



## Sustainable ROI of a 3D Printer

*Lise Laurin, [lise@earthshiftglobal.com](mailto:lise@earthshiftglobal.com)*

*Tom Etheridge, [tom.etheridge@hp.com](mailto:tom.etheridge@hp.com)*

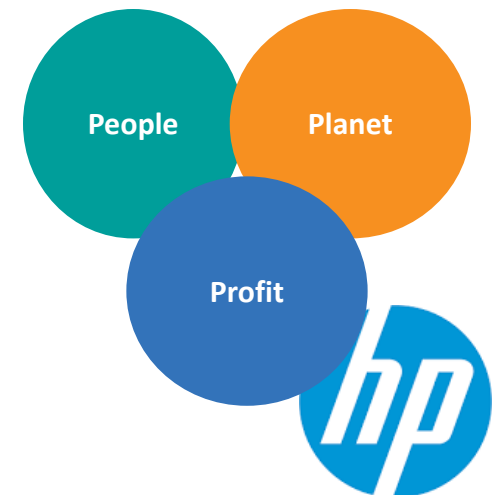
*Nathan Ayer, [nathan@earthshiftglobal.com](mailto:nathan@earthshiftglobal.com)*



# What is Sustainable Return on Investment (S-ROI)?



- Methodology developed out of Total Cost Assessment that assesses the return on investment of a decision or investment including externalities like environmental and social impacts.
- Clearly addresses the inherent uncertainty in all investments, including obvious uncertainties such as changing energy prices as well as more difficult uncertainties such as technical and social risks.
- Uses a multi-stakeholder approach to identify social risks and provide opportunities for optimization
- Originally developed by industry for industry—builds upon traditional return on investment cost accounting methodology by including uncertainty, social risk assessment, and monetization of intangibles
- Incorporates triple bottom line thinking into a single metric
- Encourages constructive dialog



