Supplemental Information for: Environmental Impacts of Surgical Procedures: Life Cycle Assessment of Hysterectomy in the United States

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Life Cycle Inventory: Database selection and allocation details

Following collection of material weights, energy values, and cost data described in the Methods section of the main text, unit processes from the life cycle inventory database were assigned to the data collected as shown in Table 1 and Table 2. Unit processes link data collected directly during the procedure to the emissions from the material extraction, production, and transportation of each item. For this study, researchers gave preference first to US based databases, i.e. USLCI [1]; second to the European database ecoinvent v2.2 [2]; and finally, alternate databases were selected if unit processes were not available in either USLCI or ecoinvent.

Certain unit processes were modified based on literature to more accurately reflect the product/process represented. Disposable gowns, drapes, and bluewrap from the OR are a type of polypropylene fabric also known as spunbond-meltblown-spunbond polypropylene (SMS PP). Since SMS PP products account for an average of 23% of the MSW by weight for all hysterectomy types, the existing PP process within the USLCI database was modified based on literature to more accurately reflect impacts associated with manufacturing plastics into a fabric form [3]. The USLCI electricity process was modified to match the energy mix of Pennsylvania for 2012 which is 73% coal, 22% nuclear, 3% natural gas, and less than 1% of hydropower, oil, and non-hydro renewables [4].
Table 1: Life Cycle Inventory Databases and Processes Chosen for Hysterectomy Materials found in MSW

| Material Type | LCI Database | Production Process Name | LCI Database | Disposal Process Name |
|---------------|--------------|-------------------------|--------------|-----------------------|
| Cotton        | ecoinvent unit process | Textile, woven cotton, at plant/GLO U | ecoinvent unit process | Disposal, inert material, 0% water, to sanitary landfill/CH U |
| PVC           | ecoinvent unit process | Polyvinylchloride, at regional storage/RER U | ecoinvent unit process | Disposal, polyvinylchloride, 0.2% water, to sanitary landfill/CH U |
| HDPE          | ecoinvent unit process | Polyethylene, HDPE, granulate, at plant/RER U | ecoinvent unit process | Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U |
| LDPE          | ecoinvent unit process | Polyethylene, LDPE, granulate, at plant/RER U | ecoinvent unit process | Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U |
| PU Foam       | ecoinvent unit process | Polyurethane, flexible foam, at plant/RER S | ecoinvent unit process | Disposal, polyurethane, 0.2% water, to sanitary landfill/CH U |
| PP            | modified ecoinvent unit process | SMS PP Disposable Gown - with energy and materials from C. Ponder dissertation | ecoinvent unit process | Disposal, polypropylene, 15.9% water, to sanitary landfill/CH U |
| Styrofoam     | ecoinvent unit process | Polystyrene, general purpose, GPPS, at plant/RER U | ecoinvent unit process | Disposal, polystyrene, 0.2% water, to sanitary landfill/CH U |
| Stainless Steel | ecoinvent unit process | Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER U | ecoinvent unit process | Disposal, steel, 0% water, to inert material landfill/CH U |
| Aluminum      | USLCI         | Aluminum, secondary, shape casted/RNA | ecoinvent unit process | Disposal, aluminium, 0% water, to sanitary landfill/CH U |
| Isoprene      | ecoinvent unit process | Synthetic rubber, at plant/RER U | ecoinvent unit process | Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U |
| Nitrile       | USLCI         | Polybutadiene, at plant/RNA | ecoinvent unit process | Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U |
The selection of environmental impact database processes for reusable materials was identical to that of single-use or disposable materials. Allocation of impacts due to production and disposal of reusable materials was allocated based on the estimated lifespan of the materials, as listed in Table 3 for linens and Table 4 for stainless steel. Limited information was available on the environmental impacts of the sterilization process and associated products for reusable materials. In the case of linen sterilization, a quantity of 27.4 g of detergent per kg of cotton laundered and 0.2 kWh of electricity per kg of cotton laundered was assumed based on previous literature, specifically a 1999 study based in Germany [9-11]. Though a US-based literature of domestic laundry estimates the electrical consumption per kilogram of cotton at 0.87 kWh, lower estimates are expected for industrial laundry facilities [12]. The sterilization of surgical trays was based off of an energy consumption estimate (2.57 kWh per stainless steel surgical instrument tray) of the sterilizing and autoclaving machines at Magee [13]. No estimate was available for the types or numbers of chemicals or solvents used to sterilize the stainless steel surgical instruments.

