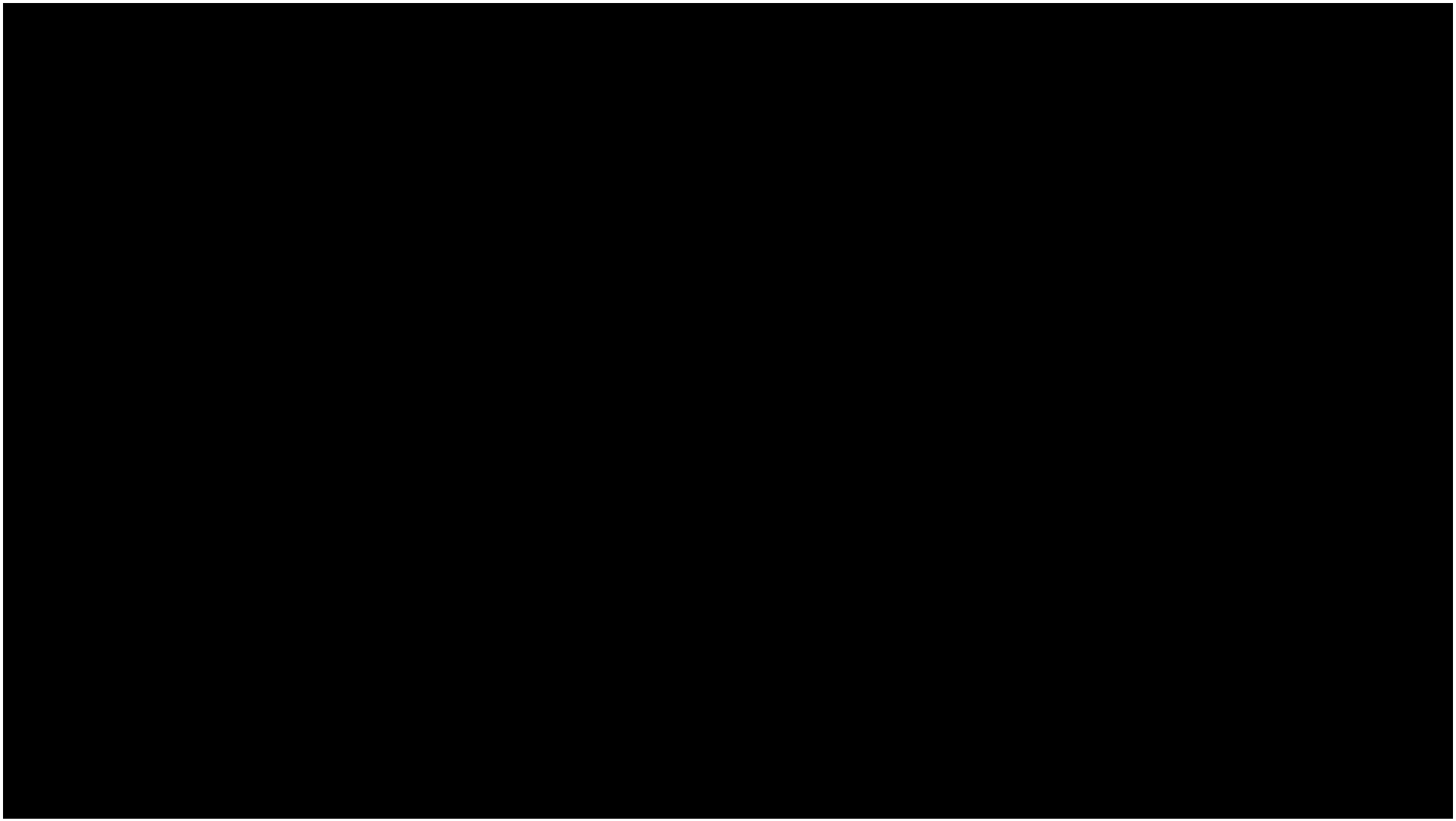
Remanufacturing

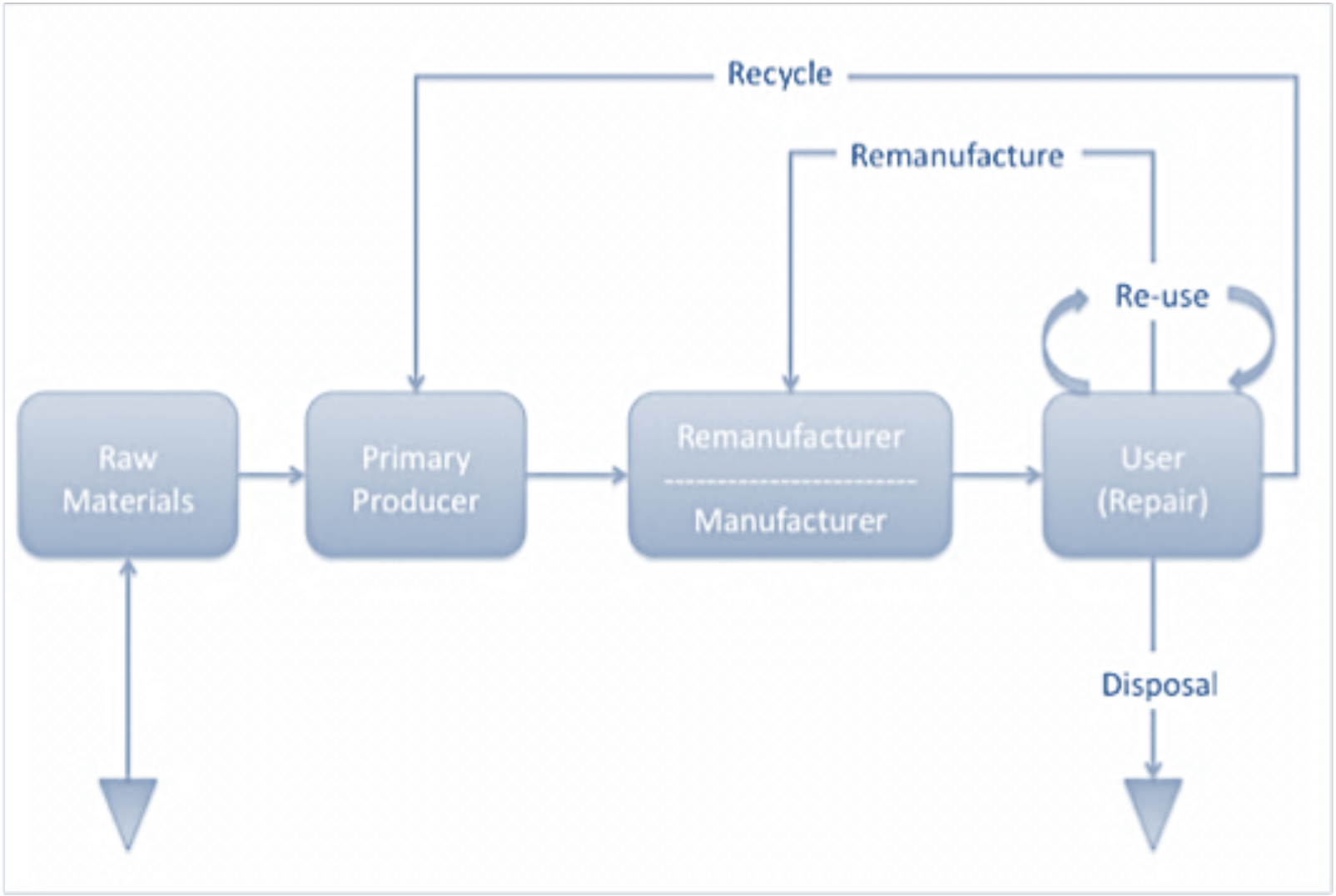
April 18th 2012

What is Remanufacturing?



http://www.youtube.com/watch?v=2XZIQOFLjXU&feature=relmfu

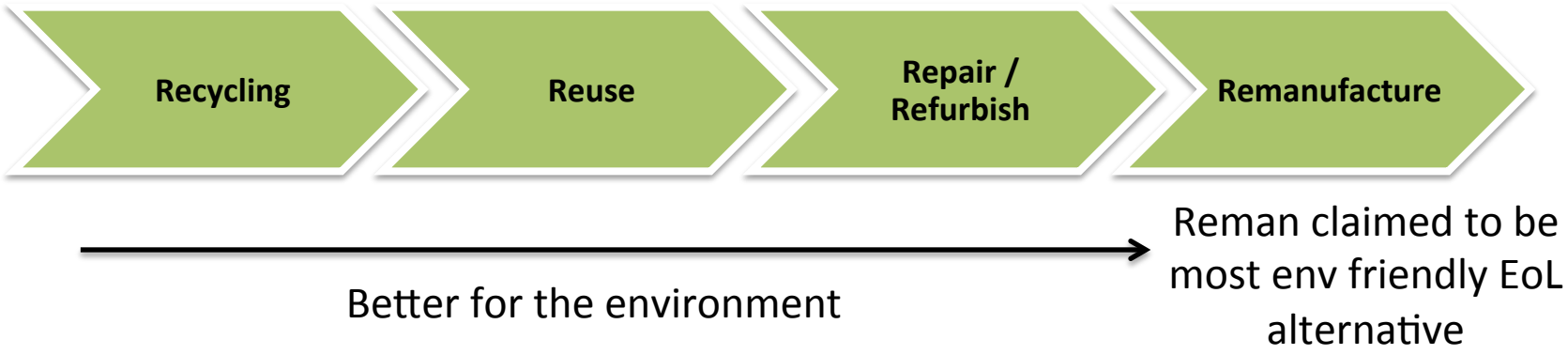
What is Remanufacturing?



What is Remanufacturing?

Remanufacturing is the process of product recovery (refurbishing) to a 'like-new' condition

- Product expected to perform like it did when it was first produced
- Saves materials, avoids material processing and manufacturing of the product



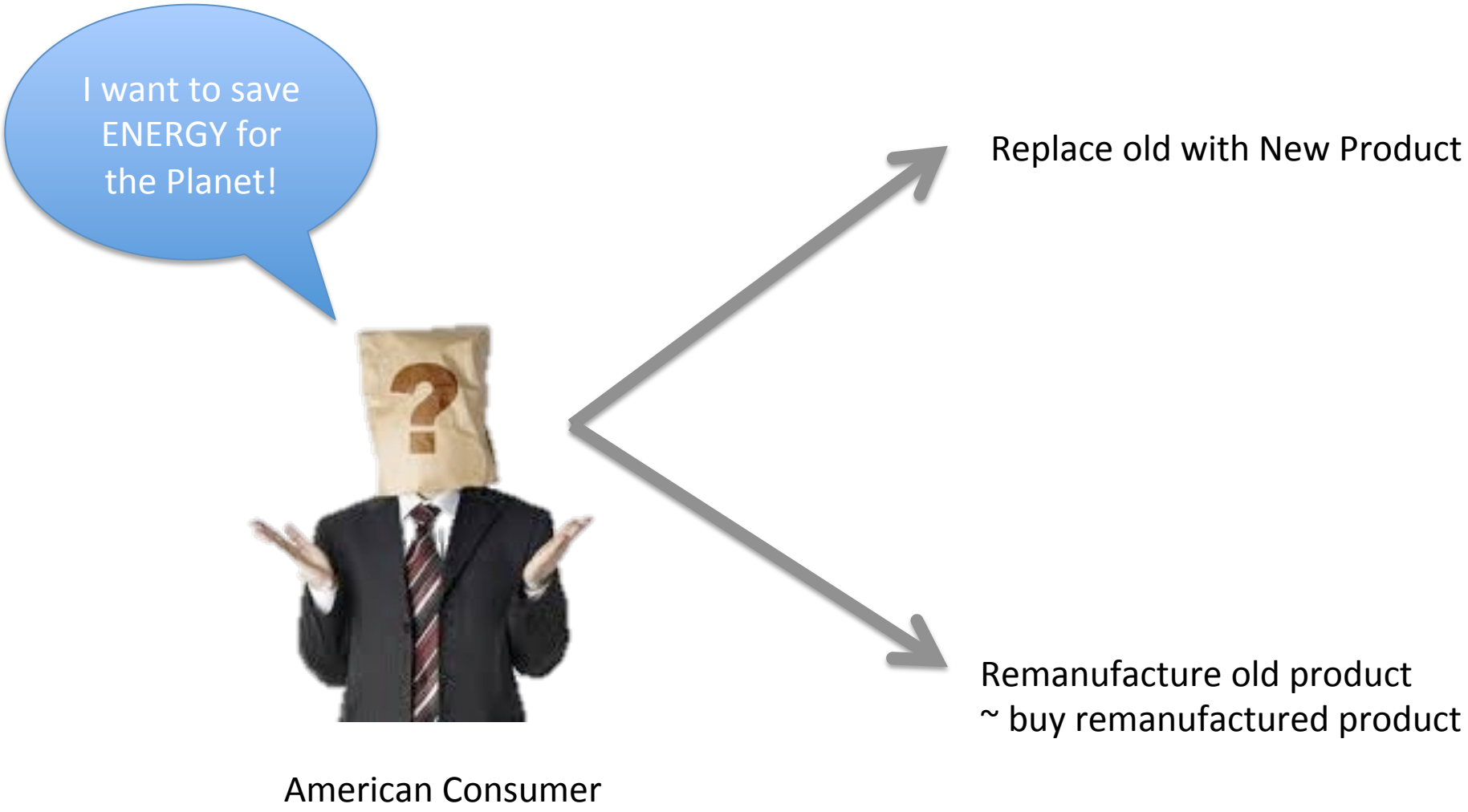
Requirements for Remanufacturing

1. Retired products (called core) have significant residual value
   - E.g. working cell phone replaced after 2 years

2. The remanufacturing firm can effectively capture the core
   - E.g. Dell and Apple laptop collection system

3. The captured core can be restored to like-new condition
   - Scrapping rates can vary from 10-90%

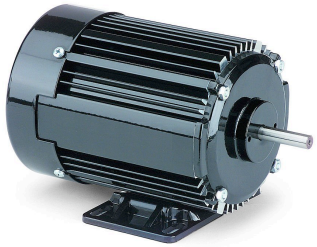
Consumer Scenario



Products in Consideration

Engines
(Remanufacture)

Office Furniture
(Reuse)



Electric Motors
(Rewind)

Tires
(Retreading)

Cartridges
(Refill)

Monitor
(Reuse)

Appliances (3)
(Reuse)

Personal Computers
(Reuse)

