Manual). Indicators from TRACI 2 are favored for products in the US but are less are widely used that some other methods. To ensure that the results from TRACI are reasonable, results from TRACI2 will be checked against the LCIA method IMPACT 2002+ for consistency, and major discrepancies will be discussed in the uncertainty analysis. Details on the TRACI 2 LCIA methods are available in APPENDIX A: IMPACT INDICATORS. This LCIA methods avoids weighed and normalized endpoints, which are optional in ISO 14040 and means the needs of this study, as they will not support any of the project goals.

Climate change is the impact of most interest to this study, and will be included. There are a number of other impact categories to choose from regarding resource consumption, human health, and environmental phenomena. This study could very easily consider other air emission impacts like eutrophication, acidification, smog creation, and human respiratory effects in great detail, however, these air emissions based metrics correlate with GWP and will only be calculated and considered briefly.

Toxicity categories like human health and the many types of ecotoxicity (marine, freshwater, and, soil, air, and radiation) are difficult to implement and require more refined data on chemical use and exposure pathways than this generic model provides to be used accurately and reliably. This study calculates these metrics using only up-to-date LCIA methods and consider them with some skepticism.

Ozone depletion can be calculated but will not be investigated in detail.

Some impact categories like land use, land use change, water consumption, and mineral resource depletion, are relevant to the goals of the study but are difficult to implement in a reliable way due to lack of data in included processes or incompletely developed assessment methods, so these impacts will not be considered. Water use and consumption, in particular, is not investigated because the topics is to complex and important to be captured in a generic LCA. Studies on the water footprint of HD must be conducted with a different approach that is able to capture the nuances of tap water use, reject water disposal, and the effects of waste water treatment.

4.7 DATA

In this section the data collection process is described, as well has how data is put into the model and supported by background data. Tables of data, sources, and cut off processes are in APPENDIX B: TABLES. This LCA uses a model built in SimaPro v7.1.8, LCIA indicators from TRACI 2 v3.0.1 and LCI background data from ecoinvent v2.2. Ecoinvent was chosen as the background database because of its consistent process formulation and breadth and depth of available data.

4.7.1 Dialyzers

The scope of dialyzer processes includes manufacture, use, and disposal. See Table 2: Dialyzer Data Sources for the data and their sources. Dialyzer related processes include:

1. Dialyzer and dialyzer membrane manufacture.
2. Water, power, and chemical sterilants for dialyzer reuse.
3. Disposal processes for processes medical waste in a converter and disposal in a sanitary landfill, as well as processes for disassembly and material recycling.

The dialyzer manufacturing processes cover the raw materials, raw material transport, and thermoforming of the dialyzer plastic parts as documented by Hanson 2009, as well as the estimated amount of packaging and transport from the factory. The base scenario dialyzer has a polypropylene membrane. The energy and materials that go into different specialized membrane materials is not well documented, though the different membrane materials are explored in the sensitivity analysis. The sterilants used on the dialyzers before packaging are excluded in the cut-off criteria (an analysis in included in Table 1: Cut Off Inputs). The modeling of the dialyzer manufacturing and distribution is simplistic and likely misses some technical processes and procedures involved in making a medical device.

The reuse processes are based on data from the Renatron II reprocessing machine manual and the Renalin manual (Minntech Renatron, Minntech Renalin). Reprocessing requires RO water, drainage for the RO water and reject water, power, and a sterilant. The RO water, RO reject water, and electricity profile are all as described later in this section. The sterilant used in this model is peracetic acid (PAA) which is the most popular sterilant in the US, although others are used. The exact production methods of PAA for dialysis proposes is not available, so the simplest method of production from hydrogen peroxide, acetic acid, and a sulfur catalyst is implemented, as well as estimated amount of packaging and transport.

Ecoinvent does not have data on how PAA could effect PAA the water treatment burden. This presents a difficulty, because in the rinsing process, PAA released into the water treatment system and potentially also into the environment. However, some research into the fate of PAA in water treatment and the environment suggests that it quickly decays into acetic acid and hydrogen peroxide, both chemicals with low environmental harm (Eberle, Eide).

Disposal processes are modeled using a number of different data sources. The outgoing medical waste, both the dialysis fittings and the dialyzer, is first sterilized before continuing to recycling or the landfill. The type of sterilization in this model is heat sterilization via an autoclave or converter. The data for the converter are from a report that summarizes the energy consumption of some converters used in the UK and US (FOE). The land filling is the generic ecoinvent process for disposing of plastics in a municipal landfill in Switzerland. The recycling process uses 100km of transportation to a recycling center, where the dialyzer is dissembled and shredded, and polycarbonate from the housing is recovered. The 75% of the original mass of polycarbonate is estimated to be recovered and allocated as an avoided product. The shredding process is modeled with a ecoinvent process meant to model metal shredding, modified to be more like plastic shredding by eliminating the metal residue and emissions.

4.7.2 Dialysate

The scope of dialysate processes includes manufacture, use, and disposal. See Table 3: Dialysate Data Sources for the data and their sources. Dialysate related processes include:

1. Active ingredients and treatment water.
2. Packaging.

3. Disposal of used dialysate to the sewers

The active ingredients were taken from the manual of brand of dialysate. They are fairly representative of the ingredients in most dialysate. The shipping of the chemical ingredients is excluded under the cut off criteria. The model assumes that the ultra-pure RO water is made on the dialysate manufacturing site and assumes a fairly simplistic manufacturing process. The dialysate manufacturing data has a lot of estimated parameters and is likely not totally representative of the actual dialysate manufacturing process, which is quite complicated and controlled due to the dialysate's pharmaceutical nature.

The packaging and distribution assumes that the dialysate is distributed 100km via truck into a gallon jug container. The extra packaging is ignored in the phase under the cut off criteria, as it is has a small in relative mass because the gallon jugs are quite sturdy. The gallon jugs are modeled simply as 60 grams of HDPE blown out into a jug shape and then transported 100km to the dialysate manufacturer. Again, this is a fairly simplistic model of dialysate distribution that is not quite representative or complete enough to capture all the impacts of dialysate distribution.

After being used in the HD treatment, the volume of the diluted dialysate is released to the municipal sewer as “unpolluted”, to reflect the minimized burden on the water treatment system. The water treatment system is the ecoinvent system for Switzerland, the only area for which water treatment data exists in ecoinvent. The data for this waste water treatment is system is probably not too different from that from the US.

4.7.3 HD Water

The scope of the HD water supply processes includes water from the tap going into the RO machine, RO reject water, and RO water going into the HD machine. See Table 4: Machine Water and Power Sources for the data and their sources.

For the RO Machine, the reject water to RO water ratio was taken from a study of an Omsoflo RO machine (manufactured in 2001) in Australia (Agar 2009), and that value was compared to the value given by Dr Weiner for his clinic in downtown Boston, USA. Dr Weiner gave a slightly lower value of 1.2:1 than Agar's value of 1.5:1, so the value o 1. 2 is used in the model for the sake of representativeness (Weiner Comments). The only inputs to the RO Machine are tap water and power, refillable filter media are not included under the cut off criteria – too little of the media is exhaused per treatment to make a noticeable contribution to the environmental impact (see Table 1: Cut Off Inputs for a list of cut-off inputs and Section 4.5 for more information on cut-off criteria). The reject water is released to the municipal sewer as “unpolluted”, to reflect the minimized burden on the water treatment system.

For the water consumption of the HD machine, information from Dr Weiner on the typical dialysis prescription was used and double checked with Agar 2009 to determine the amount of water used during the treatment and in the pre- and post- treatment rinse cycles (Agar 2009, Weiner Interview Aug). The total from Agar was a bit less than that from this study's calculations (144 L vs 220 L per treatment) so the study uses it's own value rather than Agar's, as Agar's values are from dialysis done at different prescribed volume (300 mL/min for 480 minutes) that the standard treatment in the US.

The tap water data used is from ecoinvent. It represents the tap water averages from Europe, though it is not likely to be significantly different than the tap water systems in the US. The water treatment system is the ecoinvent system for Switzerland, the only area for which water treatment data exists in ecoinvent. The the data for this waste water treatment is system is probably not too different from that from the US.

4.7.4 HD Power

The scope of the HD power supply includes electricity to the RO machine and the HD machine. See Table 4: Machine Water and Power Sources for the data and their sources. Data for the consumption of power by the RO and HD machines were taken from Agar 2010, which were based an Omsoflo RO machine (manufactured in 2001) and Fresenius 4008 HD machines. These values were checked in part by the manual for the Fresenius HD machine, and seemed to agree. The total from Agar was 22.3 MJ for the power draw of a typical Australian cycle for the combined RO and HD machines and 19.8 MJ for a US typical HD Machine cycle from the Fresenius 5008 Manual – leaving 2.5 MJ per treatment for the RO portion, which sounds reasonable (Fresenius 5008 Therapy System). This study uses Agar's value of 22.3MJ for the combined power consumption for the sake of completeness, though it represents more the slightly longer typical Australian HD treatment than the shorter typical treatment in the US.

The electrical grid is a process from ecoinvent. It uses the average transmission losses and power source profile for the US.A table of the power source profile as in the ecoinvent database is in Table 7: Power Source Profile.

4.7.5 HD Supplies and Office Needs

The scope of HD supplies includes fittings, tubing, sanitary supplies, and office water and power. It is important to note that the many medications that are commonly but not necessarily administered to dialysis patients during the procedure are excluded for the scope. See Table 5: Misc. and Commute Data Sources for the data and their sources.

The processes used to model fitting are based on their estimated mass, material type, and transportation from manufacturing. These inputs are modeled very simplistically and are likely poor representatives of the actual processes.

The data for the office consumption of power and water are primarily from a big American dialysis provider's, Gambro's, annual corporate environmental audit (Gambro 2004). The audit reports total facility energy usage of 35 MJ per treatment. Subtracting the calculated 15 MJ from operation of RO and HD Machines leaves 20 MJ for other facility needs. Gambro 2004 reports "Approximately 700 liters of water are consumed per treatment, on average. This includes the amount used in water treatment processes, directly in the treatment, for disinfection and general consumption in the clinic". Subtracting the ~500 L consumed directly in the process, as reported in Agar 2009, leaves 200 L for office use. While the audit data could closely represent the power and water consumption in American office, the audit's data collect methods are not transparent and there could be big systemic difference in how Gambro manages its water and power that make it difference form the typical dialysis provider in the US.

4.7.6 Commuting

The scope of commuting includes the commute of patients, doctors, staff, and reuse technicians. See Table 5: Misc. and Commute Data Sources for the data and their sources. The commuting data was formed from data on dialysis patient commutes in the US, with data up to 2011 (Keller). The commuting data was double checked for consistency against the data from a Medpac 2012 report (Medpac 2012). The commuting vehicle was a passenger car process from ecoinvent, representing a passenger car vehicle with European fleet-average emissions. The commuting data is very specific to hemodialysis and of good quality, but the car process used to model the commute is not quite specific to the US. The base scenario uses the average commuting distance of 3.2 miles per treatment, but different commute differences meant to reflect travel distances for urban, suburban, and rural patients and staff are explored in the sensitivity analysis.