# Sustainability ROI Cost Types

## 5 Costs

1. Direct Costs
2. Indirect Costs
3. Future Contingent Liabilities
4. Intangible Internal Costs
5. External costs

**2. Indirect Costs**



Reporting



Overhead

**3. Contingent Liabilities**



Spill




Lawsuits, fines, penalties



Clean up costs

**1. Direct Costs**



Labor and operations



Scrap disposal



Capital equipment

**4. Intangible Internal Costs**



Labor relations, morale issues, community relations




Customer relations

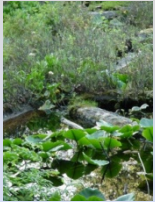


Brand value


**5. External Costs**




Effect on housing prices



Habitat restoration

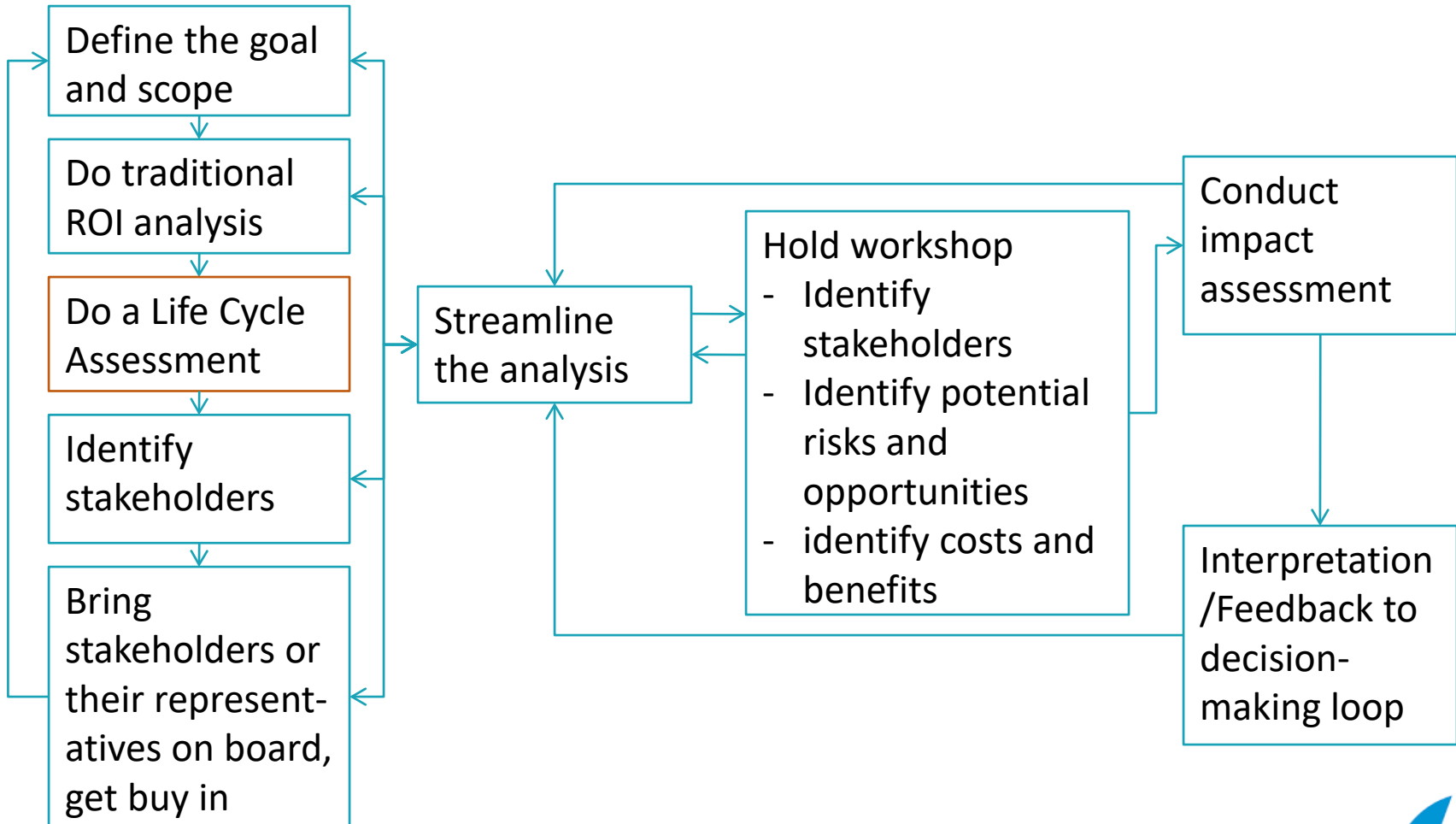


Loss of habitat

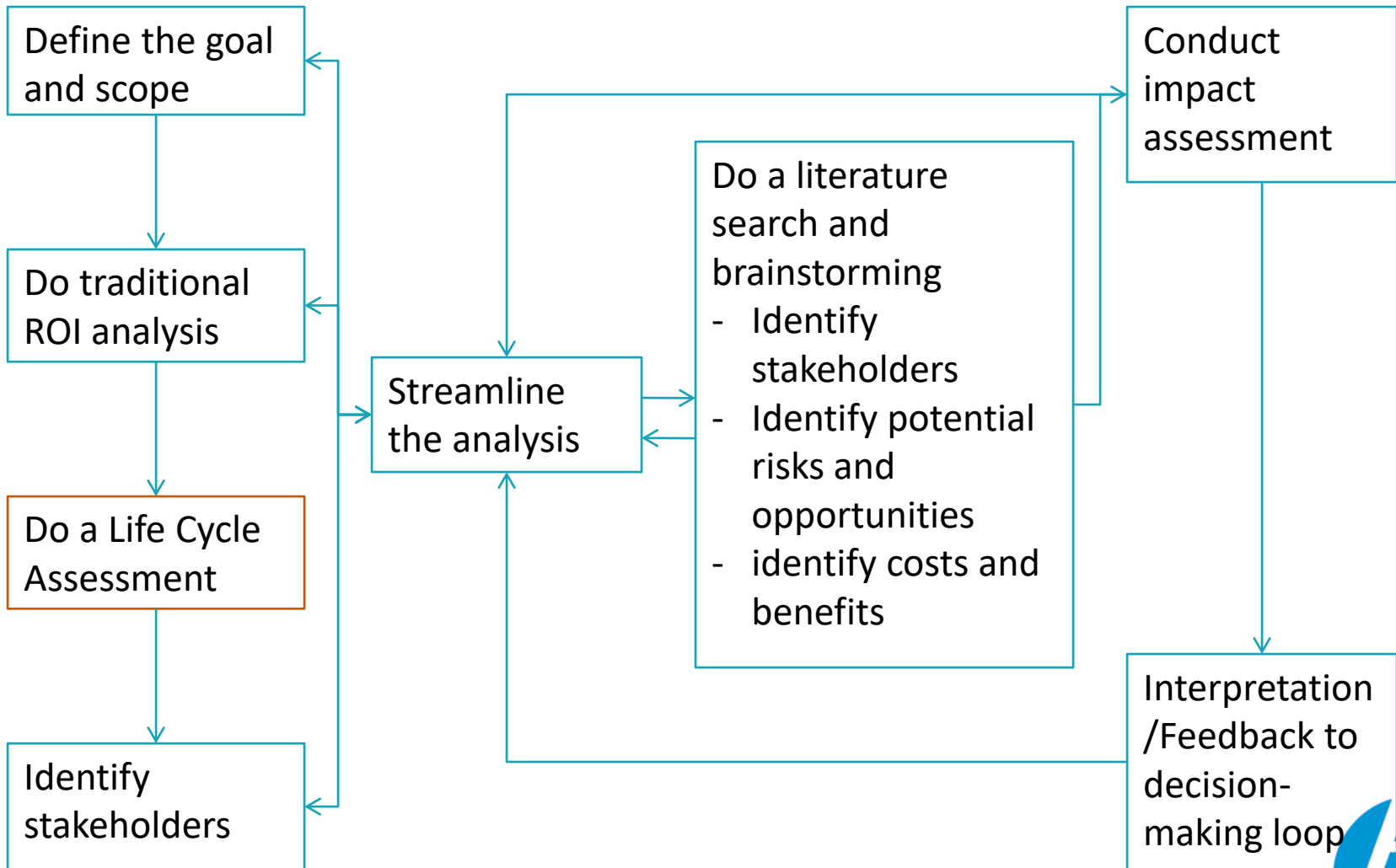


Effect of pollution on human health

# S-ROI: How Do You Do it (full study)?



# S-ROI: How Do You Do it (screening study)?



# Why Does it Work?

- Uses traditional cost accounting methodologies
- Leverages Bayesian uncertainty principles
- Allows the organization and the stakeholders to weigh the impacts (social, environmental and economic) using their own value system.
- Creates a picture of the future including best case, worst case, and most probable cases



# 3D Printer Screening S-ROI

## Goal and Scope



- The goal of this study is to provide HP with some ideas of the social impacts of 3D printing of plastic parts and how those compare with the cost of a printer.
- The goal is not to provide an exhaustive study.
- The scope is global and looks into the near future.
- Social impacts are generic to 3D printing and not specific to HP's printer



# Assumptions



- Assess the life of one 3D printer (5 years)