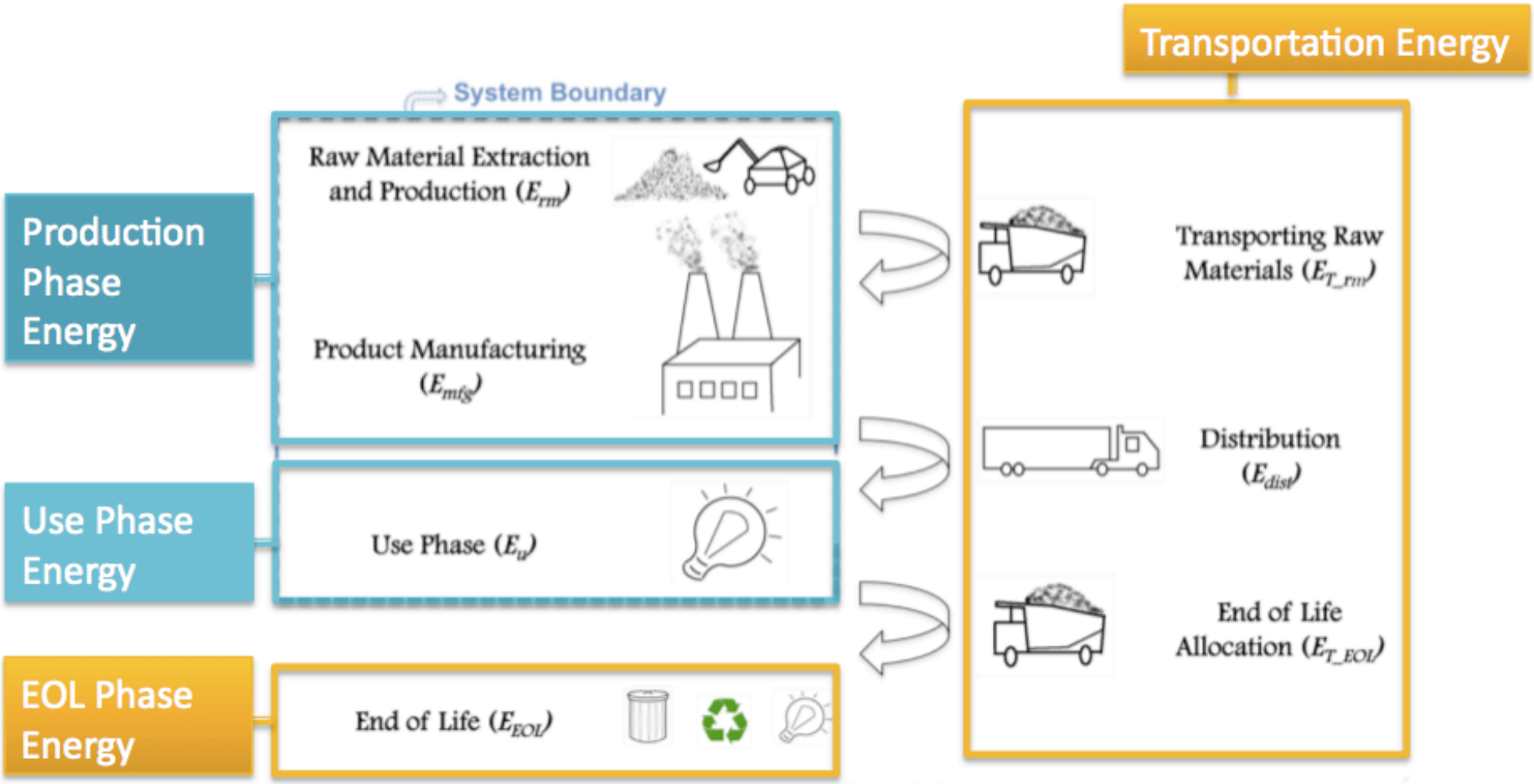
Remanufacture or New

What would you choose to save energy?

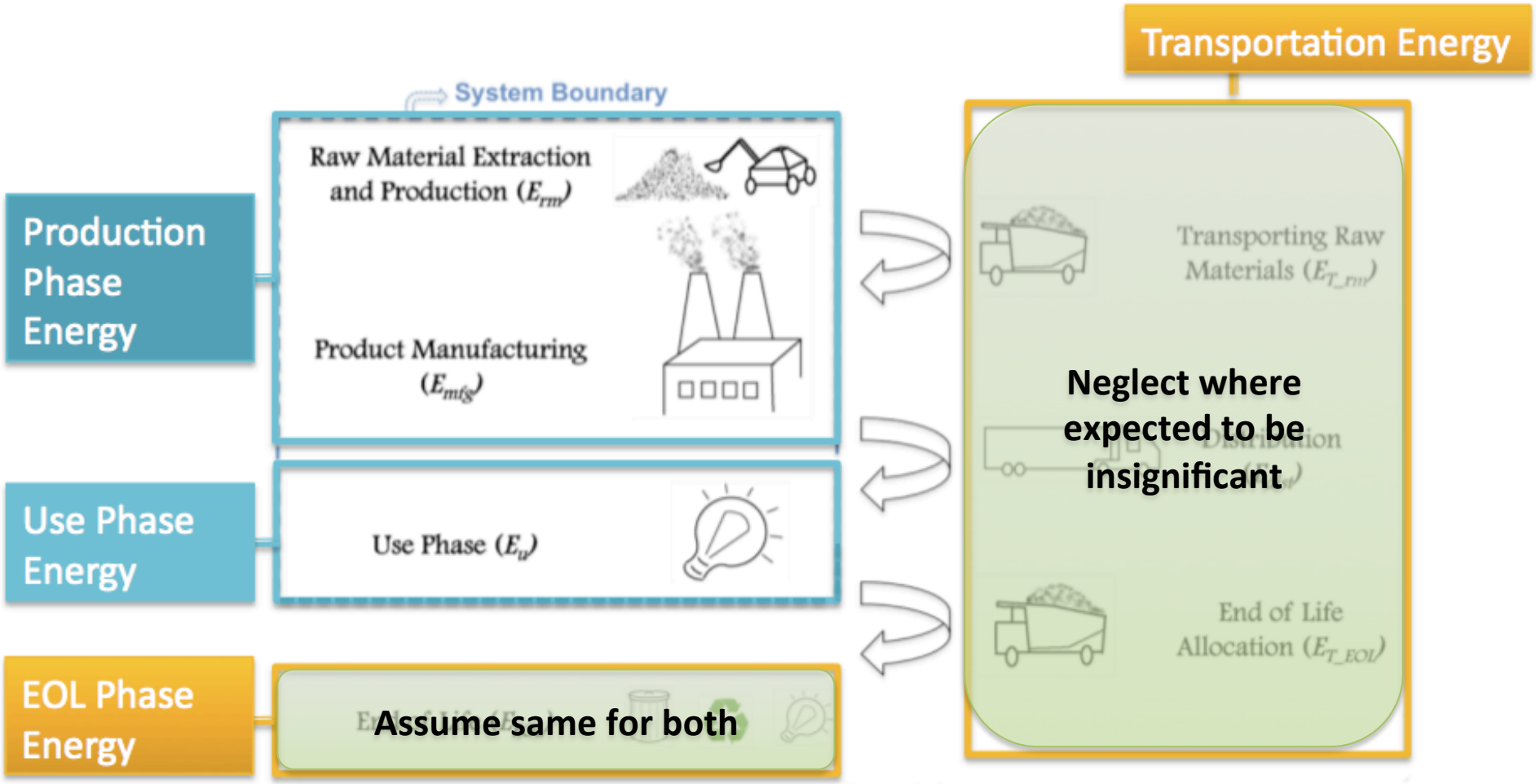
a) **Remanufacture**

b) **Replace with New**

Construct the system boundary



Construct the system boundary



Furniture

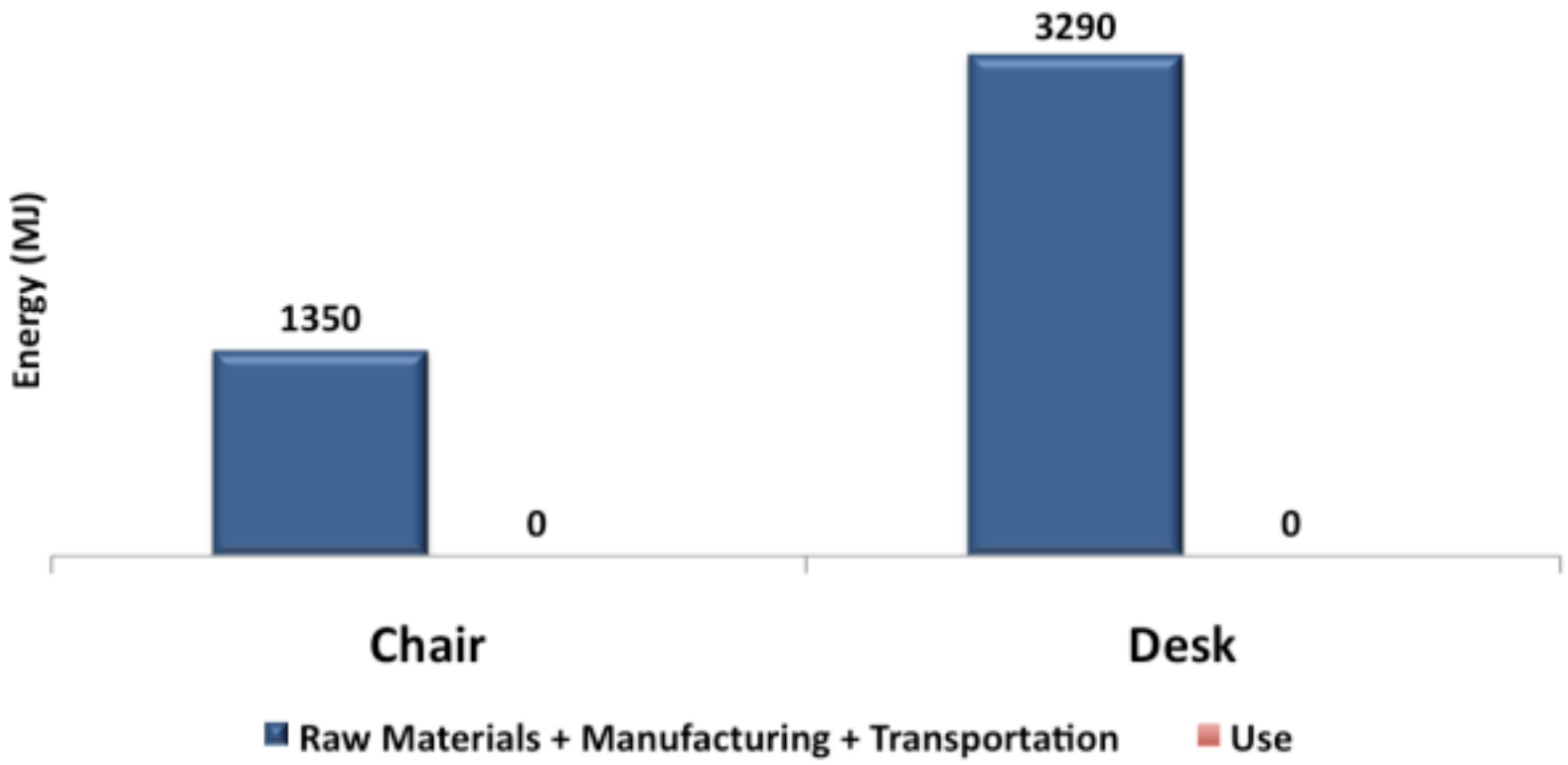
Furniture - BoM

Siento Chair		
Material	**Weights (lbs)**	**Weight (Kgs)**
Steel	32.3	14.65
Plastic	14.6	6.62
Non-ferrous metals	13.4	6.07
Leather	2.6	1.17
Other	1.7	0.77
Total	**64.6**	**29.30**

Garland Desk		
Material	**Weights (lbs)**	**Weight (Kgs)**
Particleboard	159.3	72.25
Steel	52.9	23.99
Plywood	40.2	18.23
Cherry	8.6	3.90
Otherwood/paper	3.1	1.40
Addhesives and finishes	1.9	0.86
backing material	1.6	0.72
plastics	1.5	0.68
Total	**269.1**	**122.06**

http://web.mit.edu/ebm/www/Publications/MITEI-1-e-2010.pdf

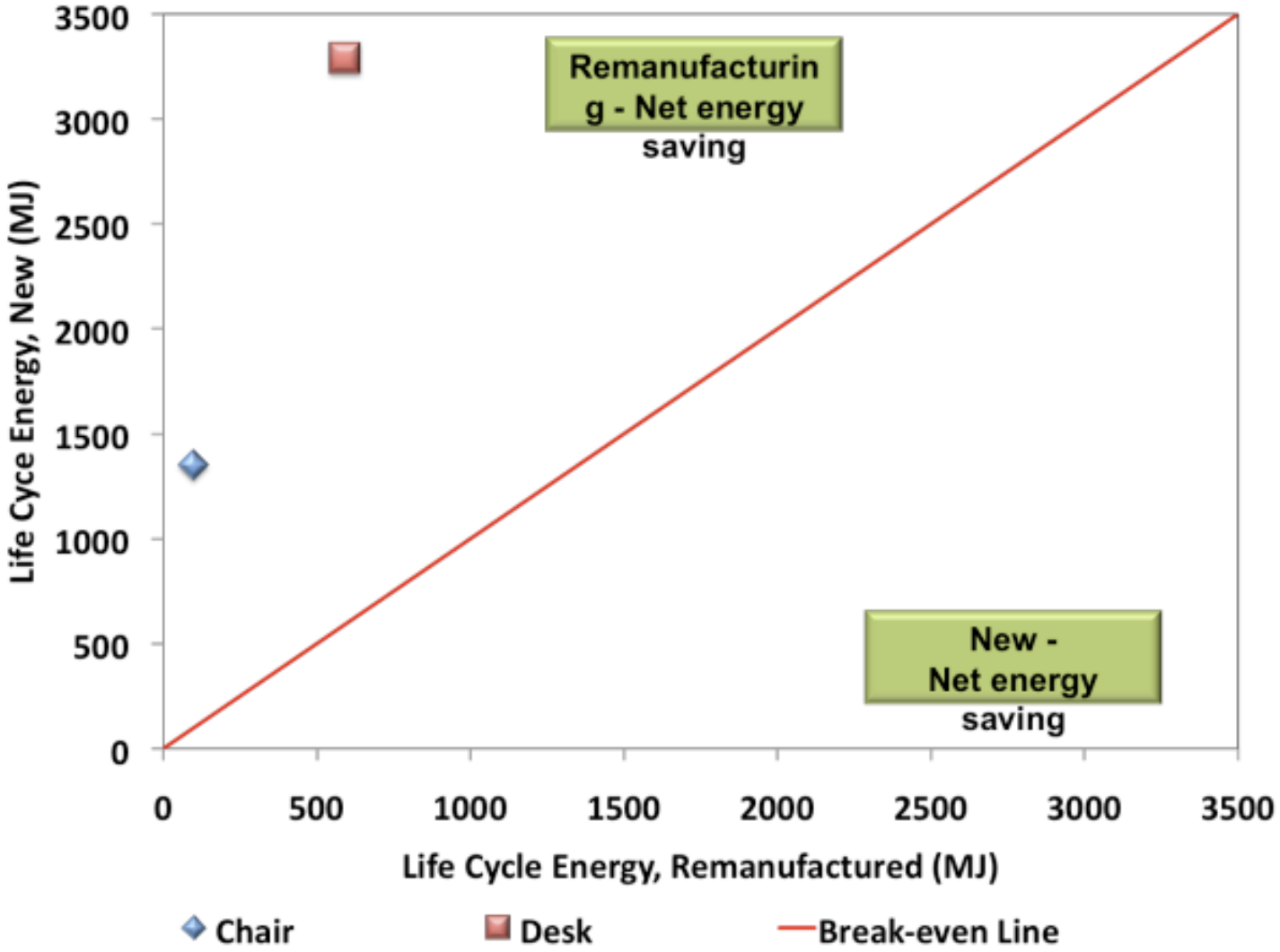
Furniture CED



Use phase maintenance not considered since assumed to cancel out between the two options

http://web.mit.edu/ebm/www/Publications/MITEI-1-e-2010.pdf

Furniture – New or remanufactured?