The model assumes that that doctors and staff work at a 1 to 4 ratio to patients and that doctors and staff travel the same distances as their patients as calculated in Keller. It also assumes that all patients, doctors, and staff drive themselves to the center, which seems unlikely given the health of the typical dialysis patient. However, the effect of another driver in the car is predicted to be minimal, as it is unlikely to affect gas consumption or car choice. The only situation this might significantly affect the results is if the driver uses this drive to co-commute to a job or necessary errand running. A sensitivity analysis explores the effect of variance in the commuting data.

4.7.7 Transport Standards

Many of the transport of supplies and waste in the foreground data are standardized to 100 km for lack of more specific and consistent data. This number is quite a bit higher than the standard transport distances recommended by the ecoinvent standards, but is more appropriate for a US based study. This assumption will be further analyzed in the sensitivity analysis in section 5.5. The transport processes are modeled as with the ecoinvent 3.5-16 ton truck process, using fleet average data from Europe, so the process used to model truck shipping is not specific to the US.

4.8 DATA QUALITY ANALYSIS

This study relies on background data from the ecoinvent data set. Ecoinvent has comprehensive, consistent, and quality controlled data and is considered a leading general purpose LCA database. The database consists of “more than 4’000 LCI data datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and specialty chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment” (ecoinvent Database.) Although it is a good and comprehensive database for this type of modeling it is important to keep in minds some of ecoinvent's drawbacks, such as lacking US specific coverage.

Consistent model formulation and data quality are critical to the validity of LCA models. Data must be standardized to include consistent and appropriate timescales, geographic regions, technology types, precision, completeness, and representativeness of data. Ideally, data is documented to the extent that the results could be reproduced. The ecoinvent data set is already very self-consistent, and the study attempts to preserve that consistency by adhering to ecoinvent formulation methods when incorporating new data or making estimations (ecoinvent Overview).

Table 6: Data Quality summarizes the qualitative data analysis of each data group from the section 4.7 DATA . The data groups are rated in terms of “GOOD”,”OK”, or “POOR” in the data quality categories designated by ISO 14040: representativeness, precision, completeness, consistency, reproducibility, geographical boundaries, temporal boundaries, and technology (ISO 14044). From this summary, it can be seen that there is some good data in the model, but that not all of the data is representative, and that the data from the dialysate and fitting and office groups is less good that the rest of the data. This will be important to keep in mind during the uncertainty analysis and interpretation phase.

4.9 LIMITATIONS

It is generally accepted that there are several types of sources of error and uncertainty in LCA (Baker, ILCD Handbook):

1. Missing, unrepresentative, or overly generic data. This type of error is difficult to test for or quantify, but can be discussed qualitatively.
2. Measurement error in primary data. This type of error is difficult to test for or quantify, but can be discussed qualitatively, including a discussion of measurement method precision and accuracy.
3. Natural variation in the represented processes. Some of this variation can be captured with stochastic values and analyzed in the model via analytically solutions or a Monte Carlo analysis. It can also be considered qualitatively.
4. The uncertainty introduced by decisions made in the model formulation,

including goal, scope, allocation, technology choice, and LCIA method. This can be analyzed to some extent by doing a sensitivity analysis for important model choices and assumptions.

5. Uncertainty in LCIA methods. Currently, very few LCIA methods incorporate stochastic uncertainty in the weighting factors for each substance. This is inaccuracy is difficult to quantify.
6. Difficulties translating the model to real outcomes due to forces not in the model (market forces, sourcing changes, future environmental problems, etc). This is obviously impossible test for or quantify within the model, but the applicability of the model can be considered qualitatively.

An uncertainty analysis is done to quantify the known uncertainty in the background data and model formulation. A sensitivity analysis is also conducted to ascertain the most environmentally critical components of these products in order to direct further research on this topic. Sensitivity analyzes are also done for key model decisions, including impact indicator choice.

5 RESULTS

5.1 GENERAL

The life cycle impacts of hemodialysis sessions done with single use, reuse, and recycled dialyzers can be seen in Figure 2 though Figure 6 and in tabular form in Table 8 through Table 14. Figure 2: Comparative Results shows the relative performance of the three scenarios for each of the nine impact indicators. In the most important category, GWP, the scenarios score closely, with reused and recycled scenarios having about 96% and 98% percent the impact of the single use scenario. The categories with the biggest difference between scenarios are NCP and OD for reasons that are explored in the following sections.

5.2 CLIMATE CHANGE

Figure 3: Comparative Global Warming (kg CO2) Impacts shows the contributions of individual processes to the GWP in each scenario. The HD session have a baseline of about 14.5 kg CO2 impact outside of dialyzer specific processes. Dialyzer manufacture, reuse, and disposal processes contribute another 1.4 to 2 kg CO2 to the GWP impact.

5.3 OTHER CATEGORIES

As expected, the patterns in AP, RE, and SC are similar due to the effects of air emissions from fossil fuel based energy. Reuse and recycle scenarios contribute 1 % to 7% less to these categories than single use. In the reuse and recycle scenarios, the AP, SC and RE are reduced by the decreased need for new dialyzers and landfill disposal by the need for additional shipping, power, commuting, and recycling energy.

OD has a different trend than the other inorganic emissions, reuse is notably higher than the single use and recycle scenarios. An analysis of the process contributions shows that the increase is attributed to the increase in motor vehicle use by the commuting technicians and the increase in power needs for dialyzer processing.

5.4 TOXICITY

The trends in NCP and CP are similar. A analysis of the process contributions shows that the reductions in these categories seem to be driven by the reduction in the amount of plastics disposed on in a landfill.

ET seems to have the same pattern as the other emissions categories – there is only a slight net reduction across scenarios – so we can deduct that they are likely driven by fossil fuel consumptions in the same manner.

5.5 UNCERTAINITY & SENSITIVITY ANALYSIS

5.5.1 Uncertainty in Background Data

A Monte Carlo analysis uses numerical experiments to show how the uncertainty data from many inputs propagate through a model to the results. See Figure 9: Background Uncertainty for the Monte Carlo analysis of the single use scenario using the uncertainty built into the background processes. The Monte Carlo analysis was done with over 300 runs. The vertical T-lines indicate the 95% confidence intervals. This graph only shows uncertainty from processes from the ecoinvent database, no uncertainty distributions were entered for the foreground processes. The graph also does not account for uncertainty in the LCIA, as TRACI 2 does not provide uncertainty values for its characterization factors.

The potential variance in all impact categories is quite large, especially in the human toxicity categories. This high uncertainty is typical in LCA and does not mean the results are abnormal, as much of the background data is from amalgamated sources and the uncertainty represents the natural variation present in the real world. High background uncertainty does not necessarily effect the differences between dialyzer scenarios, but it does mean that the impact of dialyzer scenarios may represent a much higher or lower portion of the total impact.

5.5.2 Commute

In the single use scenario, the commute of staff and patients contributes about 17.6% kg CO2 to the total GWP impact. However, the data for these commutes are the average data for the US. The data indicate that that rural and urban actually commute with at greater distances (Keller). Keller reports that rural dialysis patients must travel an average of 30 miles round trip. Keller makes no remark on the average for urban and suburban patients, but we can calculate the average for suburban and urban patients is 2.5 miles if we assume that 20% of dialysis patients live in a rural area (Medpac 2011). This means that the commute contributions are 3.75 times higher for rural patients, and only 1/3 thirds of the average value for urban patients.

It is important to note that this model does not taken into account travel via modes other than a personal car, and also does not account for other work or errands that many be conducted during the commute. This may lead to a slight overestimation of the environment impacts of the staff and patient commutes.

5.5.3 Staff Ratio

In the single use scenario, the commute of staff contributes about 3.5% to the total GWP impact. This assumes that there is 1:2 ratio of staff to patient ratio for the entire day, which means a 1:4 commute ratio for an individual session (as two sets of patients are treated). If the ratio is higher, such as 1:1 for the day, the commute ratio would be 1:2. this would double the contribution of staff commute.

In the reuse scenario, the reuse technician commute contributes 5.7% percent to the total GWP impact. This assumes that techs process 30 dialyzers per commute. If a tech is also a full time staff member or has other responsibilities, the contributions of their commute should be adjusted to reflect this. For example, burden can be allocated on the basis of time, so if a tech spends one half of their day reprocessing dialyzers and the other half acting as general staff, then one half of his commute is attributed to reprocessing. This burden could also be allocated on the basis of wage, but this is not explored in this study. The affect of different staff ratios on GWP can be seen in Table 16: Staff Ratios and Figure 17: Staff Ratios.

5.5.4 Transport

For the single use scenario, a network analysis of the GWP impact shows that 1.2% of the impact is from the transport of raw materials and good in the foreground process (see Figure 10: Network analysis of GWP – Single Use).This is likely because of the small mass of the transported products in this energy heavy process. This study doesn't have very good data for transport distances, but the estimate of a standard of 100km transport would have to be off by almost an order of magnitude to make a large difference in the GWP impacts.

5.5.5 Dialyzer Membranes

Figure 12: Dialyzer Membrane Materials Sensitivity Analysis shows the performance of four difference possible dialyzer materials relative to polypropylene. The polypropylene membrane used in the base scenarios has a GWP burden of about 0.5 kg CO2, compared to a total of 16.5 in the single use scenario.

This comparison is based on mass and assumes that all dialyzers membranes requires the same mass of plastic to function properly. While this study does not have very detailed data on the processes that go into manufacturing a dialyzer, this analysis shows that the choice of base plastic can have a large effect on the GWP impacts of dialyzer manufacture. For example, the membrane material with the highest GWP burden is polyamide, which has a score about 3.5 times higher than the polypropylene membrane. If this type of plastic were used in a dialyzer, it would noticeably increase the

GWP impact of the HD session.

5.5.6 Dialyzers

If dialyzer manufacturing has a larger impact than this study indicates, then relative benefits of dialyzer reuse are larger than predicted. If dialyzers are reused less than 18 times, then the relative benefits of reuse are over predicted.

5.5.7 Recycling Processes

Figure 13: Recycling Sensitivity Analysis shows the results of a sensitivity analysis on the plastic recovery yield and power requirements of the recycling process. The low and high yield processes represent a 50% and 90% recovery rate of the polycarbonate in the dialyzer (where the base scenarios have a 75% recovery rate). The low and high energy processes represent 50% and 150% of the power required to recycle the plastic. The analysis shows that yield is very important in determining the impact of the recycling process in all impact categories.

5.5.8 Impact Indicator Choice

The indicator scores given by TRACI 2 were checked for consistency against the LCIA method IMPACT2002. IMPACT 2002+ is an LCIA method that was originally developed at the Swiss Federal Institute of Technology – Lausanne. It has fifteen categories, including all those examined in TRACI2, except for smog creation. Figure 7: LCIA Method: IMPACT2002– Single Use and Figure 8: LCIA Method: IMPACT2002 – Scenarios show the results from IMPACT2002. The patterns in proportional contributions to GWP, air emissions, CP and NCP, and ecotoxicity seem very similar, as do the relationships between the three dialyzer scenarios.