| Neoprene | ecoinvent unit process | Synthetic rubber, at plant/RER U | ecoinvent unit process | Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U |
|----------|------------------------|---------------------------------|------------------------|------------------------------------------------------------------|
| Rubber   | ecoinvent unit process | Synthetic rubber, at plant/RER U | ecoinvent unit process | Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U |
| Paper    | ecoinvent unit process | Kraft paper, bleached, at plant/RER U | ecoinvent unit process | Disposal, paper, 11.2% water, to sanitary landfill/CH U |
| Paperboard | ecoinvent unit process | Solid bleached board, SBB, at plant/RER U | ecoinvent unit process | Process-specific burdens, sanitary landfill/CH U |
| Glass    | ecoinvent unit process | Packaging glass, white, at plant/RER U | ecoinvent unit process | Disposal, glass, 0% water, to inert material landfill/CH U |
| Wood     | USLCI                  | Plywood, at plywood plant, US SE/kg/US | ecoinvent unit process | Process-specific burdens, sanitary landfill/CH U |
| Complex Instruments (Sharps) | EIO-LCA            | Sector # 339112: Surgical and Medical Instrument Manufacturing | EIO-LCA | Sector #562000: Waste management and remediation services |
Table 2: Additional LCI Databases and Processes

| Material Type                        | LCI Database     | Process Name                                                                 |
|--------------------------------------|------------------|------------------------------------------------------------------------------|
| *Chemo/Path Waste (Uterus)*          | ecoinvent unit   | Disposal, biowaste, 60% H2O, to municipal incineration, allocation price/CH U |
| *Waste Transport*                    | ecoinvent unit   | 1 tkm Transport, lorry 16-32t, EURO3/RER S (of project Ecoinvent system processes) |
| *Recycling*                          | ecoinvent unit   | Recycling PP/RER U                                                            |
| *Recycling*                          | ecoinvent unit   | Recycling PET/RER U                                                           |
| *Recycling*                          | ecoinvent unit   | Recycling PS/RER U                                                            |
| *Reusable Linens*                    | ecoinvent unit   | Textile, woven cotton, at plant/GLO U                                          |
| *Stainless Steel Surgical Instruments* | ecoinvent unit | Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER U |
| *Laundry Detergent*                  | ecoinvent unit   | Sodium perborate, tetrahydrate, powder, at plant/RER S                        |
| *Electricity*                        | modified USLCI   | Electricity 2012 PA mix                                                        |
| *Natural Gas*                        | USLCI            | Natural gas, combusted in industrial equipment/RNA                            |

Table 3: Average Weight and Estimated Lifespan of Reusable Surgical Linens

| Cotton Material          | Weight (kg) | Lifespan (# Uses) |
|--------------------------|-------------|-------------------|
| *Sheet*                  | 0.292       | 50                |
| *Blanket*                | 0.698       | 52                |
| *Pillowcase*             | 0.098       | 32                |
| *Blue Towel*             | 0.054       | 10                |
| *Under-Patient Chuck*    | 0.51        | 42                |
| *Gown*                   | 0.344       | 48                |
Table 4: Reusable Stainless Steel Surgical Instrument Weight and Quantity per Hysterectomy