- Use “average” data from the screening LCA to estimate number of parts and their impacts.
- Assume 3D printing will replace processing (Injection molding) with approximately the same cost and environmental impact; i.e., volumes are low and not significantly different between the technologies





# Proposed Scenarios



- Amputees have a better quality of life due to the availability of **custom prostheses**
- **Better surgeries** are done using 3D models to train
- Products **last longer**
- Parts are **lightweighted**
- **More widgets** are produced because they are easy to produce and customize
- **Fewer widgets** are produced because products are “right”
- Risk of **design piracy**
- Opportunity for **subsistence farmers to become inventors** and manufacturers
- **Sculpture** becomes more affordable



# Amputees Have a Better Quality of Life



- 1.9 million amputees in the US
- 10 million amputees in the world
- Prosthetics need to be replaced every 6-12 months for children, every 3-5 years for adults
- Percent of arm amputees: 30%
- WHO value of:
  - Amputation of one arm without treatment: 0.079-0.167 DALYs/year
  - Amputation of one arm with treatment: 0.024-0.059 DALYs/year
  - Amputation of one leg without treatment: 0.118-0.240 DALYs/year
  - Amputation of one leg with treatment: 0.023-0.176 DALYs/year



# Prosthetic Assumptions

- Assume all amputees are either one arm or one leg
- Assume benefit moves the amputee from “without” to “with” treatment
- Assume benefit of one prosthesis per printer per year
- Assume benefit of a DALY is between 1-3 times per capita GDP (WHO)
- Assume Global GDP