5.5.9 Cut-off Criteria

The cut-off criteria for this study was 5% of mass, energy, or total GWP impact. Cut-off inputs and their values can be seen Table 1: Cut Off Inputs. the largest cut-off contribution is the building capital costs estimated to be 3% of the total GWP impact. Most of the other cut-off impacts are much smaller. The total cut off impact is estimated to be less that 7 percent.

6 INTERPRETATION

6.1 ENVIROMENTAL ISSUES

As an energy consuming medical treatment, the highest impacts are seen in the use phase. For the same reason, electricity consumption is the majority contributor to GWP, and the highest contributor in all other impact categories, with the exception of human toxicity impacts.

Patient and staff commuting is shown to be a significant contributor in many impact categories. It contributes about 20% of the GWP in the single use scenarios. Additionally, fittings are the majority contributors to human toxicity impacts and a significant contributor to ecotoxicity, smog, and eutrophication.

Reusing and recycling creates substantial reductions in the life cycle impacts of the dialyzers, but offers only modest benefits when put in context of the entire HD treatment. If commuting distances for reuse techs are too high – reusing dialyzers no longer has a lower GWP burden than single use. If material recovery rates are very low in dialyzer recycling processes, recycling is no longer more beneficial than single use.

6.2 LIMITATIONS

In terms of the simple quantification of impacts, we can have some confidence in the results. The data is of fair quality and the findings are within range of previous studies.

As for identifying major contributors to the impacts, again, there is a fair amount of confidence, especially since this confirms previous studies.

For comparing dialyzer use strategies, actual results will be highly variable. Relative performance depends heavily on staff commuting distances, recycling yields, and manufacturing energy, all of which are highly variable in the real world.

6.3 COMPARE AND CHALLENGE

Figure 16: Comparison to Other Studies illustrates the comparison to the only other HD LCA in the literature, Connor’s LCA of HD in the UK. Since Connor uses a different scope than this study, an “adjusted” version of his results is also shown on this chart, which reflect results that do not included contributions from other medical visits and machine installation, which are excluded from this study's scope. These adjustments bring the values between these studies into agreement. Connor shows higher relative benefits from reusing compared to single use, but this is because he omitted the power and staff requirements of reprocessing.

6.4 RECOMMENDATIONS

To reduce the overall impact of HD treatments, reduce power consumption in the use phase. On the dialyzer level, there is no clear cut results on which dialyzer use methods – single use, reuse, or recycling – could minimize environmental impact for US dialysis clinics.

6.5 FURTHER RESEARCH

As this study confirms the importance of commuting and energy consumptions and the literature has noted that HD treatments in the future may be longer and more frequent, future studies should address the alternative HD regimens (Connor). Also, implementing gray water reuse systems in dialysis clinics shows promise in reducing the therapy’s water footprint; it could be interesting to incorporate this water recovery into this analysis (Agar). Another possibility is to investigate the use of centralized, regional reprocessing centers for reusable dialyzers, especially for urban centers.

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APPENDIX A: IMPACT INDICATORS

Abbr	**Indicator Name**	**Unit**
GWP	Global Warming	kg CO2 eq
AP	Acidification	H+ moles eq
CP	Carcinogenics	kg benzen eq
NCP	Non carcinogenics	kg toluen eq
CP	Respiratory effects	kg PM2.5 eq
EP	Eutrophication	kg N eq
OD	Ozone depletion	kg CFC-11 eq
ET	Ecotoxicity	kg 2,4-D eq
SC	Smog	kg NOx eq

APPENDIX B: TABLES

Table 1: Cut Off Inputs

Input	Cut Off Reason	Estimate	Source
Dialysate – Manufacture Simplified	Extra energy for dialysate is likely very small compared to that required for HD Machine	0	Rodriduez
Dialysate – Raw Materials Shipping	Low mass of materials are suspended in the fluid, impact likely to be very small	0.002 t-km	Est
Dialysate – Shipping Packaging	Very small mass – the dialysate bins are quite sturdy.	0.010 kg	Est
Dialyzer – Effects of Reprocessing on Office Requirements	Reprocessing is done in a small space and only for a few hours few week.	0.21 MJ	Est based on HVAC reqs
Dialyzer – Manufacturing Sterilant	Two types of sterilizing were analyzed, Ethylene Oxide (EtO) and electron beam (e-beam). Eto was analyzed assuming a 20/80 mix of Eto and CO2, that 1% of the the dialyzer volume's (100mL) worth of gas is consumed in the process and emitted as a fugitive emission. The e-beam was modeled as consuming 0.04 kWh of electricity per mass of treated plastic.	See Table 15	OSHA, Fresenius Dialysis Products, "Irradiation, Biological, and Other Technologies"
Dialyzer – PAA Water Treatment Burden	PAA is thought to degrade easily into peroxide and acetic acid. (Eberle, Eide)	0 MJ	(Eberle, Eide)
Dialyzer – Peracetic Acid (PAA) Manufacture Energy	PAA is used in very small quantities.	0 MJ	Est
Dialyzer – Recycling Capital Costs of a Converter	Very small compared to the energy consumed in use phase.	0.02 MJ	Est (500 MJ for life cycle of converter, over 10 years processing 10 kg waste of day)
Fittings - Disposal of packaging	Very small mass compared to rest of materials.	0.001t-km and 0.010 kg landfill	
Fittings – Needles for Hemodialysis Tubing	Very small compared to rest of materials, and not particularly difficult to manufacture or dispose of.	1.5 MJ	Est (5 mj per kg for manu, use, and disposal each, times .1kg needle)
HD – Hemodialysis and RO Machine Capital Costs	Very small compared to the energy consumed in use phase.	0.15 MJ	Est (500 MJ for life cycle of converter, over 10 years 6 treatments a week)
Office – Office Building	Likely to have a small impact compared to power consumption over lifetime.	0.5 k CO2 eq	Est (0.5 t kco2 lifecycle impacts per m2, 16 sqm, building for 50 years)
Water – RO Filters & Maintenance	A very small amount of the filter media is exhausted for each treatment.	0.005 kg	

APPENDIX B: TABLES

Table 2: Dialyzer Data Sources

Process	Values	Source
Dialyzer – Manufacture	Transport of packaging and raw materials from plant for 100 km. Mass break down of dialyzer components from Hanson, thermoforming for manufacturing energy. Estimated packaging materials in packaging film and cardboard.	Hanson, Est
Dialyzer – Membrane Materials	The membrane mass of the ecoinvent base material (acrylonitrile, celloluse, polymade, polypropylene, and polyethylene) plus energy from thermoforming.	Hanson, Est
Dialyzer – Transport and Distribution	Transport of dialyzer and packaging for 100 km.	Est
Disposal – Converters	Waste travels an estimated 100km to the converter site (The standard ecoinvent distance of 10 km for waste because this is to a specialty waste center). Converter energy consumption from FOE Report	FOE, Est
Disposal – Landfill	Defined by ecoInvent: Waste travels 10km from converter site to municipal sanitary landfill.	EcoInvent
Recycling	All plastic is disinfected in a converter. Estimated 100 km transport from converter to recycling facility. All plastic is shredded with modified shredding process from ecoinvent. Not all plastic can be recycled – estimated 75% of the polycarbonate is recovered and the rest of dialyzer is land filled (10km transport to land fill included in disposal process.)	EcoInvent, Est.
Reuse	Water, Power, and Sewage treatment from Renatron II manual. Mass estimated for red bag for post dialyzer storage.	Renatron II, Est
Reuse – PAA	PAA made from acetic acid and hydrogen peroxide with a sulfur catalyst, packaged in HDPE and shipped 100km. Assumes the Peracetic is used in the cleaning liquid at 1 percent.	Eberle, Eide, PAA Manual, Est.

Table 3: Dialysate Data Sources

Process	Values	Source
Active Ingredients	Shipping of (3.5 kg) of the finished product for an estimated 100 km from dialysate manufacturing to treatment center. Transport of chemicals to manufacturing is cut off and likely to be very small. Assumes water is refined on site.	Citrasate Manual, Est
Disposal	Used dialysate is released to the municipal sewer system and represents a dilute, relatively unpolluted contribution the water treatment burden. (ecoinvent Class 2 plants serve a medium-large urban municipalities of about 71,000 people per plant.)	Weiner Interview Aug, Ecoinvent
Jug	Estimated 60 g of blown out HDPE from ecoInvent per jug. Transported 100km from packaging manufacturer.	Est

APPENDIX B: TABLES

Table 4: Machine Water and Power Sources

Process	Values	Source
Electrical Grid	Ecoinvent US power source gird and electrical grid.	Ecoinvent
HD Machine Water Consumption	220 liters total of RO Water. From a pre and post dialysis rinse of 32 L each and 750mL/min of dialysate for 3.5 hours.	Weiner Interview Aug, Agar 2009
Power Consumption	22.3 MJ per use, inc all power stages of HD machine, before and after rinsing with heat.	Agar 2010, checked in part with Fresnius 5008 HD Machine Manual
RO Water Input	2.5 Kg ecoinvent tap water input per 1 kg Ro water produced, 1.5kg reject water produced.	Agar 2009, Weiner Interview Aug

Table 5: Misc. and Commute Data Sources

Process	Values	Source
Commute – Doctors and Staff	Assumes one staff member commutes an average of 8 miles round trip to the center, the same as the average patient travel from Keller, using an ecoinvent passenger vehicle.. Assumes a 4 to 1 staff to patient ratio. Assumes one person in car.	Keller, Medpac 2012, ecoinvent.
Commute – Patients	Assumes patients commute an average of 8 miles round trip to the center. Using an ecoinvent passenger vehicle. Assumes one person in car.	Keller, Medpac 2012, ecoinvent.
Commute – Reuse Technicians	Assumes reuse techs commute an average of 8 miles round trip to the center, the same as the average patient travel from Keller, using an ecoinvent passenger vehicle.. Assumes techs process 30 dialyzers per commute. Assumes one person in car.	Keller, Medpac 2012, ecoinvent.
Commute – Vehicle	Passenger car process from Ecoinvent, representing a passenger car vehicle with European fleet-average emissions.	Ecoinvent
Fitting – Gloves	An estimated 0.010 of acrylonitirile and extrusion (assumes gloves weight 5 grams each) and 100km transport.	Weiner Interview Aug, Est
Fitting – Towels and bandages	An estimated 0.015 of woven cotton and 100km transport.	Weiner Interview Aug, Est
Fittings – Disposal	Waste is sanitized in a converter and then land filled – similar to dialyzer disposal.	See Dialyzer Disposal
Fittings – Tubing	0.38 kg PVC and extrusion and 100km transport, estimated based on 149 ml of 8mm tubing at a plastic density of 1.3 g/cm3.	Weiner Interview Aug, Est
Office – Power	20 MJ of electricity. Gambro 2004 reports total facility energy usage of 35 MJ per treatment. Minus 15 MJ from operation of RO and HD Machines, that leaves 20 MJ for other facility needs.	Gambro 2004
Office – Water	150 L of tap water. Gambro 2004 reports "Approximately 700 liters of water is consumed per treatment, on average. This includes the amount used in water treatment processes, directly in the treatment, for disinfection and general consumption in the clinic" . Minus the ~500 L consumed directly in the process, as reported in Agar 2009	Gambro 2004, Agar 2009