http://web.mit.edu/ebm/www/Publications/MITEI-1-e-2010.pdf

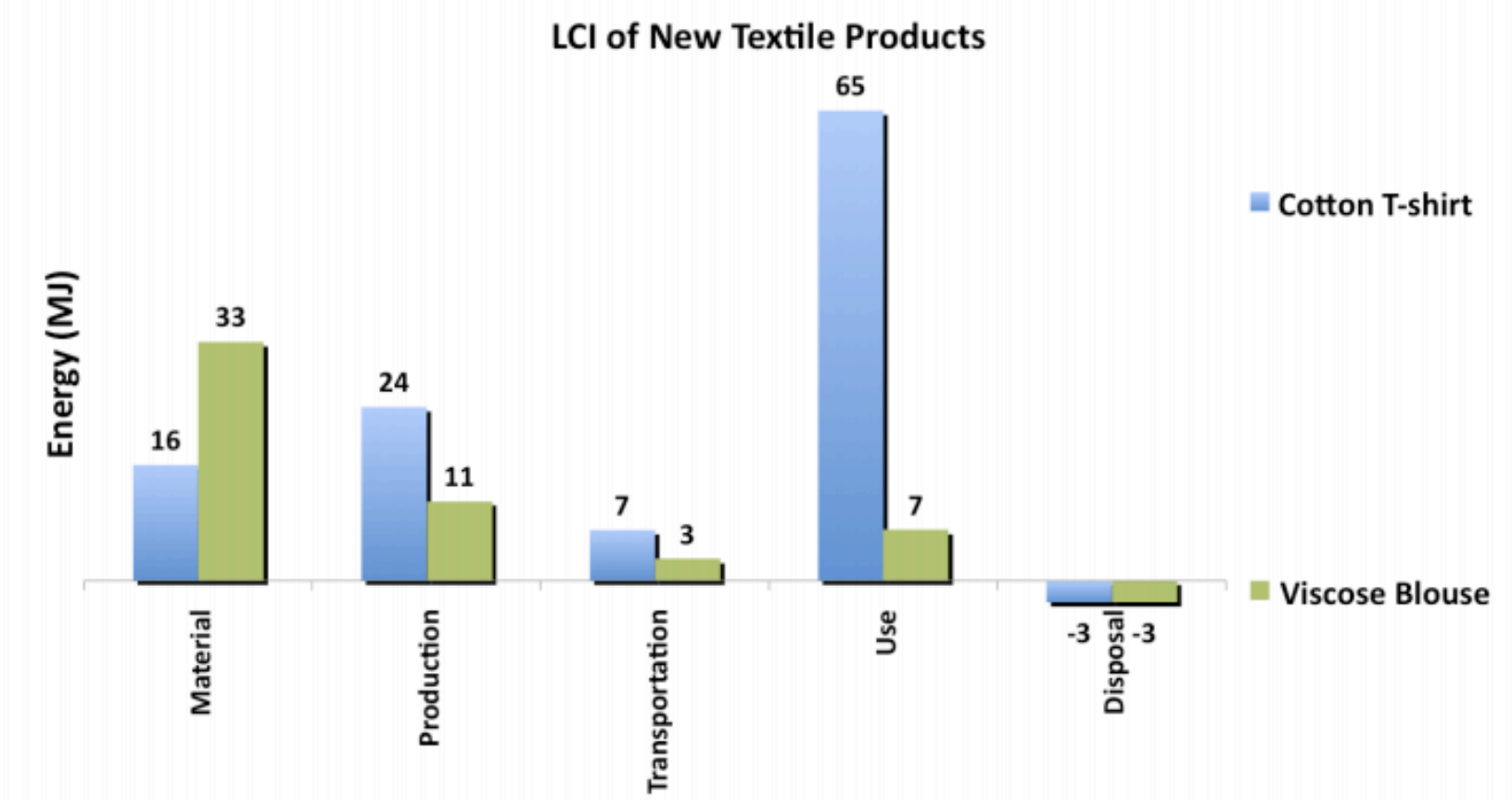
Textiles

Textile EoL Management UK in 2004/5	'000 tonnes	'000 tonnes	% of New Consumption
Apparent consumption of new textiles	1,812		97%
Imports of used textiles	12		1%
Consumption of used textiles	41		2%
Total Consumption		**1,865**	**100%**
Textiles entering the MSW waste stream		**1,165**	**63%**
Textiles collected for resale and recycling	324		**17%**
Of which:			
Resale for re-use in the UK	41		13%
Exported for resale for re-use	174		54%
Recycled in the UK	62		19%
Exported for recycling	26		9%
Rubbish, returned to waste stream	21		7%
Net textiles diverted from waste stream		**303**	**16%**
Textiles unaccounted for		397	21%

Recycling of Low Grade Clothing Waste, OAKDENE HOLLINS, 2006

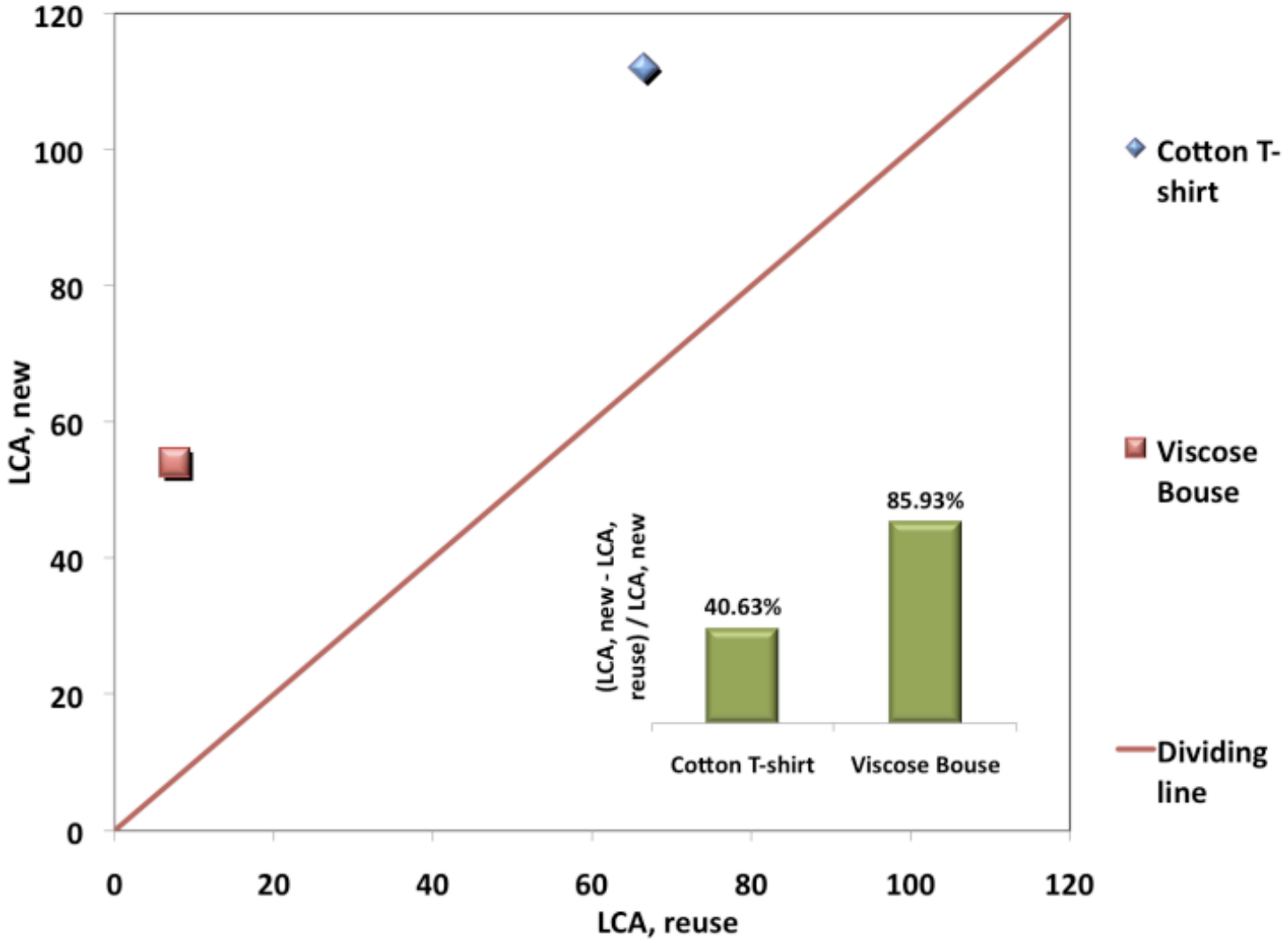
AMERICAN REUSABLE TEXTILE ASSOCIATION

Textiles - CED



http://web.mit.edu/ebm/www/Publications/MITEI-1-g-2010.pdf

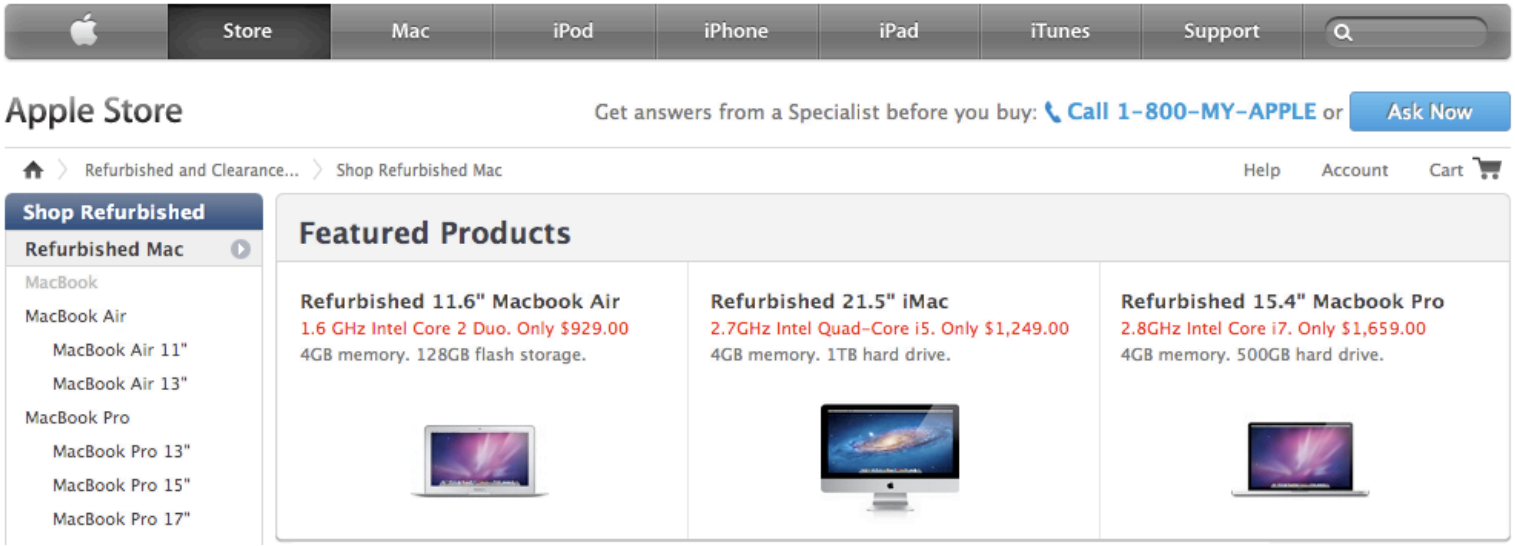
Textiles – New or Remanufactured?



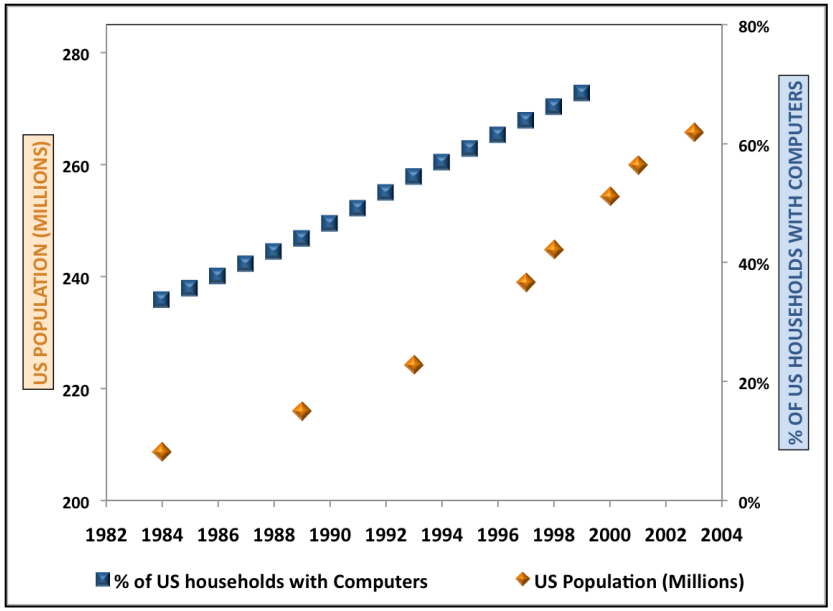
http://web.mit.edu/ebm/www/Publications/MITEI-1-g-2010.pdf