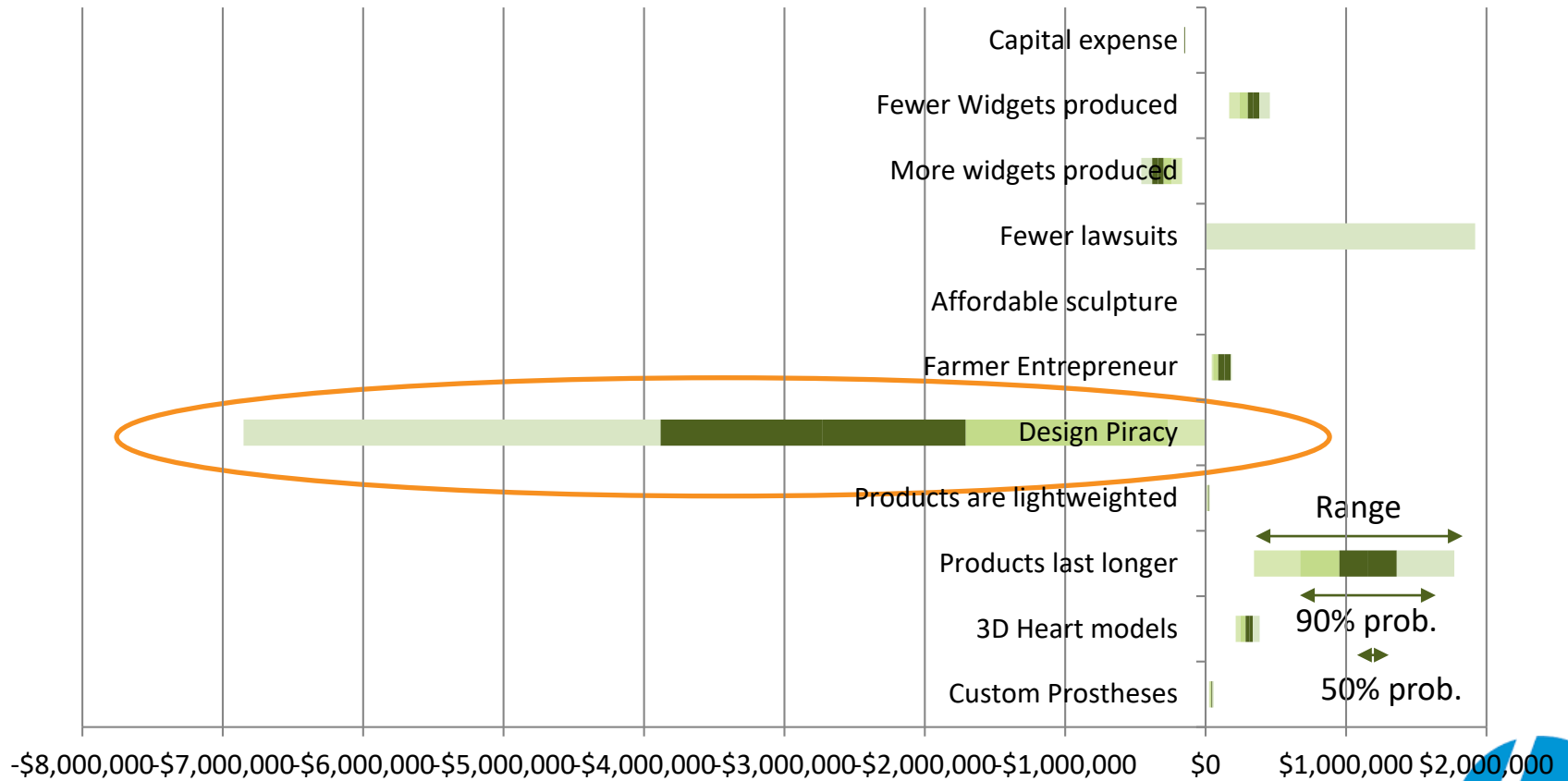
# Design Piracy

- 0-1% chance of property infringement per printer
- Use existing penalties of piracy
- Use a range from 0 to full penalty
- Consider a scenario where standards are developed
  - 0-1% reduced risk of property infringement per printer