APPENDIX B: TABLES

Table 6: Data Quality

	Representativeness	**Precision**	**Completeness**	**Consistency**	**Reproducibility**	**Geographical**	**Temporal**	**Technology**
Dialyzer	OK	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
Dialysate	OK	OK	OK	OK	OK	OK	OK	OK
HD Power	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
HD Water	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
Fittings and Office	POOR	OK	OK	GOOD	GOOD	GOOD	GOOD	GOOD
Commute	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD

Table 7: Power Source Profile

Power Source Profile					
Input	**Amount**	**Unit**	**Unc. Dist.**	**Std. Dev**	**Source**
Electricity, hard coal, at power plant/US U	4.70E-01	kWh	Lognormal	1.05	national and international statistics
Electricity, nuclear, at power plant/US U	1.96E-01	kWh	Lognormal	1.05	national and international statistics
Electricity, natural gas, at power plant/US U	1.73E-01	kWh	Lognormal	1.05	national and international statistics
Electricity, production mix photovoltaic, at plant/US U	1.49E-04	kWh	Lognormal	1.05	national and international statistics
Electricity, hydropower, at power plant/SE U	7.28E-02	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, hydropower, at pumped storage power plant/US U	8.74E-03	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, oil, at power plant/UCTE U	3.32E-02	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, lignite, at power plant/UCTE U	2.34E-02	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, industrial gas, at power plant/UCTE U	9.89E-04	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, at wind power plant/RER U	3.51E-03	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, at cogen 6400kWth, wood, allocation exergy/CH U	9.64E-03	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available
Electricity, at cogen with biogas engine, allocation exergy/CH U	1.64E-03	kWh	Lognormal	1.3	national and international statistics; no US-specific dataset available

Note in EcoInvent documentation:
Included processes: It includes the shares of domestic electricity production by technology and imports from neighbouring countries (described by their production mixes) at the busbar of power plants. It does not include transformation, transport nor distribution losses. Remark: Electricity domestic net production and import shares are based on year 2004 data.
Remark: US-specific datasets for electricity production are only available in ecoinvent v2.0 for hard coal, nuclear, natural gas, and photovoltaic power plants (though with different modelling characteristics), which accounted together for about 85% of US electricity supply in year 2004. Other technologies are modeled using European datasets as first approximation. Electricity imports from Canada and Mexico were less than 1% of US electricity supply in 2004. Due to lack of datasets for these countries, electricity imports are modeled using for the different technologies the same datasets as for the US.; Geography: Data apply to utilities and self producers in the US. It includes imports from Canada and Mexico.
Technology: No technology description is provided because the dataset just describes the power plant portfolio of the country + imports using current (2000 - 2005) average technology per energy carrier

Table 8: Results – Single Use

Impact category	**Unit**	**Total**	**Dialysis Session (Single Use) (Extended Scope)**	**Dialysate, Gallon of Concentrate, at center**	**Power, RO and Dialysis Machine, per session**	**Dialysate, 220 L, Used, to drain**	**Dialyzer Disposal**	**RO Water, at Dialysis Machine**	**Fittings, for Dialysis (inc disposal)**	**Dialyzer, new, at center**	**Power, for Dialysis Center Office, per session**	**Commute, Doctors and Staff, per session**	**Commute, Patient, per session**	**Office Water, per dialysis session**
Global Warming	kg CO2 eq	1.66E+01	0.00E+00	3.33E-01	5.16E+00	1.27E-01	3.00E-02	3.03E-01	1.34E+00	1.72E+00	4.63E+00	5.84E-01	2.34E+00	2.33E-02
Acidification	H+ moles eq	4.91E+00	0.00E+00	1.05E-01	1.85E+00	3.50E-02	5.08E-03	7.67E-02	3.64E-01	3.28E-01	1.66E+00	9.61E-02	3.85E-01	4.56E-03
Carcinogenics	kg benzen eq	1.56E-01	0.00E+00	2.08E-03	1.23E-02	1.25E-03	3.52E-02	2.57E-03	8.62E-02	1.24E-03	1.10E-02	6.78E-04	2.71E-03	3.12E-04
Non carcinogenics	kg toluen eq	3.49E+03	0.00E+00	6.36E+00	3.81E+01	2.45E+01	1.17E+03	5.46E+01	2.11E+03	2.56E+01	3.41E+01	3.93E+00	1.57E+01	7.67E+00
Respiratory effects	kg PM2.5 eq	2.54E-02	0.00E+00	4.84E-04	9.80E-03	1.47E-04	1.72E-05	4.06E-04	1.65E-03	1.86E-03	8.79E-03	4.44E-04	1.78E-03	3.43E-05
Eutrophication	kg N eq	2.86E-02	0.00E+00	9.82E-04	9.74E-04	6.51E-03	2.99E-03	7.85E-03	6.35E-03	8.12E-04	8.73E-04	2.54E-04	1.01E-03	7.63E-06
Ozone depletion	kg CFC-11 eq	7.56E-07	0.00E+00	2.88E-08	1.37E-07	6.89E-09	2.60E-09	1.61E-08	2.49E-08	2.66E-08	1.23E-07	7.75E-08	3.10E-07	1.86E-09
Ecotoxicity	kg 2,4-D eq	4.07E+01	0.00E+00	3.24E-01	1.06E+01	3.72E+00	1.09E+00	7.68E+00	3.61E+00	1.13E+00	9.53E+00	4.04E-01	1.62E+00	9.37E-01
Smog	kg NOx eq	3.45E-02	0.00E+00	1.73E-03	9.99E-03	3.12E-04	9.57E-05	6.96E-04	3.36E-03	3.28E-03	8.96E-03	1.21E-03	4.84E-03	5.86E-05

APPENDIX B: TABLES

Table 9: Results – Reuse

Impact category	Unit	Total	Dialysis Session (Reuse) (Extended Scope)	Dialysate, Gallon of Concentrate, at center	Power, RO and Dialysis Machine, per session	Dialysate, 220 L, Used, to drain	Dialyzer Disposal	RO Water, at Dialysis Machine	Fittings, for Dialysis (inc disposal)	Dialyzer, new, at center	Dialyzer Reprocessing	Power, for Dialysis Center Office, per session	Commute, Doctors and Staff, per session	Commute, Patient, per session	Commute, Reuse Technicians, per session	Office Water, per dialysis session
Global Warming	kg CO2 eq	1.63E+01	0.00E+00	3.33E-01	5.16E+00	1.27E-01	1.80E-03	3.03E-01	1.34E+00	1.03E-01	3.97E-01	4.63E+00	5.84E-01	2.34E+00	9.35E-01	2.33E-02
Acidification	H+ moles eq	4.84E+00	0.00E+00	1.05E-01	1.85E+00	3.50E-02	3.05E-04	7.67E-02	3.64E-01	1.97E-02	9.24E-02	1.66E+00	9.61E-02	3.85E-01	1.54E-01	4.56E-03
Carcinogenics	kg benzen eq	1.24E-01	0.00E+00	2.08E-03	1.23E-02	1.25E-03	2.11E-03	2.57E-03	8.62E-02	7.44E-05	1.52E-03	1.10E-02	6.78E-04	2.71E-03	1.09E-03	3.12E-04
Non carcinogenics	kg toluen eq	2.39E+03	0.00E+00	6.36E+00	3.81E+01	2.45E+01	7.02E+01	5.46E+01	2.11E+03	1.53E+00	2.41E+01	3.41E+01	3.93E+00	1.57E+01	6.28E+00	7.67E+00
Respiratory effects	kg PM2.5 eq	2.49E-02	0.00E+00	4.84E-04	9.80E-03	1.47E-04	1.03E-06	4.06E-04	1.65E-03	1.12E-04	5.06E-04	8.79E-03	4.44E-04	1.78E-03	7.11E-04	3.43E-05
Eutrophication	kg N eq	2.65E-02	0.00E+00	9.82E-04	9.74E-04	6.51E-03	1.79E-04	7.85E-03	6.35E-03	4.87E-05	1.09E-03	8.73E-04	2.54E-04	1.01E-03	4.06E-04	7.63E-06
Ozone depletion	kg CFC-11 eq	9.04E-07	0.00E+00	2.88E-08	1.37E-07	6.89E-09	1.56E-10	1.61E-08	2.49E-08	1.60E-09	5.17E-08	1.23E-07	7.75E-08	3.10E-07	1.24E-07	1.86E-09
Ecotoxicity	kg 2,4-D eq	4.11E+01	0.00E+00	3.24E-01	1.06E+01	3.72E+00	6.56E-02	7.68E+00	3.61E+00	6.80E-02	1.84E+00	9.53E+00	4.04E-01	1.62E+00	6.46E-01	9.37E-01
Smog	kg NOx eq	3.42E-02	0.00E+00	1.73E-03	9.99E-03	3.12E-04	5.74E-06	6.96E-04	3.36E-03	1.97E-04	8.73E-04	8.96E-03	1.21E-03	4.84E-03	1.94E-03	5.86E-05

APPENDIX B: TABLES

Table 10: Results – Recycle

Impact category	Unit	Total	Dialysis Session (Recycling) (Extended Scope)	Dialysate, Gallon of Concentrate, at center	Power, RO and Dialysis Machine, per session	Dialysate, 220 L, Used, to drain	RO Water, at Dialysis Machine	Fittings, for Dialysis (inc disposal)	Dialyzer, new, at center	Dialyzer Recycling	Power, for Dialysis Center Office, per session	Commute, Doctors and Staff, per session	Commute, Patient, per session	Office Water, per dialysis session
Global Warming	kg CO2 eq	1.58E+01	0.00E+00	3.33E-01	5.16E+00	1.27E-01	3.03E-01	1.34E+00	1.72E+00	-7.82E-01	4.63E+00	5.84E-01	2.34E+00	2.33E-02
Acidification	H+ moles eq	4.77E+00	0.00E+00	1.05E-01	1.85E+00	3.50E-02	7.67E-02	3.64E-01	3.28E-01	-1.30E-01	1.66E+00	9.61E-02	3.85E-01	4.56E-03
Carcinogenics	kg benzen eq	1.39E-01	0.00E+00	2.08E-03	1.23E-02	1.25E-03	2.57E-03	8.62E-02	1.24E-03	1.87E-02	1.10E-02	6.78E-04	2.71E-03	3.12E-04
Non carcinogenics	kg toluen eq	2.94E+03	0.00E+00	6.36E+00	3.81E+01	2.45E+01	5.46E+01	2.11E+03	2.56E+01	6.23E+02	3.41E+01	3.93E+00	1.57E+01	7.67E+00
Respiratory effects	kg PM2.5 eq	2.46E-02	0.00E+00	4.84E-04	9.80E-03	1.47E-04	4.06E-04	1.65E-03	1.86E-03	-8.10E-04	8.79E-03	4.44E-04	1.78E-03	3.43E-05
Eutrophication	kg N eq	2.70E-02	0.00E+00	9.82E-04	9.74E-04	6.51E-03	7.85E-03	6.35E-03	8.12E-04	1.38E-03	8.73E-04	2.54E-04	1.01E-03	7.63E-06
Ozone depletion	kg CFC-11 eq	7.56E-07	0.00E+00	2.88E-08	1.37E-07	6.89E-09	1.61E-08	2.49E-08	2.66E-08	2.67E-09	1.23E-07	7.75E-08	3.10E-07	1.86E-09
Ecotoxicity	kg 2,4-D eq	3.99E+01	0.00E+00	3.24E-01	1.06E+01	3.72E+00	7.68E+00	3.61E+00	1.13E+00	3.30E-01	9.53E+00	4.04E-01	1.62E+00	9.37E-01
Smog	kg NOx eq	3.32E-02	0.00E+00	1.73E-03	9.99E-03	3.12E-04	6.96E-04	3.36E-03	3.28E-03	-1.21E-03	8.96E-03	1.21E-03	4.84E-03	5.86E-05