Computers

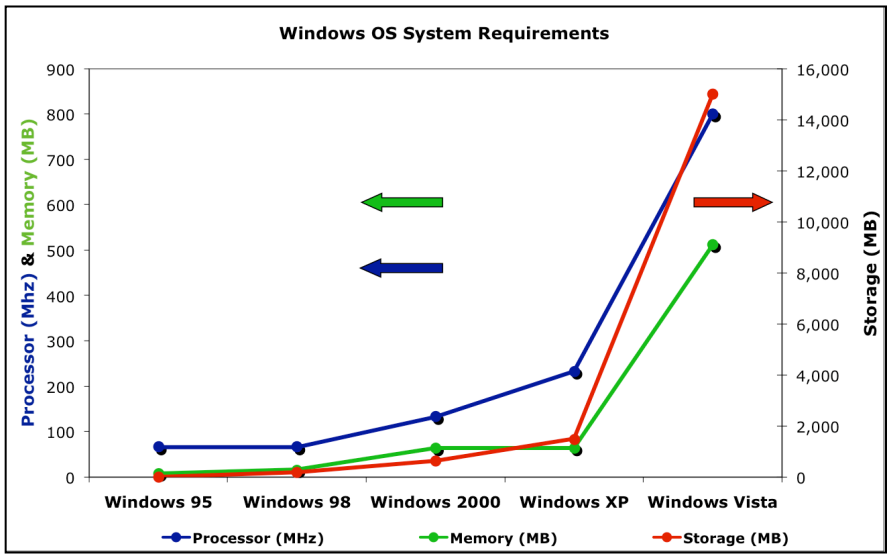
Newport Computers, Rochester, NH



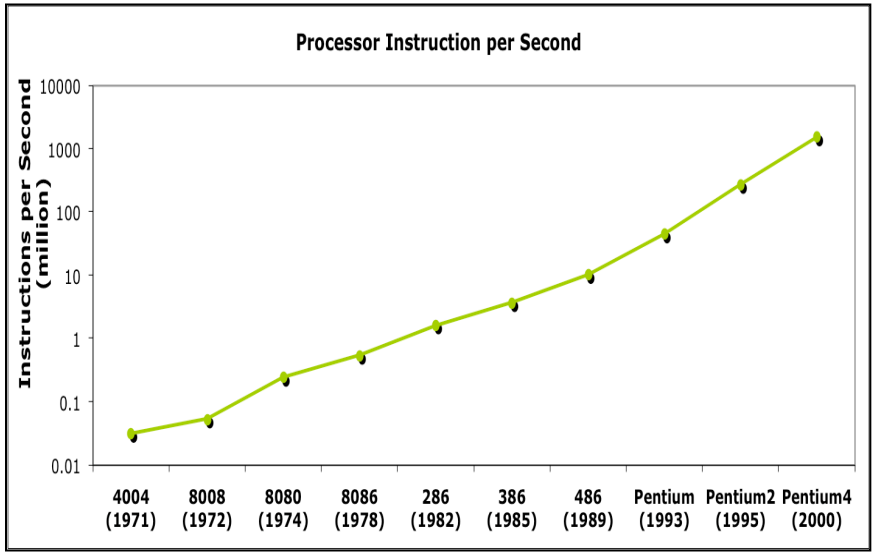
We love new computers



Consume a lot
and
Replace them quickly

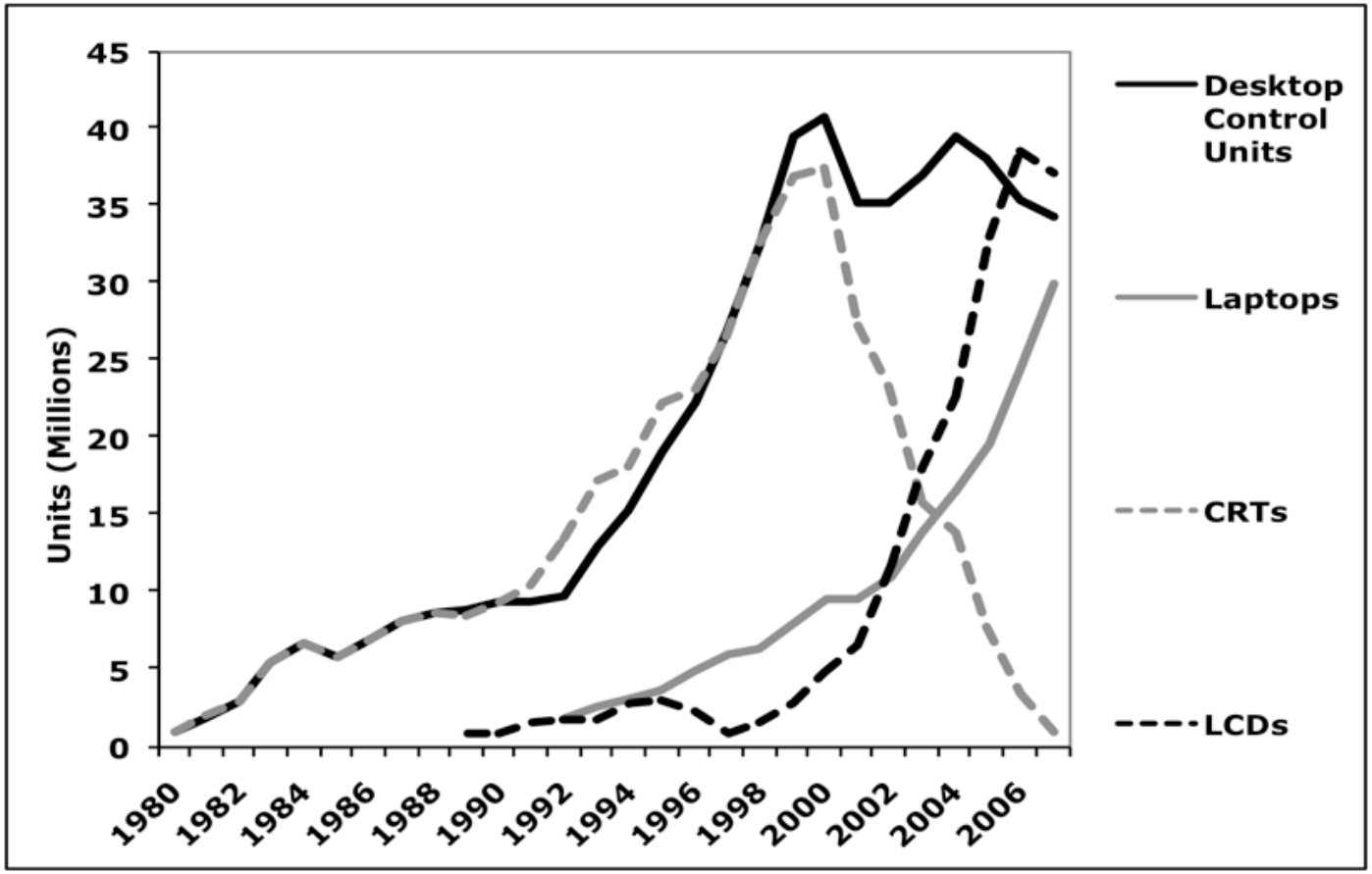


&



Sahni, S., A. Boustani, T.G. Gutowski, and S.G. Graves, ''Reusing Personal Computer Devices - Good or Bad for the Environment?'' IEEE/ International Symposium on Sustainable Systems and Technology, Washington D.C., May 16-19, 2010

Computer Sales and Market Share



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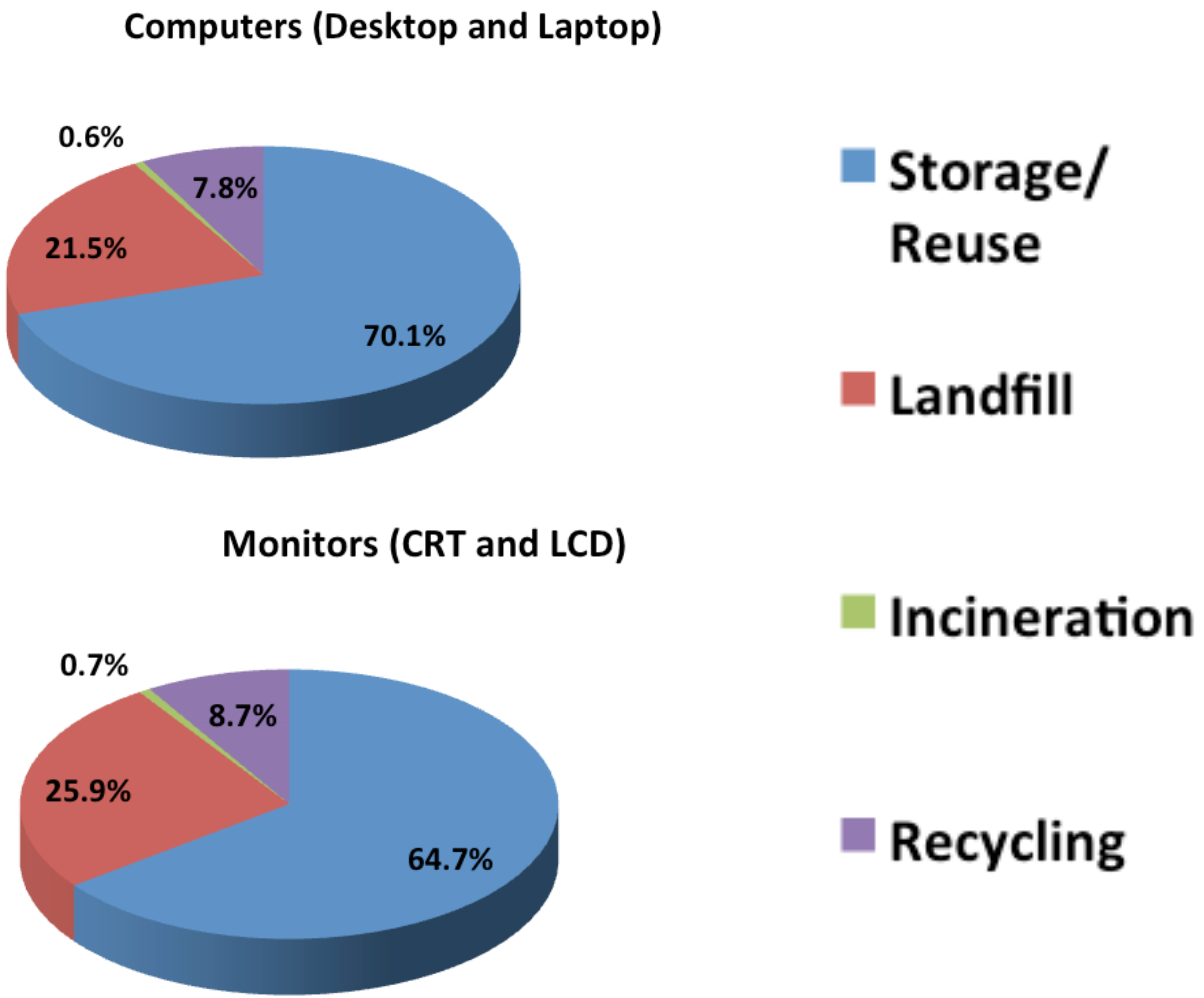
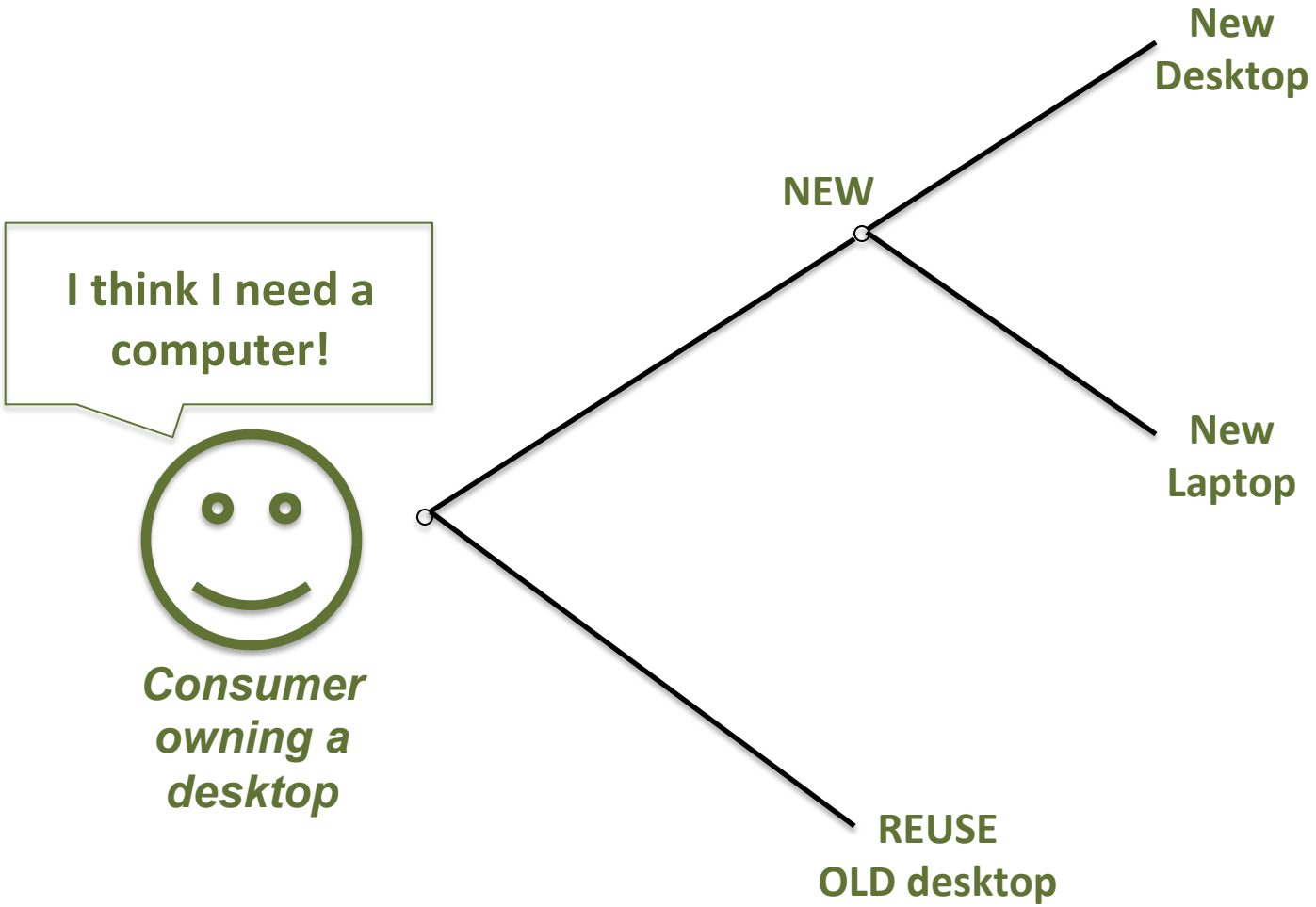
Computer EoL in the US