| Stainless Steel Surgical Instrument Tray Name | Weight (kg) | Abdominal (# trays / 14 cases) | Vaginal (# trays / 16 cases) | Laparoscopic (# trays / 13 cases) | Robotic (# trays / 16 cases) |
|-----------------------------------------------|-------------|---------------------------------|------------------------------|----------------------------------|-----------------------------|
| Cysto Pan Tray                                | 2.032       | 2                               | 4                            | 0                                | 5                           |
| Vaginal Hyst Tray                             | 10.6        | 0                               | 16                           | 2                                | 0                           |
| Book Walter 1                                 | 10.7        | 1                               | 0                            | 0                                | 0                           |
| Book Walter Table Post Set                    | 10.7        | 1                               | 0                            | 0                                | 0                           |
| Laparomtoy Tray                               | 11.1        | 15                              | 0                            | 0                                | 0                           |
| Laparomtoy Mayo String                        | 5.0         | 9                               | 0                            | 0                                | 0                           |
| Mini-Laparotomy Tray                          | 9.71        | 1                               | 0                            | 0                                | 0                           |
| Oncology Tray                                 | 3.0         | 5                               | 0                            | 0                                | 0                           |
| 0 Degree Cysto Scope                          | 0.492       | 3                               | 0                            | 0                                | 0                           |
| Hd Camera                                     | 2.132       | 3                               | 2                            | 10                               | 5                           |
| Advanced Laparoscopy                          | 5.7         | 0                               | 0                            | 13                               | 5                           |
| Olympus Operative Laparoscopy                 | 4.732       | 0                               | 0                            | 13                               | 1                           |
| D&C Pan                                       | 10.1        | 0                               | 1                            | 13                               | 2                           |
| Morcellator Knife                             | 2.432       | 0                               | 0                            | 3                                | 0                           |
| Karl-Strotz Morcillator                       | 4.132       | 0                               | 0                            | 4                                | 0                           |
| Cysto Pan Tray                                | 2.032       | 0                               | 0                            | 3                                | 4                           |
| Pellosi Uterine Manipulator                   | 2.5         | 0                               | 0                            | 9                                | 0                           |
| Bariatric High Def Scope                      | 2.432       | 0                               | 0                            | 5                                | 0                           |
| 0-Degree Bariatric Scope                      | 2.253       | 0                               | 0                            | 11                               | 0                           |
| Abdominal Sacropexy                           | 8.232       | 0                               | 0                            | 1                                | 0                           |
| 0-Degree Gyne Scope                           | 2.432       | 0                               | 0                            | 1                                | 4                           |
| Davinci Scope                                 | 2.432       | 0                               | 0                            | 0                                | 16                          |
| Davinci General Top                           | 8.7         | 0                               | 0                            | 0                                | 15                          |
| Davinci General Bottom                        | 8.7         | 0                               | 0                            | 0                                | 16                          |
| Rigid Davinci Tray                            | 8.2         | 0                               | 0                            | 0                                | 3                           |
| Average number of trays per case              |             | 3                               | 2                            | 7                                | 5                           |
| Ave. weight per case allocated over 300 uses  |             | 0.064                           | 0.040                        | 0.105                            | 0.088                       |

Anesthetic type was based on anesthesiologist preference, per routine. Type and concentration of anesthetics were recorded at one-minute intervals and transcribed from the medical record. The fresh gas
flow rates of oxygen and other carrier gases flowing from the anesthetic machine to the breathing system were determined by clinical staff to be 2L/min during anesthesia maintenance, with rates of 5L/min during induction and emergence phases (the first and last 5 minutes of IA use) per UPMC routine regardless of type used. Inhaled anesthetics (IA) undergo little in vivo metabolism, and upwards of 95% are exhaled. Intravenous propofol was used in combination with spinal anesthetics in 4 vaginal cases. Administered propofol undergoes complete biotransformation, and wasted drug was assumed incinerated in accordance with manufacturer recommendation. Anesthetic data were not available from one robotic case. The amount of CO2 used to inflate abdomens during laparoscopic and robotic hysterectomies was measured by Magee staff at 2L per minute during insufflation of the abdomen. None of these gases are captured, and they were vented to the atmosphere in their entirety per standard.

The Inhalation Anesthetics considered here include desflurane, sevoflurane, and nitrous oxide, and are themselves greenhouse gases with the Global Warming Potential (GWP100, the heat trapping property over 100 years) of 2540, 130, and 310 kg CO2-equivalent per kg of IA respectively[5, 6]. This study also utilized GHG emission factors for the production, use, and emissions of IA and propofol (total life cycle) as determined from previous literature [5-8].

**Economic Input-Output LCA Setup and LCIA**

Monetary values for EIO-LCA were evaluated using the purchaser price and assigned background emissions using the corresponding sectors within the North American Industry Classification System (NAICS). For the production of disposable complex medical devices, NAICS sector 339112 *Surgical and Medical Instrument Manufacturing* was selected. The disposal of these devices in Magee’s sharps waste stream was also evaluated with EIO-LCA through NAICS sector 562000: *Waste Management and Remediation Services*, which includes the processing of sharps-designated medical equipment. The price paid per unit for each piece of medical equipment was collected from Magee purchasing staff and matched to the number of medical equipment used in each hysterectomy based off of collected peel pack
data. The monetary values were deflated from 2012 US dollars to 2002 dollars, the basis for the most recent EIO-LCA model, using Producer Price Index Industry (PPI) Data from the US Bureau of Labor Statistics for medical instrument manufacturing[14].