APPENDIX B: TABLES

Table 11: Relative Impacts of Dialyzer Scenarios

Impact category	Single Use	Reuse	Recycle
Global Warming	1	0.98	0.95
Acidification	1	0.99	0.97
Carcinogenics	1	0.8	0.89
Non carcinogenics	1	0.69	0.84
Respiratory effects	1	0.98	0.97
Eutrophication	1	0.93	0.94
Ozone depletion	1	1.2	1
Ecotoxicity	1	1.01	0.98
Smog	1	0.99	0.96

Table 12: Relative Contribution by Inventory Category – Single Use

Impact category (Unit)	Total	Dialyzer Manufacture	Dialyzer Disposal	Dialysate	HD Water	HD Power	Office Power	Office Water	Fittings	Commute
Global Warming (kg CO2 eq)	100.0%	10.4%	0.2%	2.8%	1.8%	31.1%	27.9%	0.14%	8.1%	17.6%
Acidification (H+ moles eq)	100.0%	6.7%	0.1%	2.9%	1.6%	37.7%	33.8%	0.09%	7.4%	9.8%
Carcinogenics (kg benzen eq)	100.0%	0.8%	22.6%	2.1%	1.7%	7.9%	7.1%	0.20%	55.4%	2.2%
Non carcinogenics (kg toluen eq)	100.0%	0.7%	33.5%	0.9%	1.6%	1.1%	1.0%	0.22%	60.4%	0.6%
Respiratory effects (kg PM2.5 eq)	100.0%	7.3%	0.1%	2.5%	1.6%	38.6%	34.6%	0.14%	6.5%	8.7%
Eutrophication (kg N eq)	100.0%	2.8%	10.5%	26.2%	27.4%	3.4%	3.1%	0.03%	22.2%	4.4%
Ozone depletion (kg CFC-11 eq)	100.0%	3.5%	0.3%	4.7%	2.1%	18.2%	16.3%	0.25%	3.3%	51.3%
Ecotoxicity (kg 2,4-D eq)	100.0%	2.8%	2.7%	9.9%	18.9%	26.1%	23.4%	2.31%	8.9%	5.0%
Smog (kg NOx eq)	100.0%	9.5%	0.3%	5.9%	2.0%	28.9%	26.0%	0.17%	9.7%	17.5%

Table 13: Contribution by Inventory Category – Single Use

Impact category (Unit)	Total	Dialyzer Manufacture	Dialyzer Disposal	Dialysate	HD Water	HD Power	Office Power	Office Water	Fittings	Commute
Global Warming (kg CO2 eq)	100.0%	10.4%	0.2%	2.8%	1.8%	31.1%	27.9%	0.14%	8.1%	17.6%
Acidification (H+ moles eq)	100.0%	6.7%	0.1%	2.9%	1.6%	37.7%	33.8%	0.09%	7.4%	9.8%
Carcinogenics (kg benzen eq)	100.0%	0.8%	22.6%	2.1%	1.7%	7.9%	7.1%	0.20%	55.4%	2.2%
Non carcinogenics (kg toluen eq)	100.0%	0.7%	33.5%	0.9%	1.6%	1.1%	1.0%	0.22%	60.4%	0.6%
Respiratory effects (kg PM2.5 eq)	100.0%	7.3%	0.1%	2.5%	1.6%	38.6%	34.6%	0.14%	6.5%	8.7%
Eutrophication (kg N eq)	100.0%	2.8%	10.5%	26.2%	27.4%	3.4%	3.1%	0.03%	22.2%	4.4%
Ozone depletion (kg CFC-11 eq)	100.0%	3.5%	0.3%	4.7%	2.1%	18.2%	16.3%	0.25%	3.3%	51.3%
Ecotoxicity (kg 2,4-D eq)	100.0%	2.8%	2.7%	9.9%	18.9%	26.1%	23.4%	2.31%	8.9%	5.0%
Smog (kg NOx eq)	100.0%	9.5%	0.3%	5.9%	2.0%	28.9%	26.0%	0.17%	9.7%	17.5%

APPENDIX B: TABLES

Table 14: Contributions of Dialyzer Specific Processes to All Impact Categories

	Process (TOTAL)	Dialyzer, new, at center	Dialyzer Disposal	Dialyzer Reprocessing	Dialyzer Recycling	Commute, Reuse Technicians, per session	Total
Global Warming (kg CO2 eq)	Single Use (1.7)	1.72	0.03	0.00	0.00	0.00	1.75
	Reuse (1.4)	0.10	0.00	0.40	0.00	0.93	1.44
	Recycle (0.94)	1.72	0.00	0.00	-0.78	0.00	0.94
Acidification (H+ moles eq)	Single Use (0.33)	3.28E-001	5.08E-003	0	0	0	3.33E-001
	Reuse (0.27)	1.97E-002	3.05E-004	9.24E-002	0	1.54E-001	2.66E-001
	Recycle (0.2)	3.28E-001	0	0	-1.30E-001	0	1.97E-001
Carcinogenics (kg benzen eq)	Single Use (0.036)	1.24E-003	3.52E-002	0	0	0	3.64E-002
	Reuse (0.0048)	7.44E-005	2.11E-003	1.52E-003	0	1.09E-003	4.79E-003
	Recycle (0.02)	1.24E-003	0	0	1.87E-002	0	2.00E-002
Non carcinogenics (kg toluen eq)	Single Use (1200)	2.56E+001	1.17E+003	0	0	0	1.19E+003
	Reuse (100)	1.53E+000	7.02E+001	2.41E+001	0	6.28E+000	1.02E+002
	Recycle (650)	2.56E+001	0	0	6.23E+002	0	6.49E+002
Respiratory effects (kg PM2.5 eq)	Single Use (0.0019)	1.86E-003	1.72E-005	0	0	0	1.88E-003
	Reuse (0.0013)	1.12E-004	1.03E-006	5.06E-004	0	7.11E-004	1.33E-003
	Recycle (0.0011)	1.86E-003	0	0	-8.10E-004	0	1.05E-003
Eutrophication (kg N eq)	Single Use (0.0038)	8.12E-004	2.99E-003	0	0	0	3.80E-003
	Reuse (0.0017)	4.87E-005	1.79E-004	1.09E-003	0	4.06E-004	1.72E-003
	Recycle (0.0022)	8.12E-004	0	0	1.38E-003	0	2.19E-003
Ozone depletion (kg CFC-11 eq)	Single Use	2.66E-008	2.60E-009	0	0	0	2.92E-008
	Reuse	1.60E-009	1.56E-010	5.17E-008	0	1.24E-007	1.77E-007
	Recycle	2.66E-008	0	0	2.67E-009	0	2.93E-008
Ecotoxicity (kg 2,4-D eq)	Single Use (2.2)	1.13E+000	1.09E+000	0	0	0	2.23E+000
	Reuse (2.6)	6.80E-002	6.56E-002	1.84E+000	0	6.46E-001	2.62E+000
	Recycle (1.5)	1.13E+000	0	0	3.30E-001	0	1.46E+000
Smog (kg NOx eq)	Single Use (0.0034)	3.28E-003	9.57E-005	0	0	0	3.37E-003
	Reuse (0.003)	1.97E-004	5.74E-006	8.73E-004	0	1.94E-003	3.01E-003
	Recycle (0.0021)	3.28E-003	0	0	-1.21E-003	0	2.07E-003

Table 15: Contributions of Dialyzer Specific Processes to All Impact Categories

Impact category	Unit	Dialysis Session (Single Use) (Extended Scope)	Dialyzer Manufacture, 20/80 ETO/CO2 Sterilization	Dialyzer Manufacture, Ebeam Sterilization
Global Warming	kg CO2 eq	1.66E+001	8.11E-005	7.66E-003
Acidification	H+ moles eq	4.91E+000	6.35E-006	2.75E-003
Carcinogenics	kg benzen eq	1.56E-001	9.85E-005	1.83E-005
Non carcinogenics	kg toluen eq	3.49E+003	5.87E-003	5.65E-002
Respiratory effects	kg PM2.5 eq	2.54E-002	3.62E-008	1.45E-005
Eutrophication	kg N eq	2.86E-002	1.10E-008	1.45E-006
Ozone depletion	kg CFC-11 eq	7.56E-007	2.18E-012	2.04E-010
Ecotoxicity	kg 2,4-D eq	4.07E+001	4.34E-005	1.58E-002
Smog	kg NOx eq	3.45E-002	2.15E-007	1.48E-005