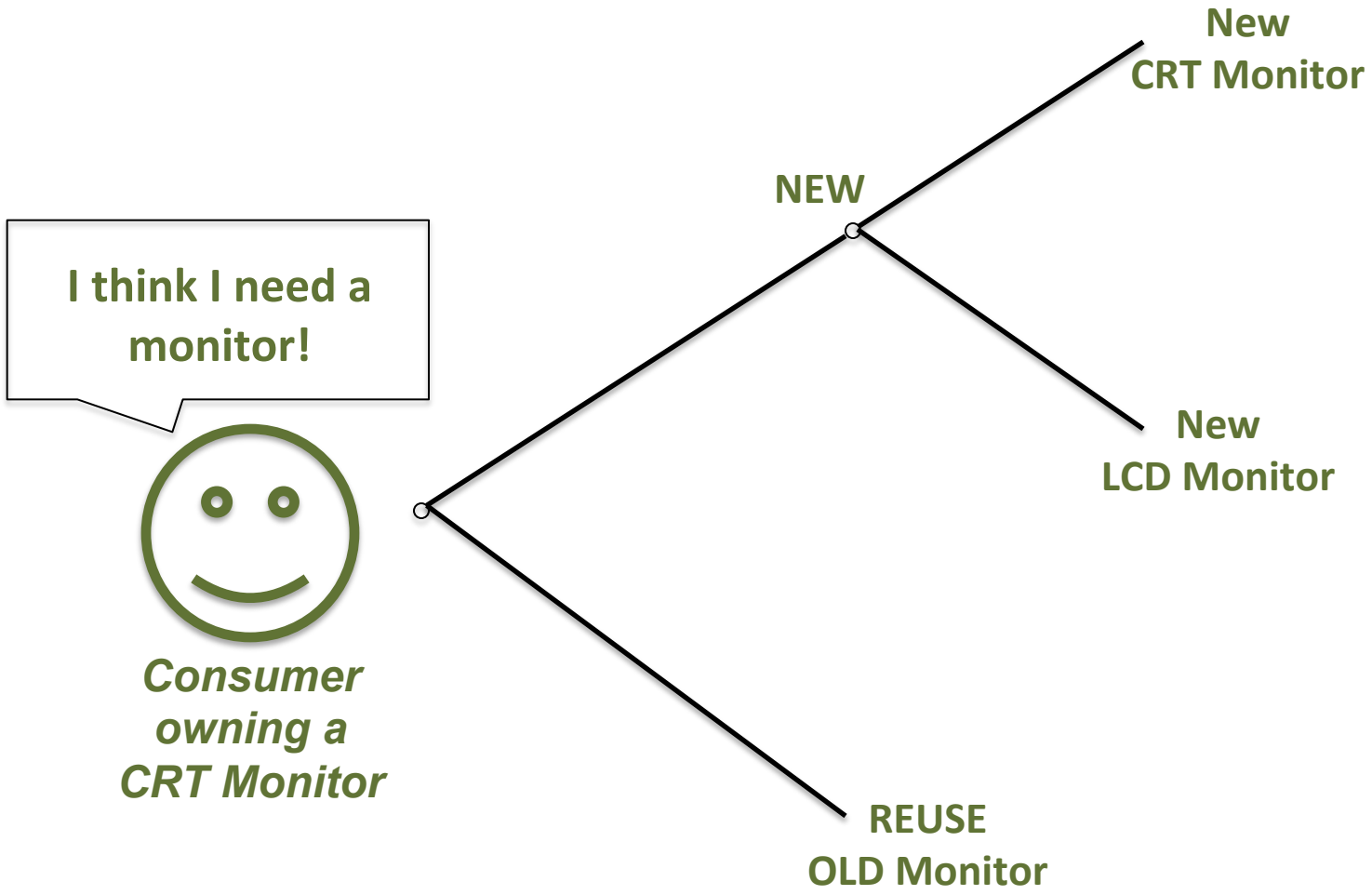


Management of electronic waste in the United States: Approach two, by EPA

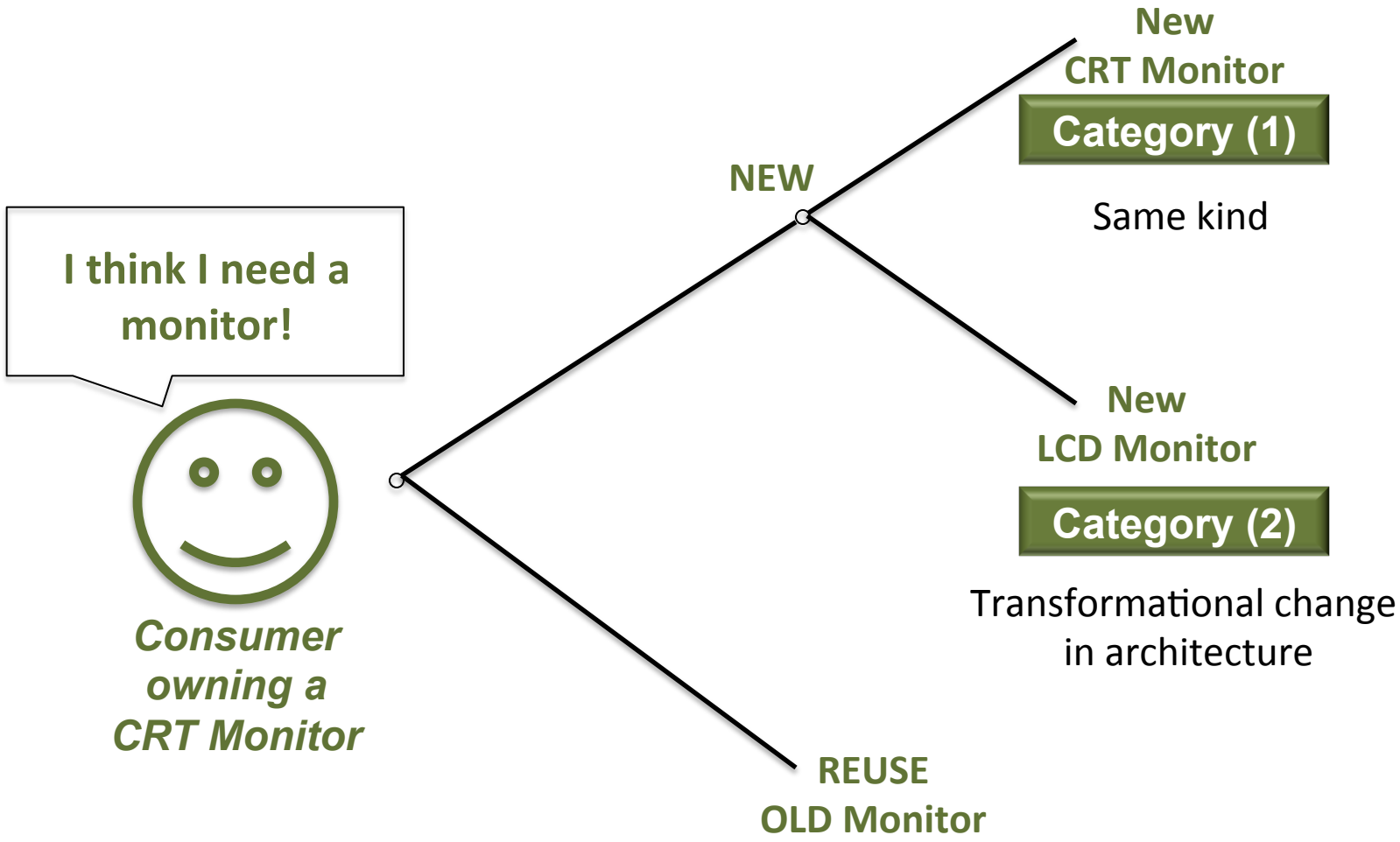
Computers – Scenario



Computers – Scenario



Computers – Scenario

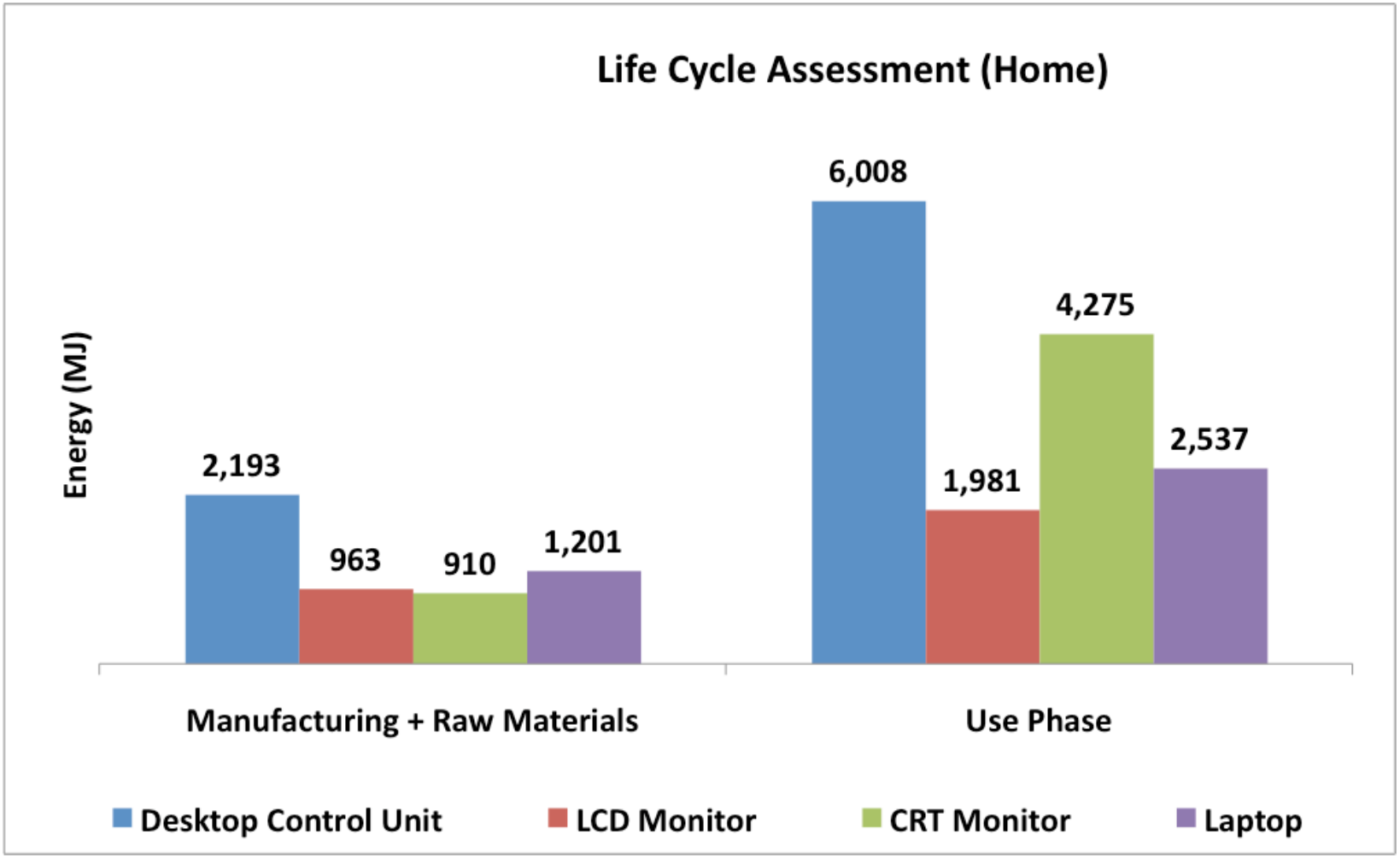


Computers – BoM of a Laptop

Material in a Laptop	Weight (g)	
LDPE	43	
PP	4	
PS	3	
EPS	50	
PVC	23	
ABS	142	
PA 6	281	
PC	267	
PMMA	36	
epoxy	3	
Steel sheet galvanized	489	
Al sheet/extrusion	38	
Cu wire	60	
Cu tube/sheet	15	
MgZn5 cast	122	
Power Coating	5	
LCD screen m sq (viewable screen size)	63	
Big caps and coils	501	
Slots/external parts	133	
Integrated Circuits, 5% Si, Au	47	
Integrated Circuits 1% Si,	31	
SMD and LED avg	50	
PWB 1/2 lay 3.75 kg/m sq.	5	
PWB 6 lay 4.5 kg/m sq	77	
solder SnAg4CuO.5	7	
Glass for lamps	1	
Cardboard	921	Not incl in total
Glass for LCD	362	
Total (Kg and MJ)	**2.9**	

EuP Report, IVF 2007

Computers - CED



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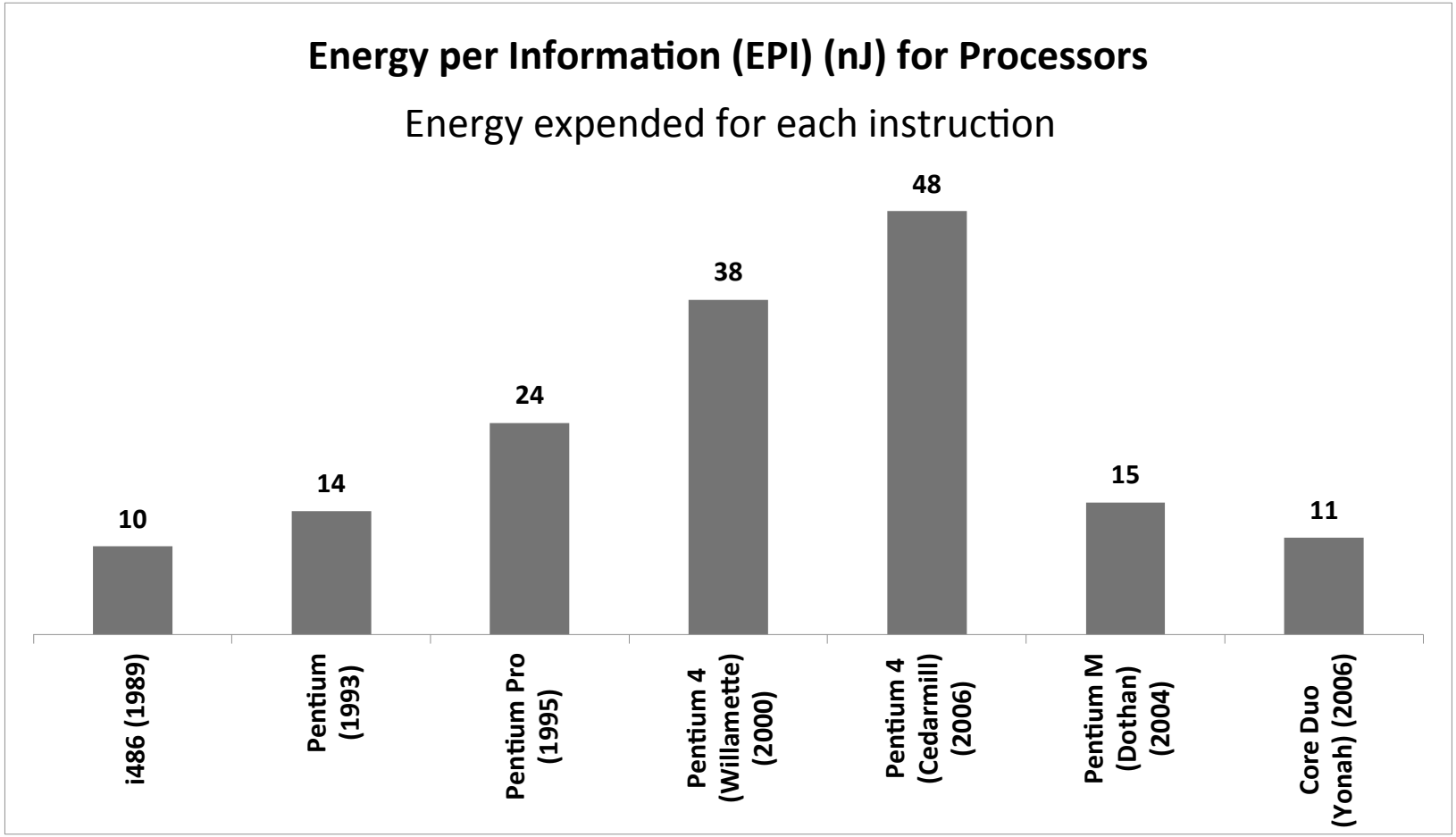
Trends in Processor Power Consumption