Environmental impacts from the inputs and outputs of the four types of hysterectomy were calculated using TRACI 2.1 version 1.0 for both process- and EIO-LCA [15]. Embodied energy or a summation of all energy used during the material’s life cycle, was calculated using Cumulative Energy Demand (CED) version 1.08 developed by ecoinvent version 2.0 and PRé Consultants [16, 17]. Impact categories analyzed and reported include greenhouse gas emissions (with the IPCC’s 100-year time horizon calculations for the potency of greenhouse gases relative to CO2 [15]), acidification, carcinogens, non-carcinogens, respiratory effects, eutrophication, ozone depletion, ecotoxicity, smog, and CED.

**Monte Carlo Analysis**

We utilized Monte Carlo Analysis (MCA) to account for the uncertainty inherent in life cycle inventory data and the variability of material and energy consumption for each type of hysterectomy. Distributions of material and energy quantities used in each type of hysterectomy were fitted to normal, lognormal, most extreme value using Anderson Darling (A-D) tests for goodness of fit, shown in Table 5. Variability of the complex, electrical laparoscopic and robotic instruments was incorporated into the MCA as a triangular distribution based on the number and cost of individual tools purchased by Magee for those cases. Where A-D tests showed distributions were not normal, lognormal, or most extreme value, a designation of “no distribution” was given and a single value (i.e. the average) was used in the MCA. Because electricity data was collected as an average and not on a per-case basis, the variability in electrical and energy consumption in the MCA was based off of the duration of surgery. The MCA randomly sampled 100,000 times from the probability distributions, creating an overall distribution (which was fit using A-D) of the GWP of each hysterectomy from which a 90% confidence interval was determined.
Unit conversion was necessary to match the impact categories Acidification, Carcinogenics, NonCarcinogenics, and EcoToxicity with the process LCA results as seen in Table 6. A characterization factor of 50.79 kg SO2 eq / H+ mole was used for acidification potential conversion. EIO-LCA reports human health toxicity impacts (cancer and non-cancer) in benzene and toluene equivalent emissions to air. For this reason, TRACI characterization factors of 2.97e-7 CTUh / kg benzene to air and 5.3e-8 CTUh / kg toluene to air were chosen, where CTUh stands for Cumulative Toxicity Unit for humans. EIO-LCA reports ecotoxicity as kg 2,4D to continental freshwater, and a characterization factor of 8.60e2 CTUe / kg 2,4D was used, where CTUe stands for Cumulative Toxicity Unit for the environment. For the EIO-LCA portion of this study, the effects of chemicals’ fate to soil and water were not considered in the categories related to human toxicity, nor were chemicals’ fate to air and soil for ecotoxicity.
| Material                  | Abdominal Hysterectomy | Vaginal Hysterectomy | Laparoscopic Hysterectomy | Robotic Hysterectomy |
|---------------------------|------------------------|----------------------|---------------------------|---------------------|
|                           | Dist. Type             | Para. 1              | Para. 2                   | Dist. Type          | Para. 1 | Para. 2 | Dist. Type | Para. 1 | Para. 2 |
| Gowns                     | Normal                 | 1.096                | 0.563                     | Normal              | 1.46    | 0.324   | Normal     | 1.2871  | 0.354  |
| Blue Drape                | No Dist.               | 0.42                 | 0                         | Normal              | 0.51    | 0.43    | No Dist.   | 0.32    | 0      |
| Blue Towels, Clean Gauze  | No Dist.               | 1.009                | 0                         | No Dist.            | 0.54    | 0       | No Dist.   | 0.709   | 0      |
| CSR Blue Wrap             | No Dist.               | 0.346                | 0                         | No Dist.            | 1.34    | 0.562   | Normal     | 0.98    | 0.442  |
| Purple Gloves             | Normal                 | 0.117                | 0.068                     | Normal              | 0.082   | 0.055   | LN         | -2.259  | 0.3731 |
| Tan Gloves                | Normal                 | 0.162                | 0.038                     | Normal              | 0.153   | 0.063   | Normal     | 0.21    | 0.071  |
| Blue Gloves               | Normal                 | 0.083                | 0.062                     | LN                  | -2.406  | 0.6773  | LN         | -2.508  | 0.5962 |
| Green Gloves              | No Dist.               | 0.004                | 0                         | No Dist.            | 0.01    | 0       | No Dist.   | 0.005   | 0      |
| Rubber                    | No Dist.               | 0.042                | 0                         | No Dist.            | 0.035   | 0       | No Dist.   | 0.029   | 0      |
| Hard Plastic (#5)         | LN                     | -1.73                | 0.6504                    | No Dist.            | 0.2734  | 0       | LN         | -1.988  | 0.6052 |
| Soft Plastic              | No Dist.               | 0.508                | 0                         | No Dist.            | 0.5107  | 0       | No Dist.   | 0.693   | 0      |
| Styrofoam                 | No Dist.               | 0.023                | 0                         | No Dist.            | 0.032   | 0       | No Dist.   | 0.018   | 0      |
| PU Foam                   | No Dist.               | 0.004                | 0                         | No Dist.            | 0.005   | 0       | No Dist.   | 0.11    | 0      |
| Cardboard/Paperboard      | LN                     | -3.23                | 1.2096                    | No Dist.            | 0.0571  | 0       | MEV        | 0.149   | 0.118  |
| Glass                     | Normal                 | 0.14                 | 0.139                     | Normal              | 0.23    | 0.18    | Normal     | 0.16    | 0.138  |
| Paper                     | Normal                 | 0.35                 | 0.131                     | No Dist.            | 1.237   | 0       | Normal     | 0.362   | 0.111  |
| Syringes                  | Normal                 | 0.088                | 0.034                     | LN                  | -2.268  | 0.9233  | Normal     | 0.16    | 0.079  |
| Aluminum/Metal            | LN                     | -2.77                | 0.5402                    | No Dist.            | 0.06    | 0.045   | LN         | -3.324  | 0.6075 |
| IV Bags                   | MEV                    | 0.038                | 0.057                     | MEV                 | 0.068   | 0.069   | Normal     | 0.07    | 0.065  |
| Wood                      | No Dist.               | 0.002                | 0                         | No Dist.            | 0.002   | 0       | No Dist.   | 0.002   | 0      |
| Metal (Non-Aluminum)      | No Dist.               | 0                    | 0                         | No Dist.            | 0.004   | 0       | No Dist.   | 0.001   | 0      |
Table 6: Impact Category Characterization and Conversion for EIO-LCA and Process LCA