Table 16: Staff Ratios

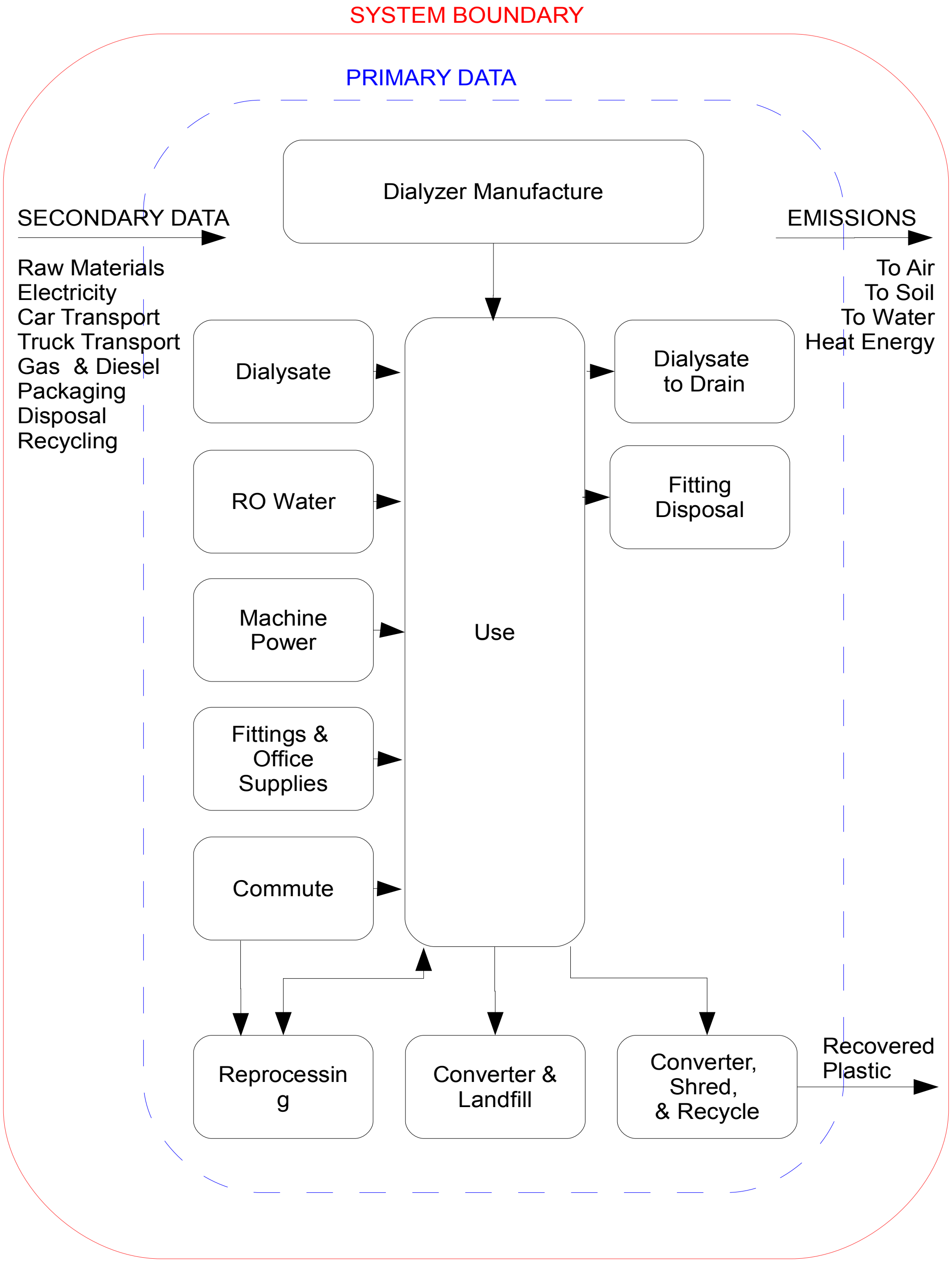
Ratio	Scenario	GWP Staff	GWP Techs	GWP Other	GWP Total	% Total
1 to 1	1:1 SU	2.34	0	16	18.34	0.13
1 to 1	1:1 full time RU	2.34	0.93	14.75	18.02	0.18
1 to 1	1:1 half time RU	2.34	0.47	14.75	17.56	0.16
1 to 2	1:2 SU	1.17	0	16	17.17	0.07
1 to 2	1:2 full time RU	1.17	0.93	14.75	16.86	0.12
1 to 2	1:2 half time RU	1.17	0.47	14.75	16.39	0.1
1 to 4	1:4 SU*	0.58	0	16	16.58	0.04
1 to 4	1:4 full time RU*	0.58	0.93	14.75	16.27	0.09
1 to 4	1:4 half time RU	0.58	0.47	14.75	15.8	0.07

*Starred scenarios are in the original analysis

APPENDIX C: FIGURES

Figure 1: Scope

This is the scope of the project.



APPENDIX C: FIGURES

Figure 2: Comparative Results

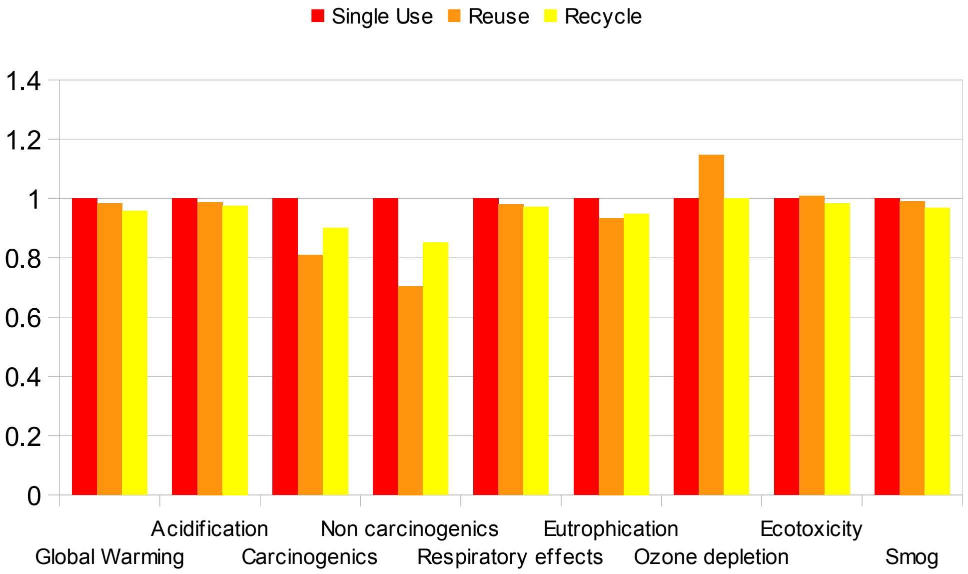
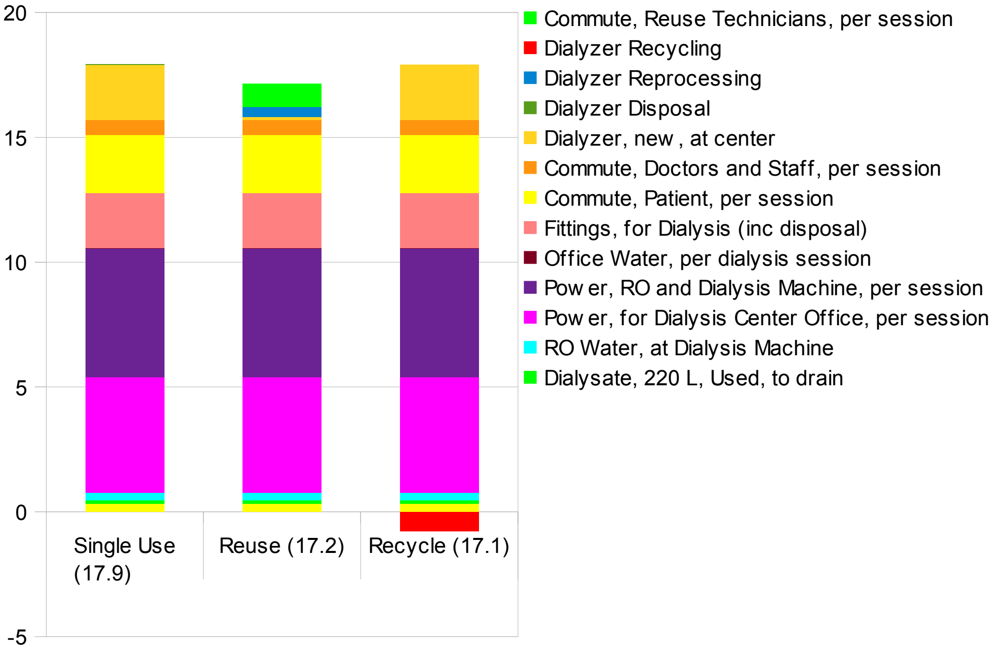