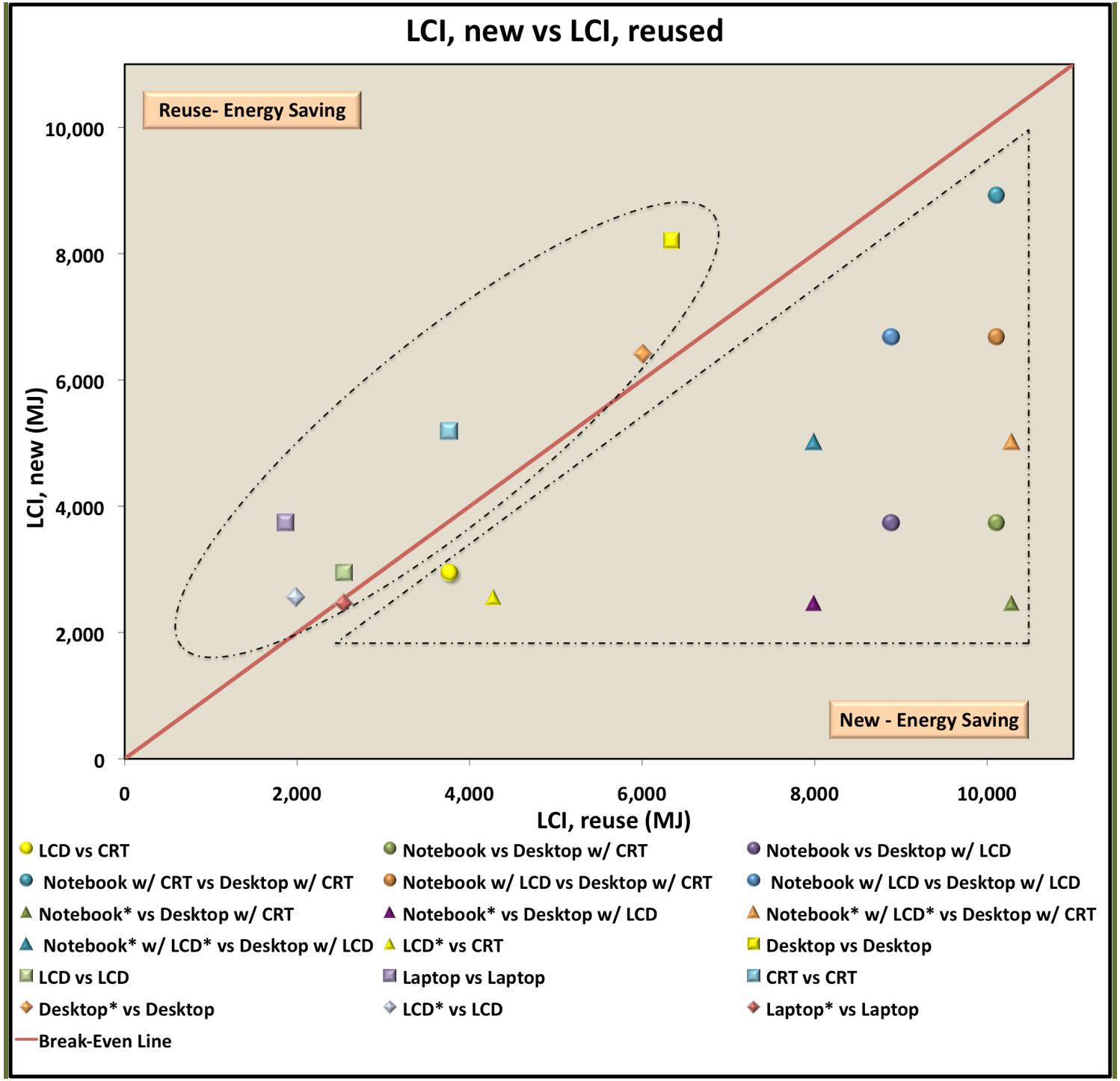


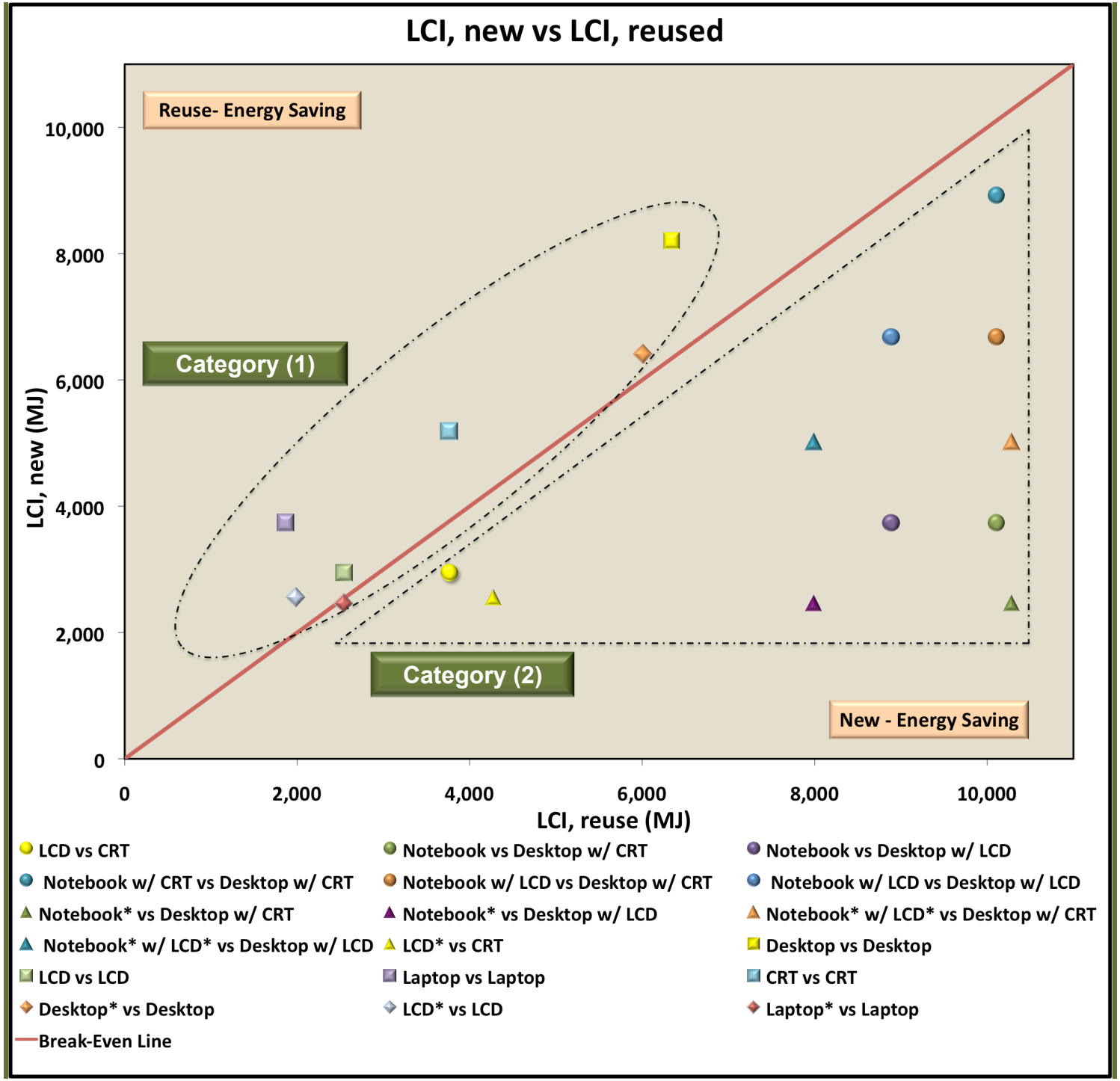
Energy per Instruction Trends in Intel® Microprocessors, *Microarchitecture Research Lab, Intel Corporation*

How do we use computers?

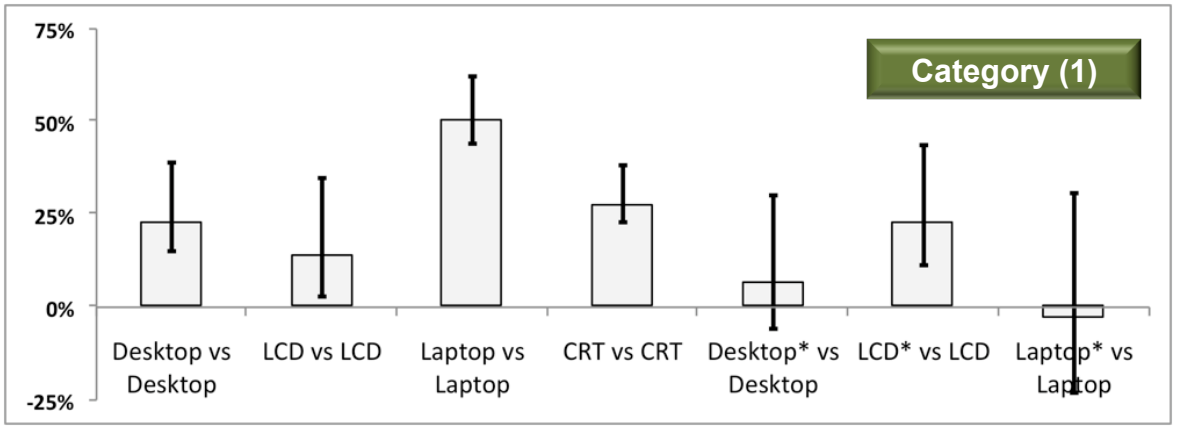
Computer Usage Pattern	Location	Mode	hours/day
Desktop	office	off	9.0
		sleep	8.8
		active	6.2
	home	**off**	**11.8**
		sleep	**7.9**
		active	**4.3**
Laptop	office	off	8.6
		sleep	8.2
		active	7.2
	home	**off**	**12.2**
		sleep	**8.0**
		active	**3.8**
Monitor	office	off	6.5
		sleep	10.4
		active	7.1
	home	**off**	**13.2**
		sleep	**7.2**
		active	**3.5**

EuP Report, IVF 2007


LCI, new vs LCI, reused
Reuse- Energy Saving
New - Energy Saving
LCI, new (MJ)
LCI, reuse (MJ)
0
2,000
4,000
6,000
8,000
10,000
LCD vs CRT
Notebook vs Desktop w/ CRT
Notebook vs Desktop w/ LCD
Notebook w/ CRT vs Desktop w/ CRT
Notebook w/ LCD vs Desktop w/ CRT
Notebook w/ LCD vs Desktop w/ LCD
Notebook* vs Desktop w/ CRT
Notebook* vs Desktop w/ LCD
Notebook* w/ LCD* vs Desktop w/ CRT
Notebook* w/ LCD* vs Desktop w/ LCD
LCD* vs CRT
Desktop vs Desktop
LCD vs LCD
Laptop vs Laptop
CRT vs CRT
Desktop* vs Desktop
LCD* vs LCD
Laptop* vs Laptop
Break-Even Line


LCI, new vs LCI, reused
Reuse- Energy Saving
Category (1)
Category (2)
New - Energy Saving
LCI, new (MJ)
LCI, reuse (MJ)
0
2,000
4,000
6,000
8,000
10,000
LCD vs CRT
Notebook vs Desktop w/ CRT
Notebook vs Desktop w/ LCD
Notebook w/ CRT vs Desktop w/ CRT
Notebook w/ LCD vs Desktop w/ CRT
Notebook w/ LCD vs Desktop w/ LCD
Notebook* vs Desktop w/ CRT
Notebook* vs Desktop w/ LCD
Notebook* w/ LCD* vs Desktop w/ CRT
Notebook* w/ LCD* vs Desktop w/ LCD
LCD* vs CRT
Desktop vs Desktop
LCD vs LCD
Laptop vs Laptop
CRT vs CRT
Desktop* vs Desktop
LCD* vs LCD
Laptop* vs Laptop
Break-Even Line

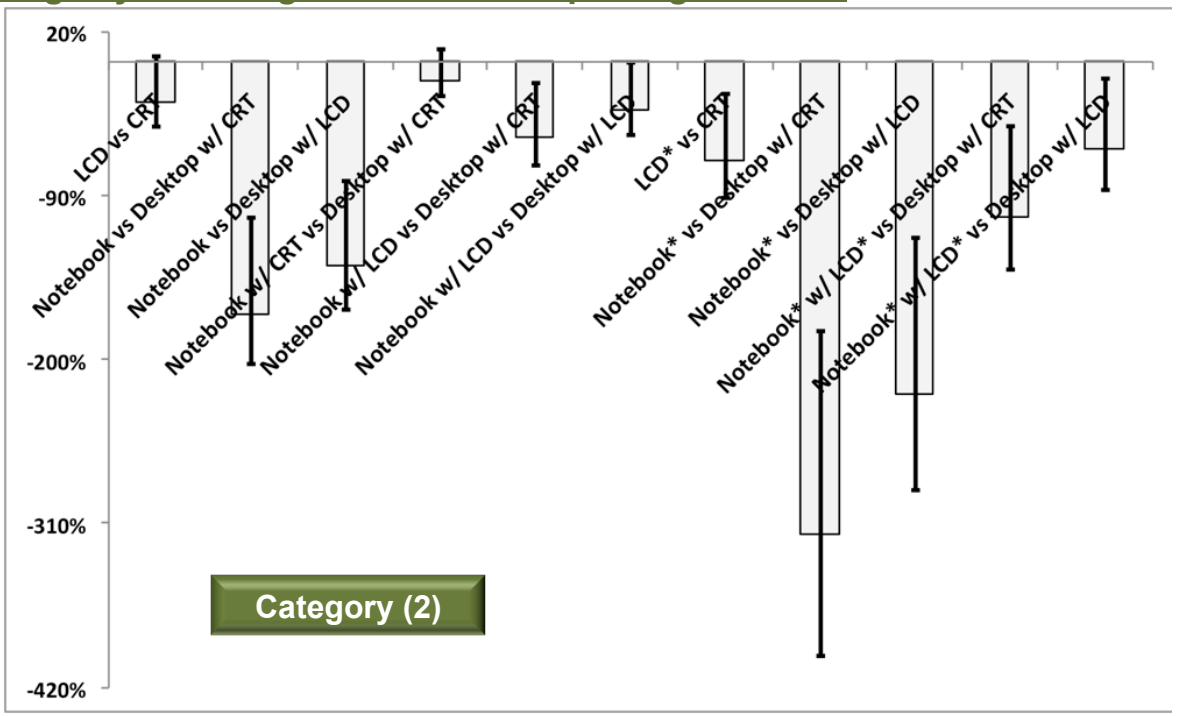
Key Sensitivity Analysis



Assumption:

The average lifetime for the use of a computer as home is assumed to be 4 years

Life cycle energy savings by choosing to reuse over replacing with new



Sensitivity Analysis:

Columns: 4yrs

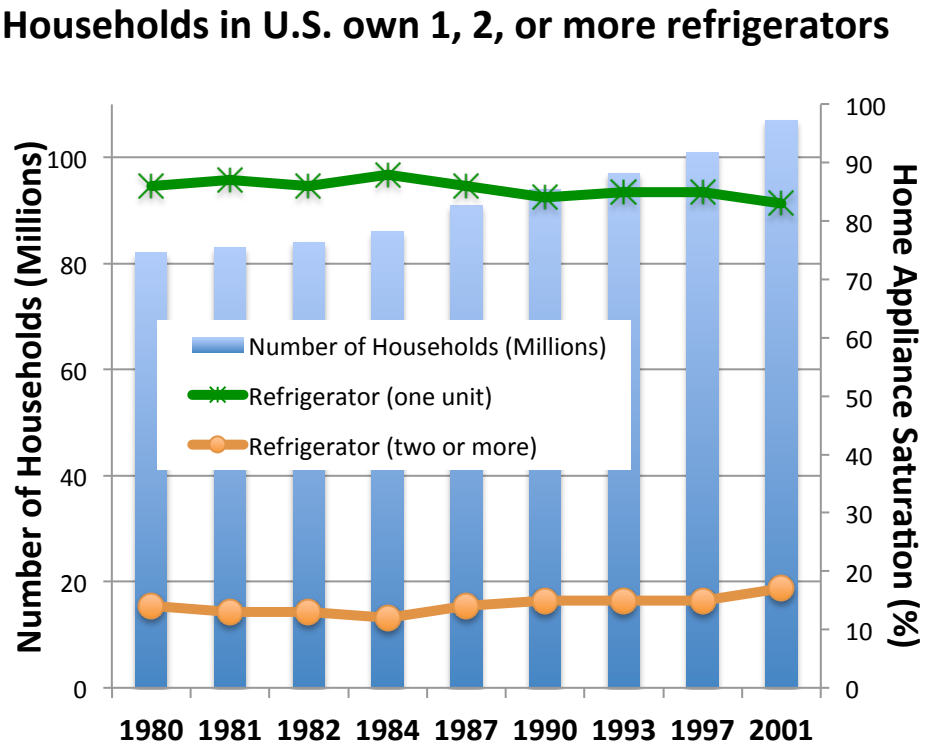
Outside end:6 yrs

Inside end: 2 yrs

Sahni, S., A. Boustani, T.G. Gutowski, and S.G. Graves, ''Reusing Personal Computer Devices - Good or Bad for the Environment?'' ISSST 2010

Appliances – What's their footprint?