# Results by Scenario

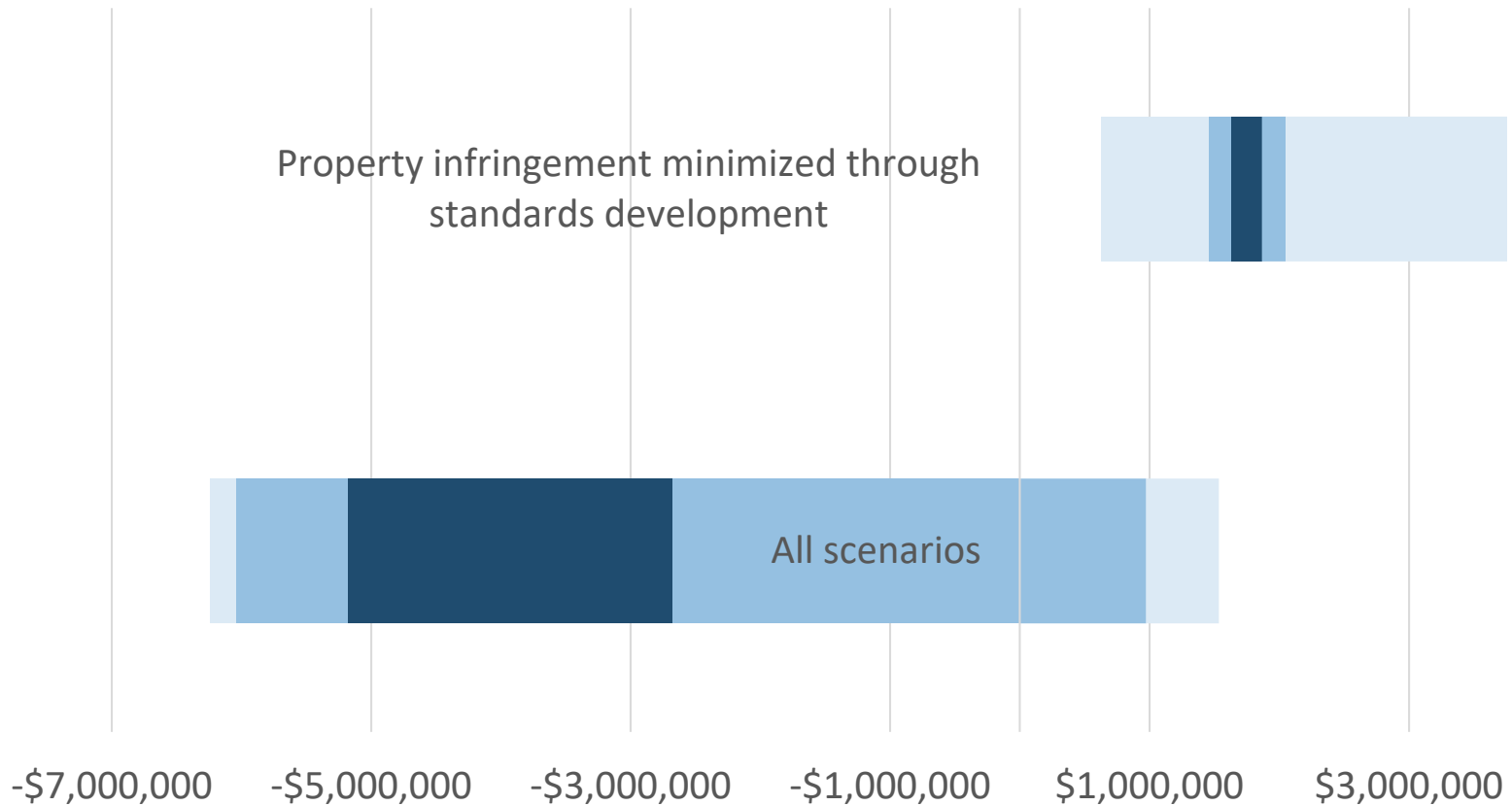
## Impacts of 3D printer by scenario NPV over the life of the printer



# Combined Results



## Combined impacts of a 3D Printer NPV over the lifetime of one printer



# Takeaways for Users of 3D Printers



- **Design piracy** is a big risk . . . Standards may alleviate the risk
- The ability to **make obsolete parts** is a boon to both the environment and our pocketbooks