Figure 3: Comparative Global Warming (kg CO2) Impacts



***Red recycling processes actually represent negative contributions.**

APPENDIX C: FIGURES

Figure 4: Single Use Distribution of Impacts

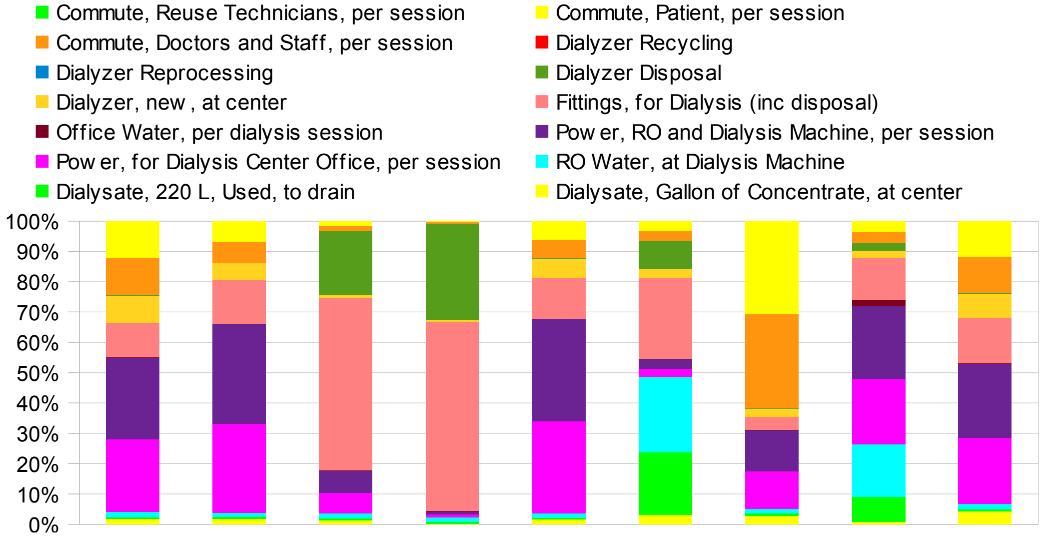


Figure 5: Reuse Distribution of Impacts

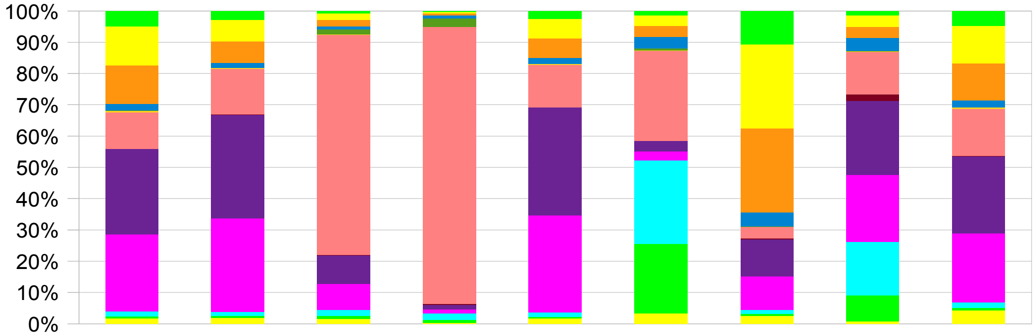
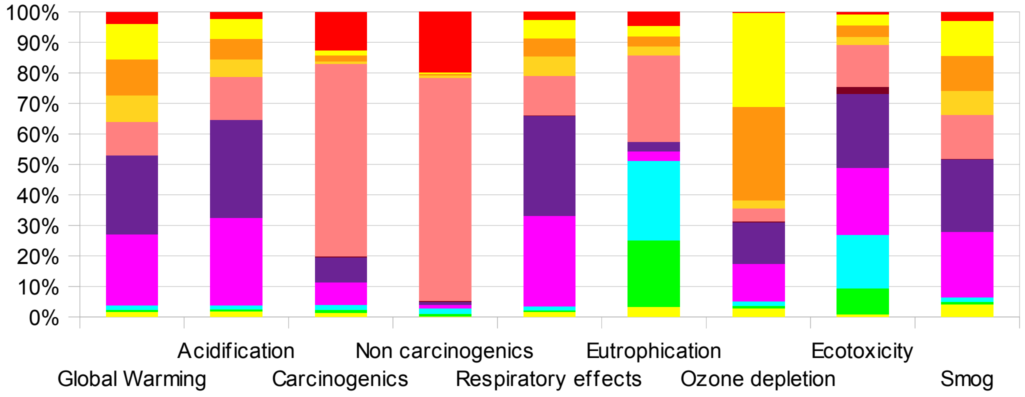
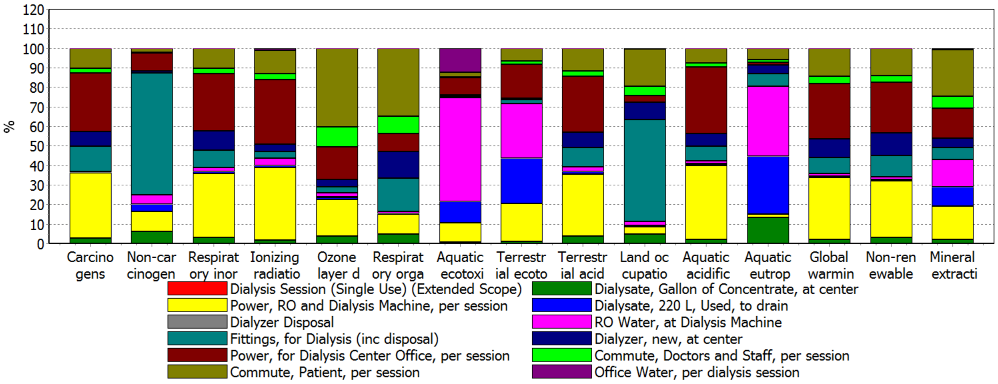


Figure 6: Recycle Distribution of Impacts



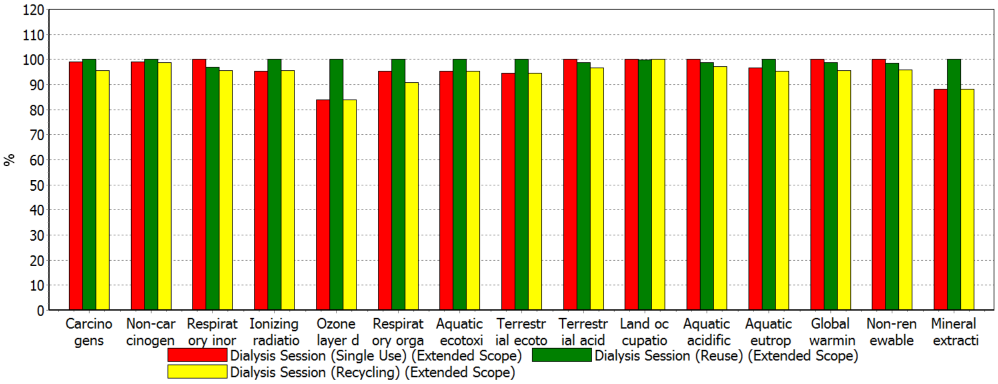
*Red recycling processes actually represent negative contributions.

Figure 7: LCIA Method: IMPACT2002– Single Use



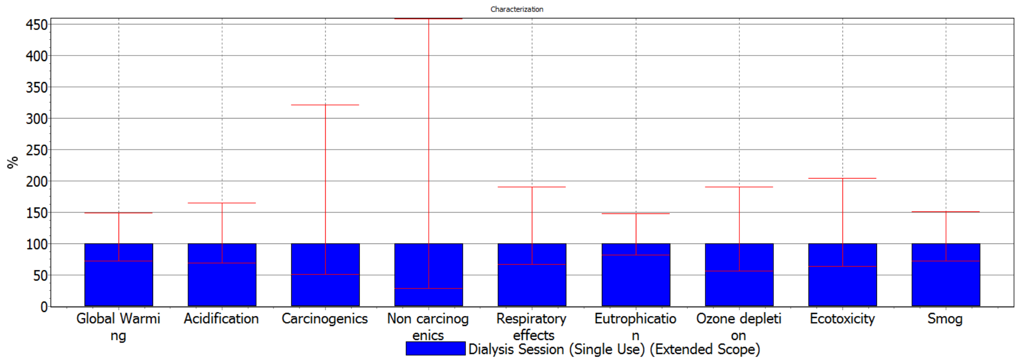
Analyzing 1 p 'Dialysis Session (Single Use) (Extended Scope)'; Method: IMPACT 2002+ V2.05 / IMPACT 2002+ / characterization

Figure 8: LCIA Method: IMPACT2002 – Scenarios



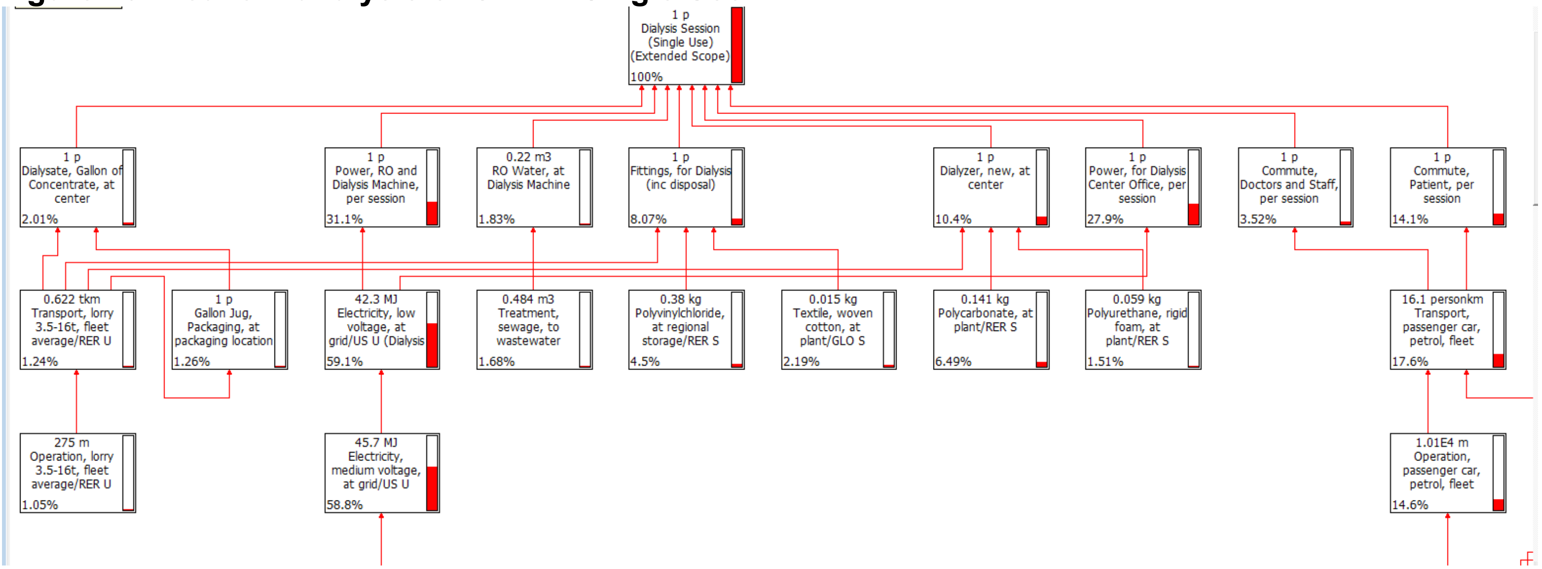
Comparing 1 p 'Dialysis Session (Single Use) (Extended Scope)', 1 p 'Dialysis Session (Reuse) (Extended Scope)' and 1 p 'Dialysis Session (Recycling) (Extended Sco

Figure 9: Background Uncertainty



Uncertainty analysis of 1 p 'Dialysis Session (Single Use) (Extended Scope)',
method: TRACI 2 V3.01, confidence interval: 95 %