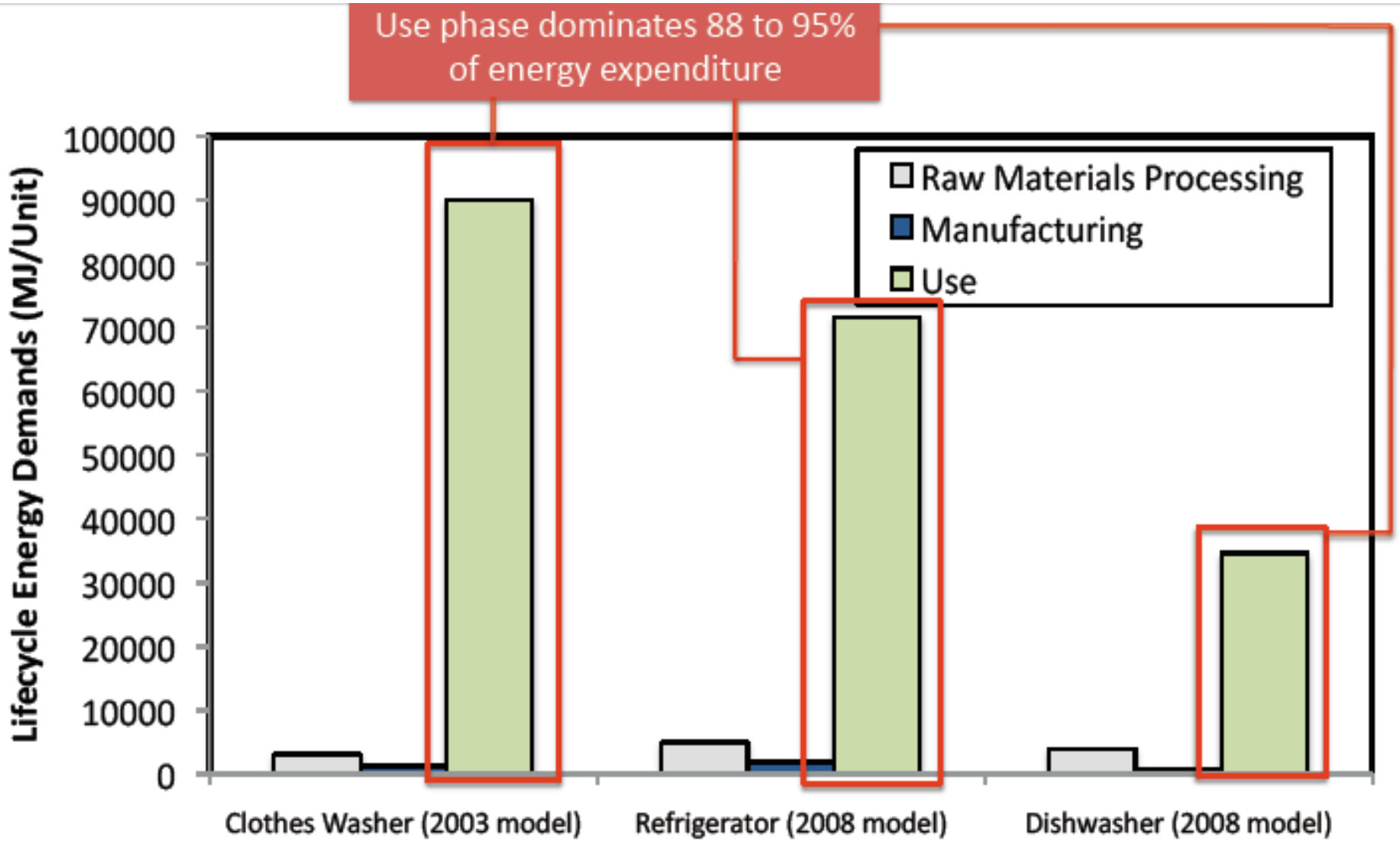
- Appliance energy consumption
  - Home appliances
    - 30% of the U.S. residential electricity consumption
    - More than 10% of the total US Electricity consumption



Source: Energy Information Association (EIA). 2001. Appliance Reports: US Data Table 2001.

http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf

Appliances - CED

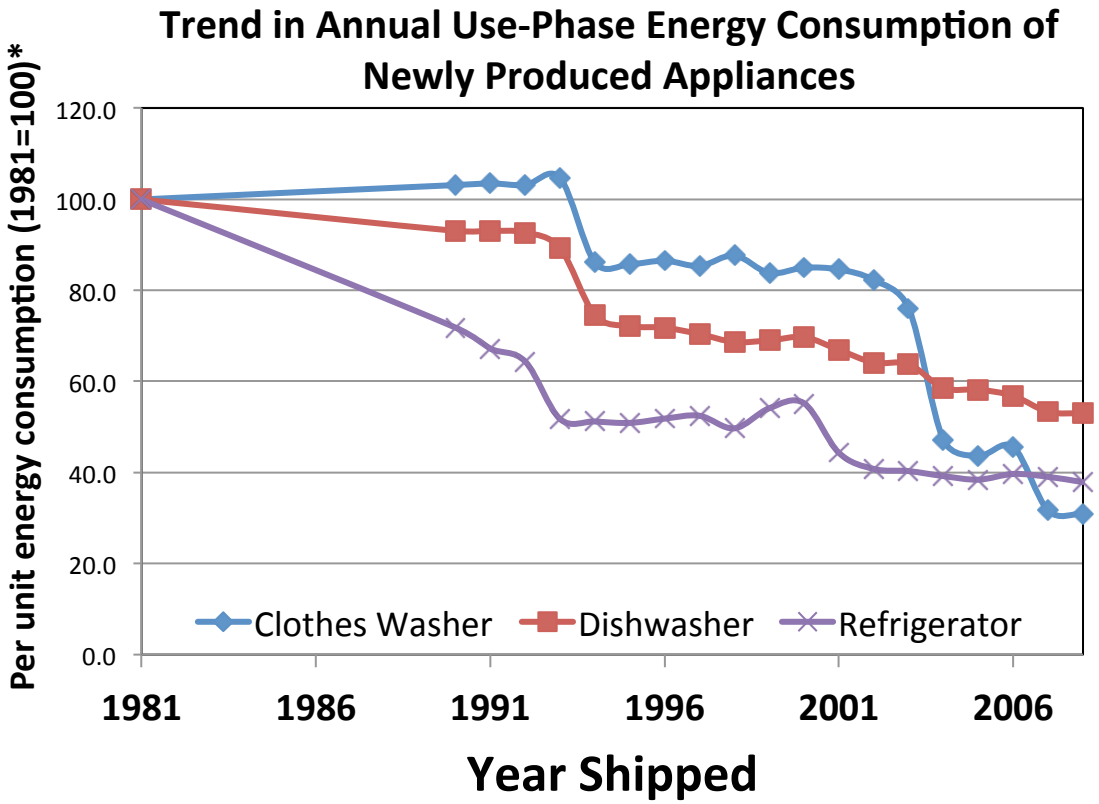


http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf

Appliance – Use Phase

- Appliances presented are
  REFRIGERATOR
  DISHWASHER
  CLOTHES WASHER

- Unit energy consumption of major appliances have dropped by 40-70% between 1981 and 2008.



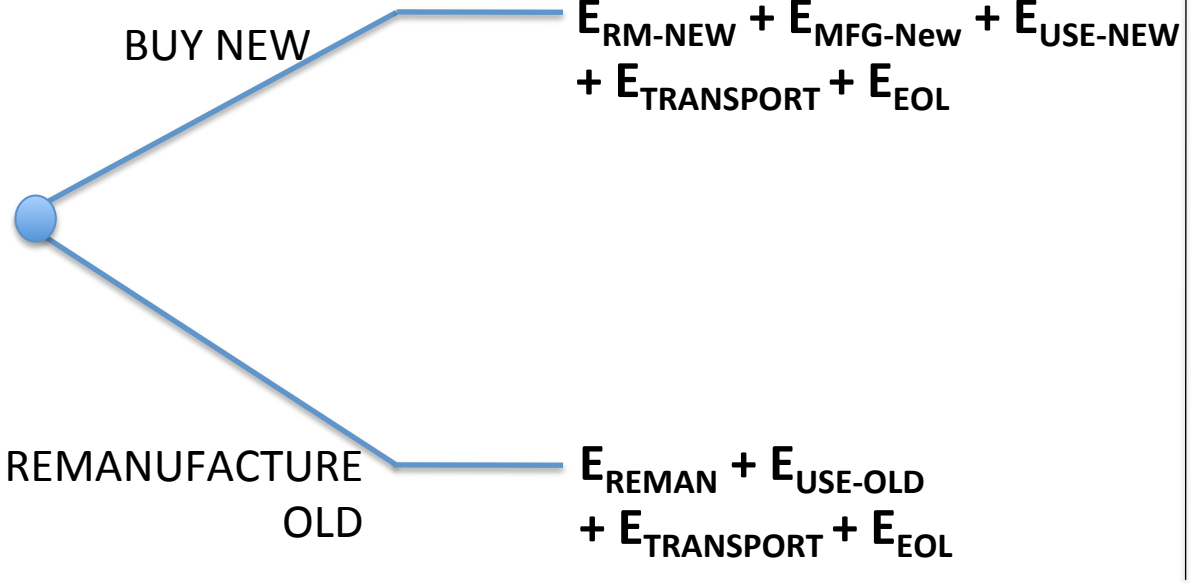
Source: AHAM, 2008.

*service unit for clothes washer, dishwasher, and refrigerator are energy consumption per cycle, energy consumption per cycle, and annual energy expenditure.

http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf

Appliances - Scenario

- **Scenario**: As a used appliance reaches end-of-life the consumer has a decision to make:



Assumptions for New

-Conventional unit
-Product purchase-to-purchase
-lifetime same regardless of year manufactured
  -Refrigerator:14 Years
  -Clothes Washer: 11 Years
  -Dishwasher: 10 Years

Assumptions for Reman

-Service lifetime=Prior lifetime
-Restored to like-new condition
-E_{REMAN}=0, again in S.A.
  (*in favor of Remanufacturing*)

Appliance – New or Remanufactured?

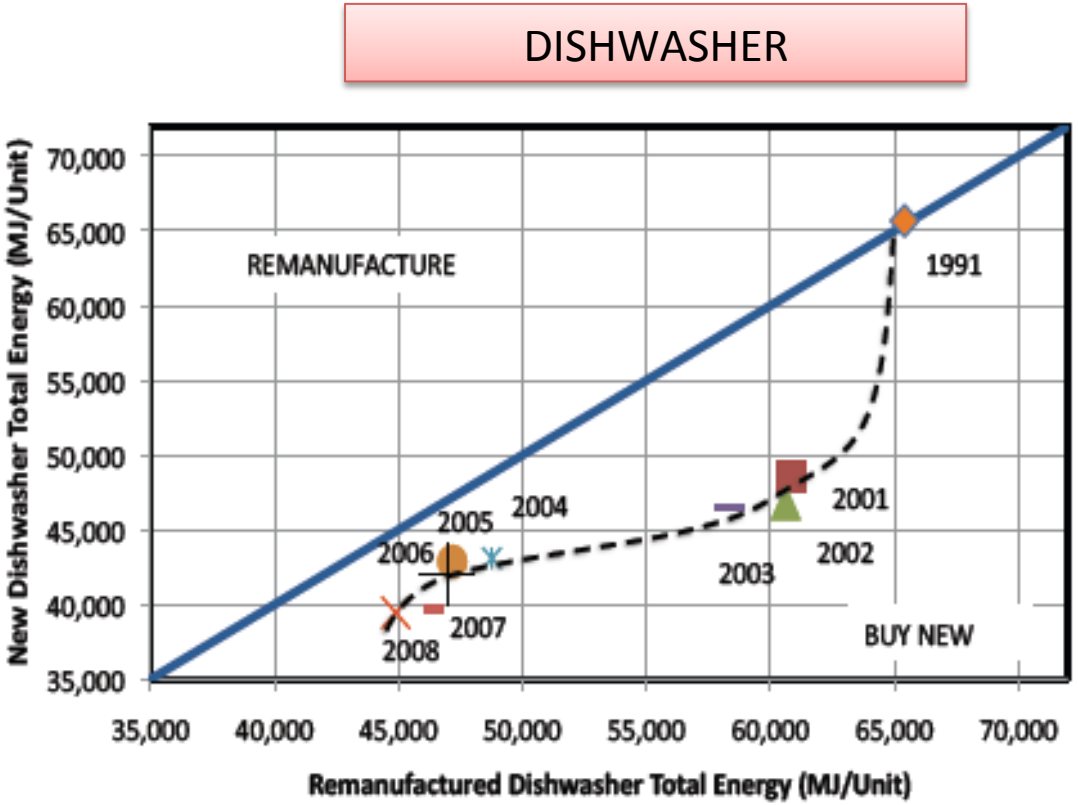
	Energy New Unit (MJ/Unit Service[a])	Energy Remanufactured Unit (MJ/Unit Service[a])	Energy Savings (%)
Clothes Washer (2003 model versus 1992 model)	**1,108,194**	**1,590,310**	**- 44%**
Refrigerator (2008 model versus 1994 model)	**129,886**	**170,852**	**-32%**
Dishwasher (2008 model versus 1998 model)	**39,459**	**44,896**	**- 14%**

[a] Unit service for clothes washer and refrigerator are cubic meters while for dishwasher is a unit product. Dishwashers are not normalized by unit volume because their volumes have not changed substantially.

http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf

Appliance - Dishwasher

- Life cycle energy demands for new dishwashers reduced by 40% from 1991 to 2008.
- Life cycle energy impacts of new and remanufactured dishwashers break-even in 1991.
- Remanufacturing leads to 25% and 14% more life cycle energy use in 2001 and 2008.



http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf

Appliance – Clothes Washer

- Life cycle energy demands for new clothes washers reduced by 32% from 1992 to 2003.
- Life cycle energy impacts of new and remanufactured clothes washers break-even in 1992.
- Remanufacturing leads to 44% more life cycle energy use in 2003.

http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf

Appliance – Clothes Washer

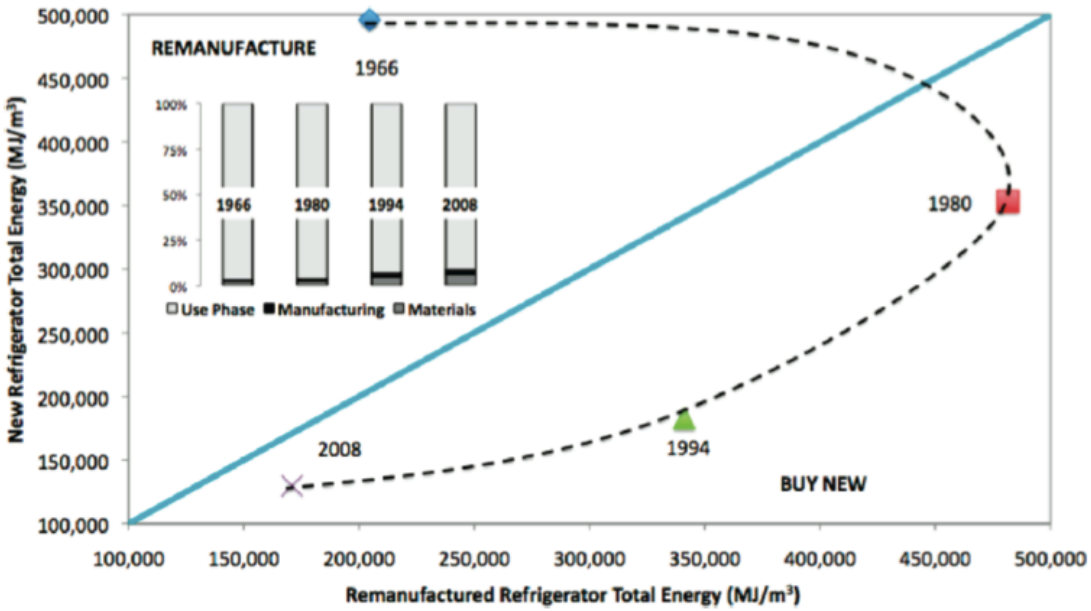
- Technological transformation (architectural changes) from top-load-vertical-axis washers to front-load-horizontal-axis washers.
- By 2004, most efficient horizontal-axis washer 76% more efficient than average clothes washer.
- Main efficiency improvements influenced by advances in water resources management.
- Efficiency improvements makes remanufacturing energy expending end-of-life option.

Source: Bole, R. (2006). Life-cycle optimization of residential clothes washer replacement. Dep. Natural Resources and Environment, Univ. of Michigan, Ann Arbor.