| Impact Category     | EIO-LCA Units | Process LCA Units (TRACI) | EIO-LCA Impacts per $1US2002 Purchaser | CF (TRACI) | EIO-LCA Impacts per $1US2002 Purchaser (Converted) |
|---------------------|---------------|----------------------------|------------------------------------------|------------|-------------------------------------------------|
| Ozone depletion     | kg CFC-11e    | kg CFC-11 eq               | 0.000002                                 | 1          | 0.000002                                        |
| Global warming      | kg CO2e       | kg CO2 eq                  | 0.403317                                 | 1          | 0.403317                                        |
| Smog                | kg O3e        | kg O3 eq                   | 0.000002                                 | 1          | 0.000002                                        |
| Acidification       | kg SO2e       | mol H+ eq                  | 0.002117                                 | 50.79      | 0.10752243                                      |
| Eutrophication      | kg Ne         | kg N eq                    | 0.000068                                 | 1          | 0.000068                                        |
| Carcinogenics       | kg benzene eq | CTUh                       | 0.000037                                 | 2.97E-07   | 1.0989E-11                                      |
| Non carcinogenics   | kg toluene eq | CTUh                       | 0.023076                                 | 5.3E-08    | 1.22303E-09                                     |
| Respiratory effects | kg PM10e      | kg PM10 eq                 | 0.000698                                 | 1          | 0.000698                                        |
| Ecotoxicity         | kg 2,4D       | CTUe                       | 0.000018                                 | 860        | 0.01548                                         |
| Energy              | MJ            | MJ                         | 5.87                                    | 1          | 5.87                                            |
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