Figure 10: Network analysis of GWP – Single Use



APPENDIX C: FIGURES

Figure 11: Commute Sensitivity Analysis

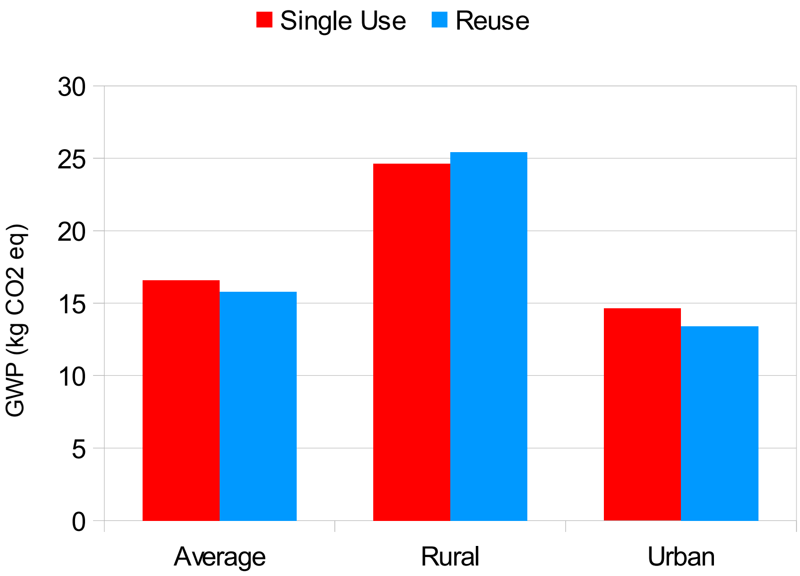


Figure 12: Dialyzer Membrane Materials Sensitivity Analysis

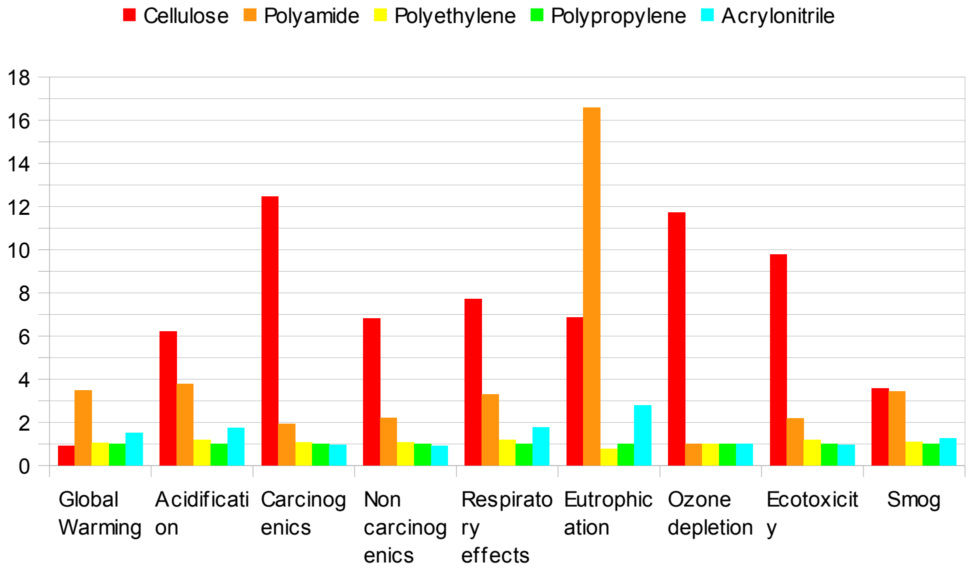


Figure 13: Recycling Sensitivity Analysis

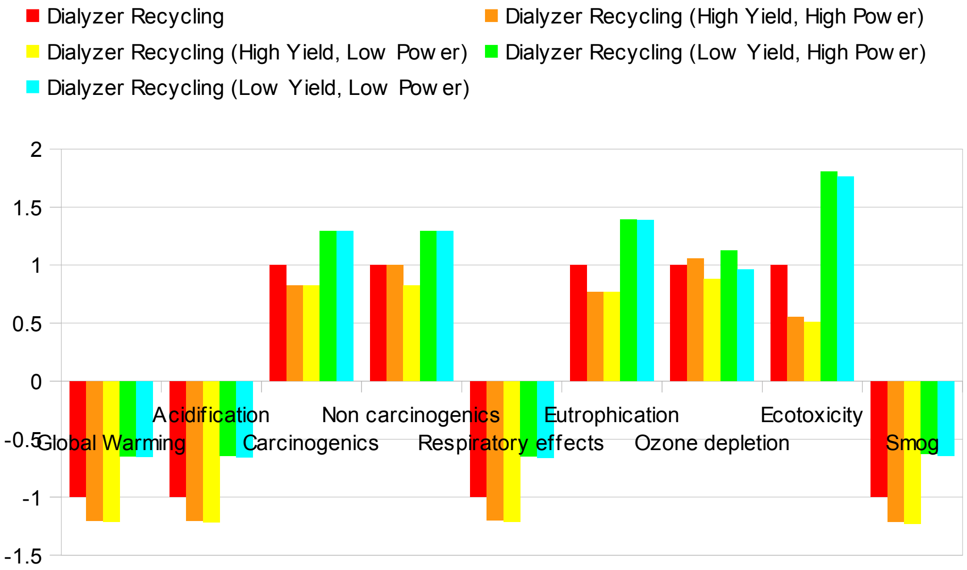
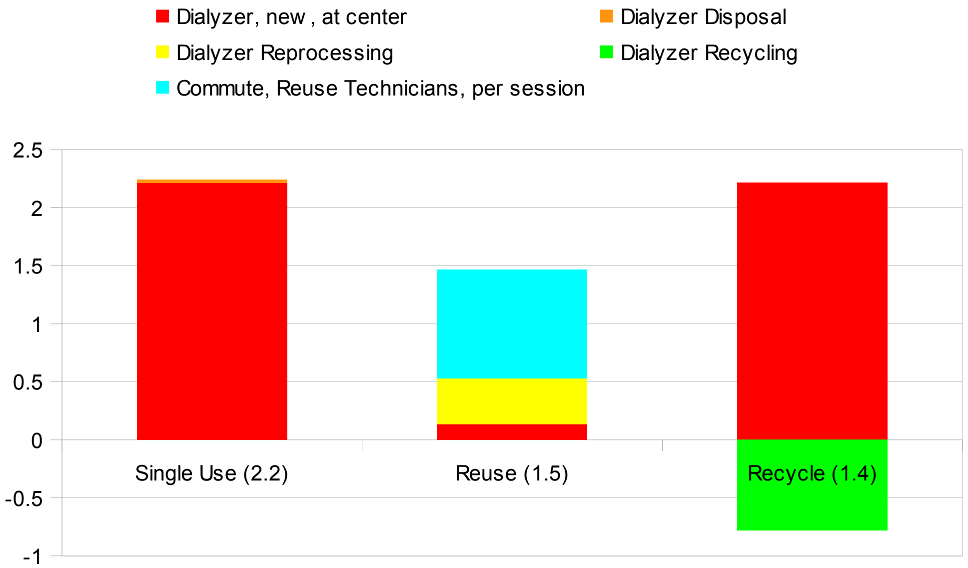


Figure 14: GWP Impact of Dialyzer Specific Processes



APPENDIX C: FIGURES

Figure 15: All Impacts of Dialyzer Specific Processes

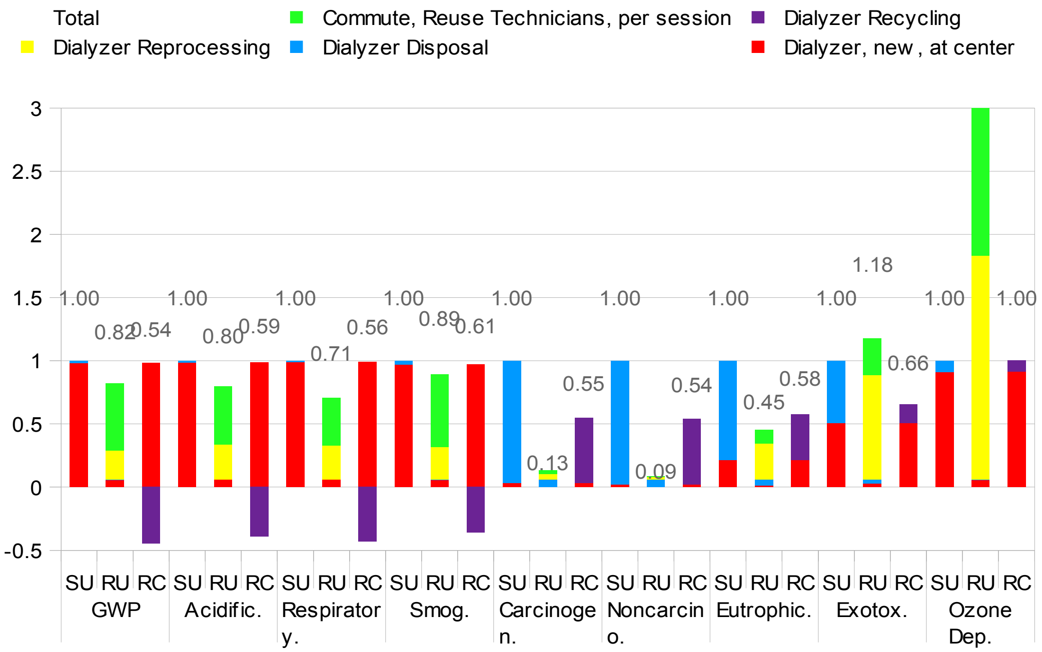


Figure 16: Comparison to Other Studies

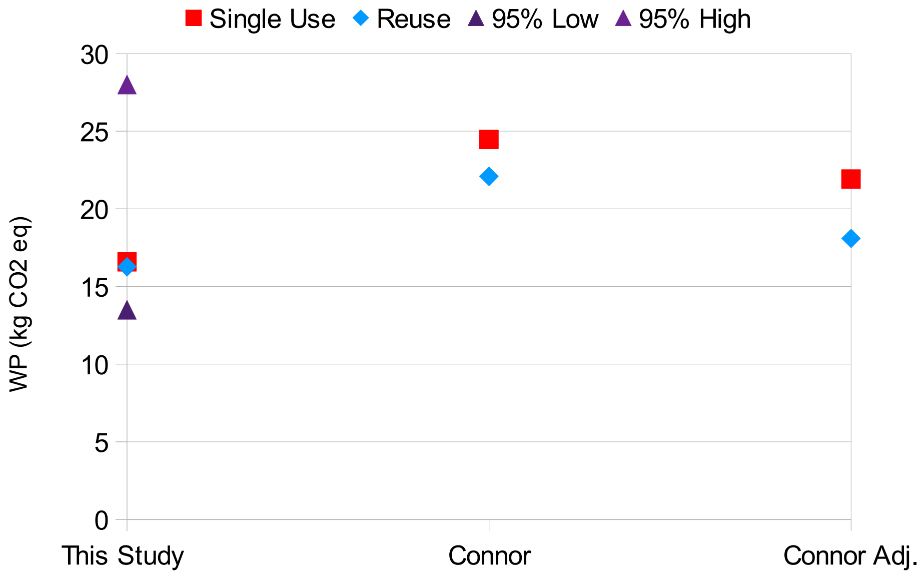
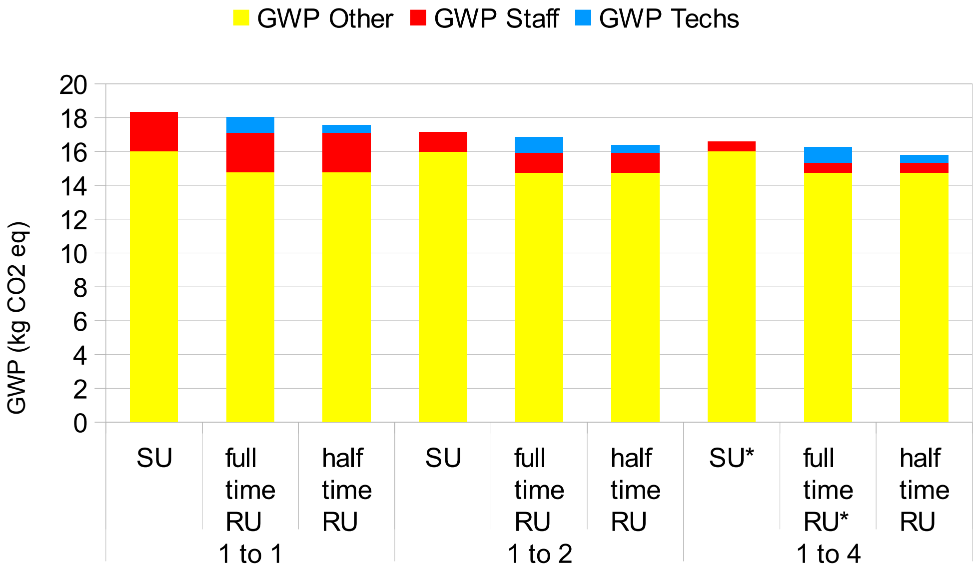


Figure 17: Staff Ratios



*Starred categories were included in the original analysis.