# References

- Number of amputees in the US: 1.9 million  
[https://www.nist.gov/sites/default/files/documents/tip/wp/pswp/239\\_limb\\_prosthetics\\_services\\_devices.pdf](https://www.nist.gov/sites/default/files/documents/tip/wp/pswp/239_limb_prosthetics_services_devices.pdf)
- Number of amputees in the World: 10 million; Percent of arm amputees: 30%  
<https://web.stanford.edu/class/engr110/2011/LeBlanc-03a.pdf>
- World per capita GDP 2015: \$10,005 <http://data.worldbank.org/indicator/NY.GDP.PCAP.CD>
- US per capita GDP 2015 \$55,837 <http://data.worldbank.org/indicator/NY.GDP.PCAP.CD>
- Number of heart surgeries in the US 500k <http://www.texasheart.org/HIC/Topics/Proced/>
- Heart surgery failure rate: 4.9% for pediatric at one hospital <http://www.chop.edu/pages/open-heartcardiopulmonary-bypass-cases-and-outcomes>; 2-5% for bypass surgery [http://www.healthcentral.com/heart-disease/patient-guide-44625-6\\_3.html](http://www.healthcentral.com/heart-disease/patient-guide-44625-6_3.html)
- GHG society min:\$ 0.018 /kg CO2-eq <http://www.sciencedirect.com/science/article/pii/S0140988306000090>
- GHG society max: \$0.15/kg CO2-eq <http://www.ecocostsvalue.com/EVR/model/theory/subject/2-eco-costs.html>
- Value of a patent lawsuit (median \$2.3 million) <https://www.bjs.gov/content/pub/pdf/ipt02.pdf>
- Between 700000 and 900000 small arms produced annually  
<https://www.amnesty.org/en/latest/news/2015/08/killer-facts-the-scale-of-the-global-arms-trade/>
- 437000 murdered in 2012, 50% under 30 <https://www.unodc.org/unodc/en/press/releases/2014/April/some-437000-people-murdered-worldwide-in-2012-according-to-new-unodc-study.html>
- Life expectancy: 71 [https://en.wikipedia.org/wiki/List\\_of\\_countries\\_by\\_life\\_expectancy](https://en.wikipedia.org/wiki/List_of_countries_by_life_expectancy)
- Minimum wage in Guatemala: 26742 quetzales/year= \$3,429 US, Average wage: \$6634  
[https://www.numbeo.com/cost-of-living/country\\_result.jsp?country=Guatemala](https://www.numbeo.com/cost-of-living/country_result.jsp?country=Guatemala)
- Difference in lifespan vs income for Americans [https://www.brookings.edu/wp-content/uploads/2016/06/differential\\_mortality\\_retirement\\_benefits\\_bosworth\\_version\\_2.pdf](https://www.brookings.edu/wp-content/uploads/2016/06/differential_mortality_retirement_benefits_bosworth_version_2.pdf)
- Difference in lifespan vs education for Guatemalans: Approximately 5 years for above change, based on change in Gross national income; as much as 13 years in Guatemala, simply for the change from indigenous to non-indigenous people.  
[http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736\(08\)61405-1.pdf](http://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(08)61405-1.pdf)





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# Better Surgery



- 500,000 heart surgeries annually in US
- Risk of failure 2-5%
- WHO value of Heart failure
  - Mild 0.041 (0.026–0.062) DALYs
  - Moderate 0.072 (0.047–0.103) DALYs
  - Severe 0.179 (0.122–0.251) DALYs



# Surgery Model Assumptions



- Each printer prints one heart model per year
- Model moves risk of failure from high (5%) to low (2%)
- Failure is equal to severe heart failure (in comparison with mild heart failure)
- Use WHO 1-3 x per capita GDP for US



# Longer lifespan products



- Use assumptions and values in Screening LCA
- Assume 10-30% of products printed fit this model
- Use WHO 1-3 x per capita GDP/DALY (global)
- Use literature ranges for climate change, ecosystem quality, and water scarcity
- Use ReCiPe values for Resources



# Parts are Lightweighted



- 10-20% of parts are made lighter than with traditional manufacturing
- 1-5% of parts improve efficiency
- Use Screening LCA results for environmental impacts



# Change in Number of Widgets Produced



- Explore environmental impacts of 20% of widgets printed would not have been otherwise
- Explore environmental impacts of 20% fewer widgets produced



# Farmers Become Inventors



- 1 farmer per printer
- Assume farmer is in Guatemala (data in hand from workshop in Guatemala)
- Wages go from minimum to average
- Kids get a better education
  - Project better wages based on literature (doesn't show up due to time horizon)
- Family has longer life expectancy (5-13 years)
  - Use literature for estimates and WHO value (impacts brought to today)



# More Affordable Sculpture



- Print 1 sculpture/year
- Sculpture increases happiness
- Happiness reduces stress
- Reduced stress means we sleep better
- 1 sculpture = 1-5 more nights without insomnia per year