Appliance - Refrigerator

REFRIGERATOR

- Remanufacturing in year 1966 leads to 59% savings in total lifecycle energy.
- After establishment of Energy Policy & Conservation Act in 1975 new appliances have become increasingly more efficient.
- In 1994 utilizing a remanufactured 1980 model refrigerator would expend 86% more energy from a total lifecycle perspective.



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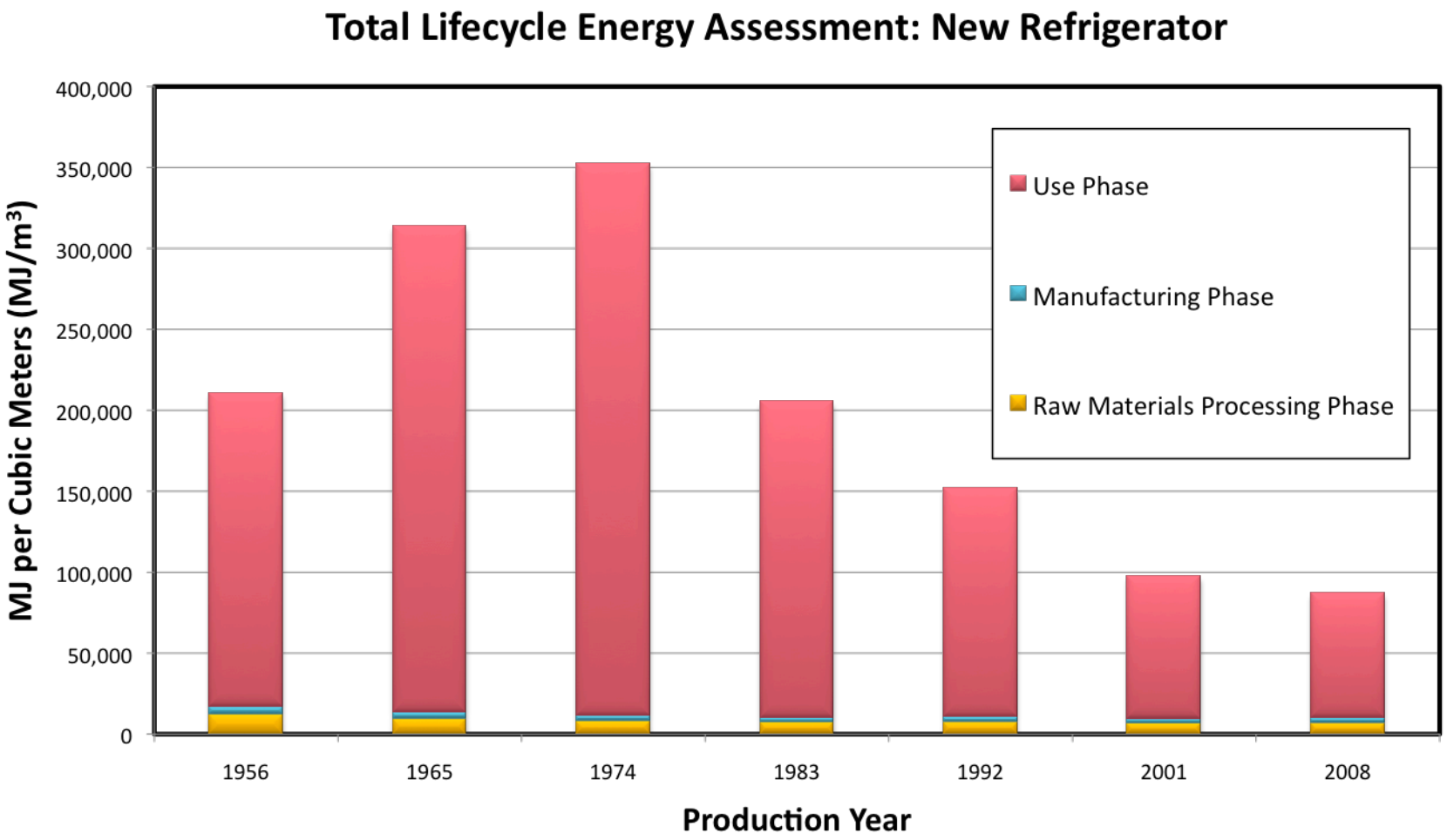
Appliance – Refrigerator - CED



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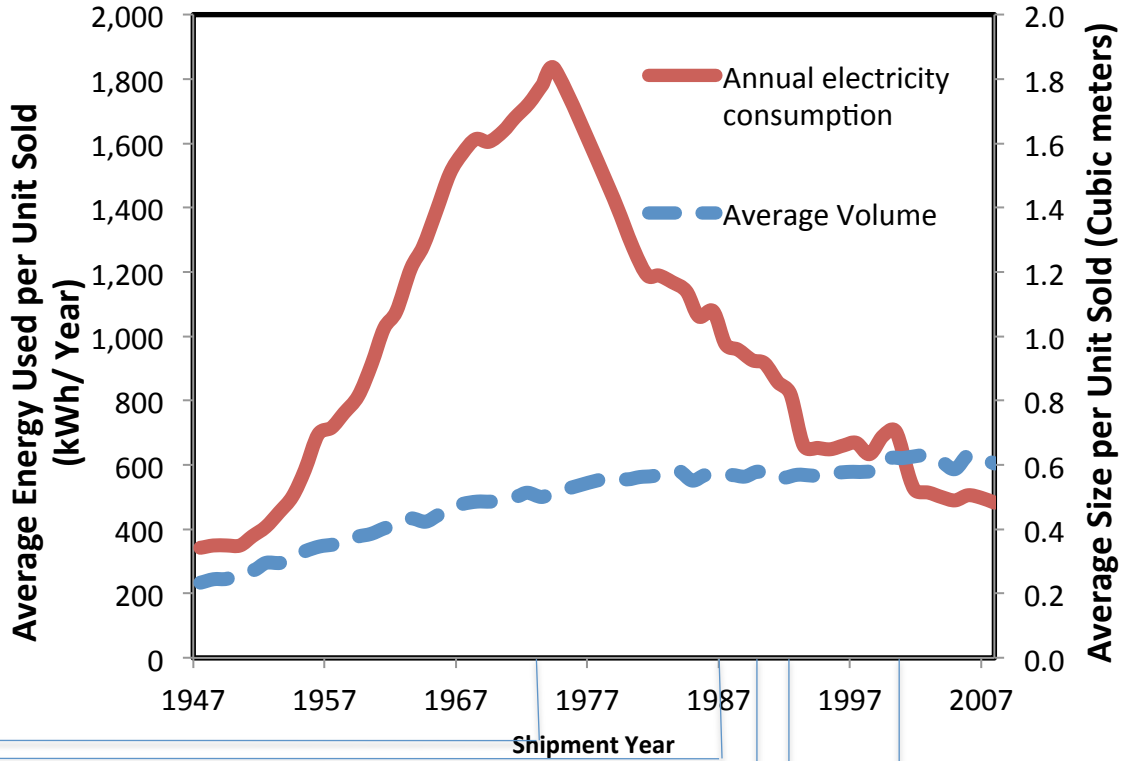
Appliance - Refrigerator

- Refrigerators have improved in time
  - 400% rise from 1947 to 1974
  - 75% drop from 1974 to 2008
  - 2x increase in size from 1947 to 2008

- Improvements driven by:
  - Advancement in cooling and insulation technologies
  - Standards
  - Volunteer programs: Energy Star



1974
- First State-Wide Appliance Energy Efficiency Standard (CA)

1975
- Establishment of Energy Policy & Conservation Act

1987
- Establishment of National Appliance Energy Conservation Act

1990
- First U.S. Standard for Refrigerators (976 kWh)

1993
- 1st Update to U.S. Standard (686 kWh)

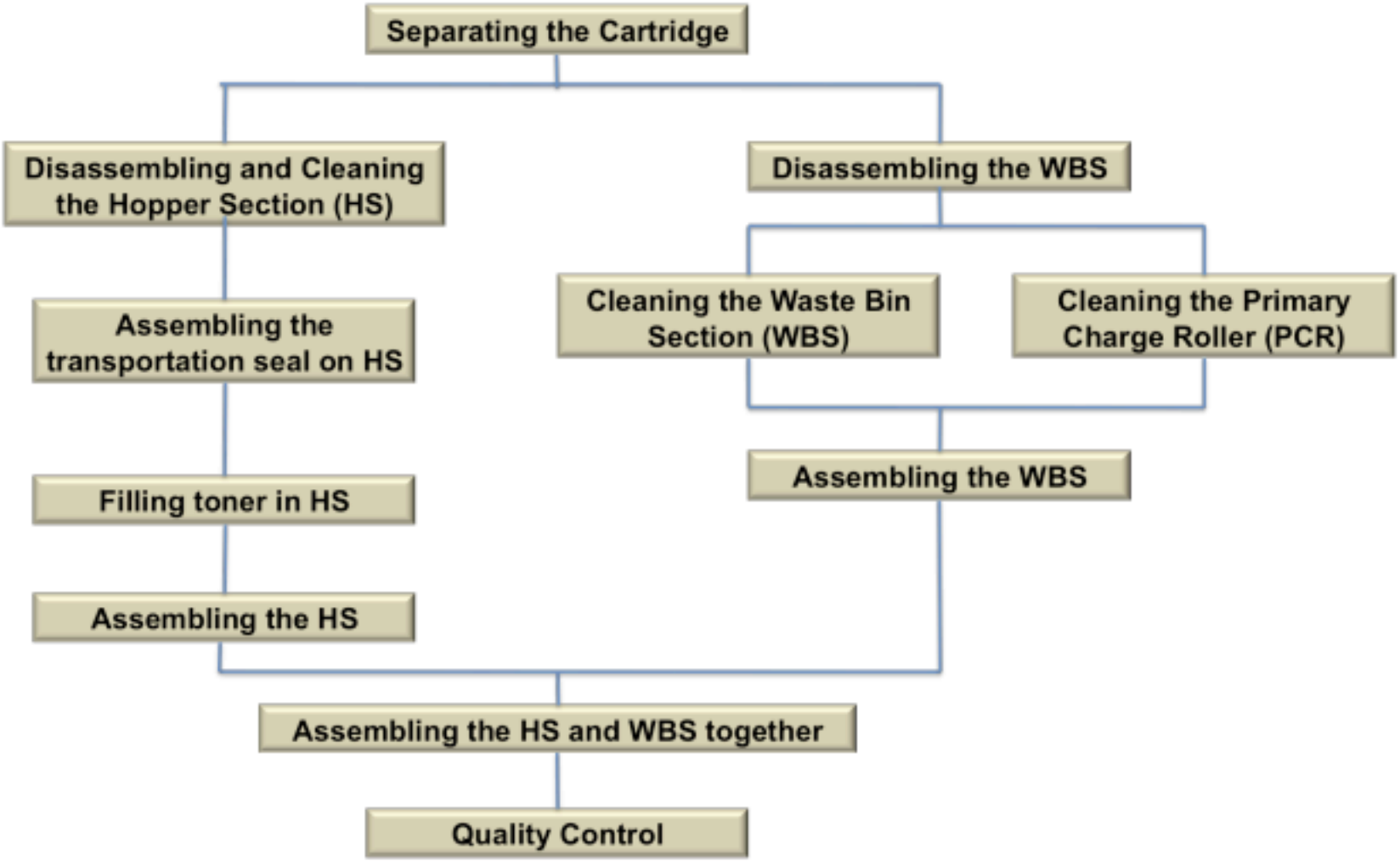
2001
- 2nd Update to U.S. Standard (486 kWh)

Cartridges

Remanufactured toner cartridge with Xerox c6130

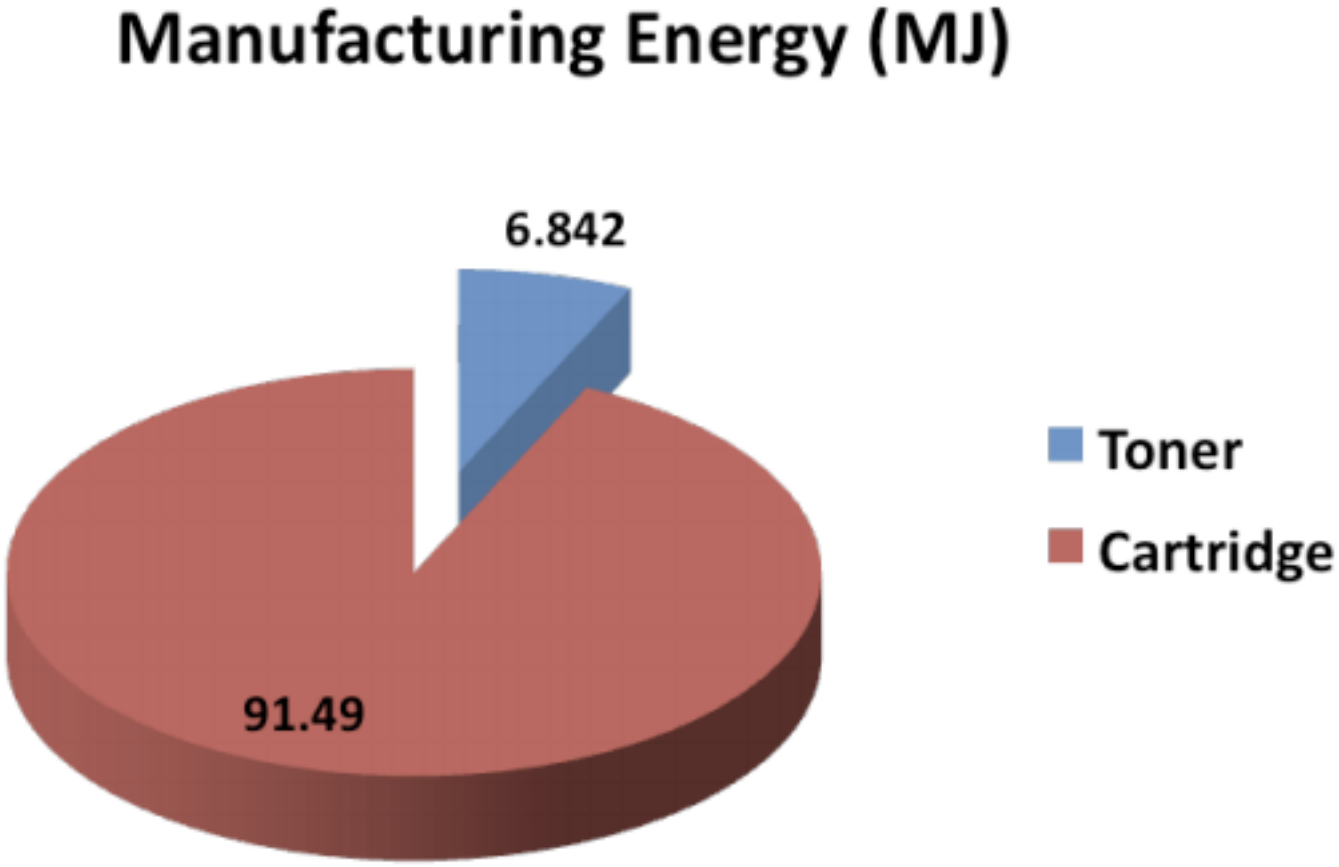
Model:	C6130
Brand:	Xerox
Origin:	Made In China
Category:	Office Supplies / Office Consumable / Other Office Consumable
Keywords:	Toner cartridge
Price:	-
Min. Order:	50 pc

Cartridge – Remanufacturing (Refilling)



http://web.mit.edu/ebm/www/Publications/MITEI-1-b-2010.pdf

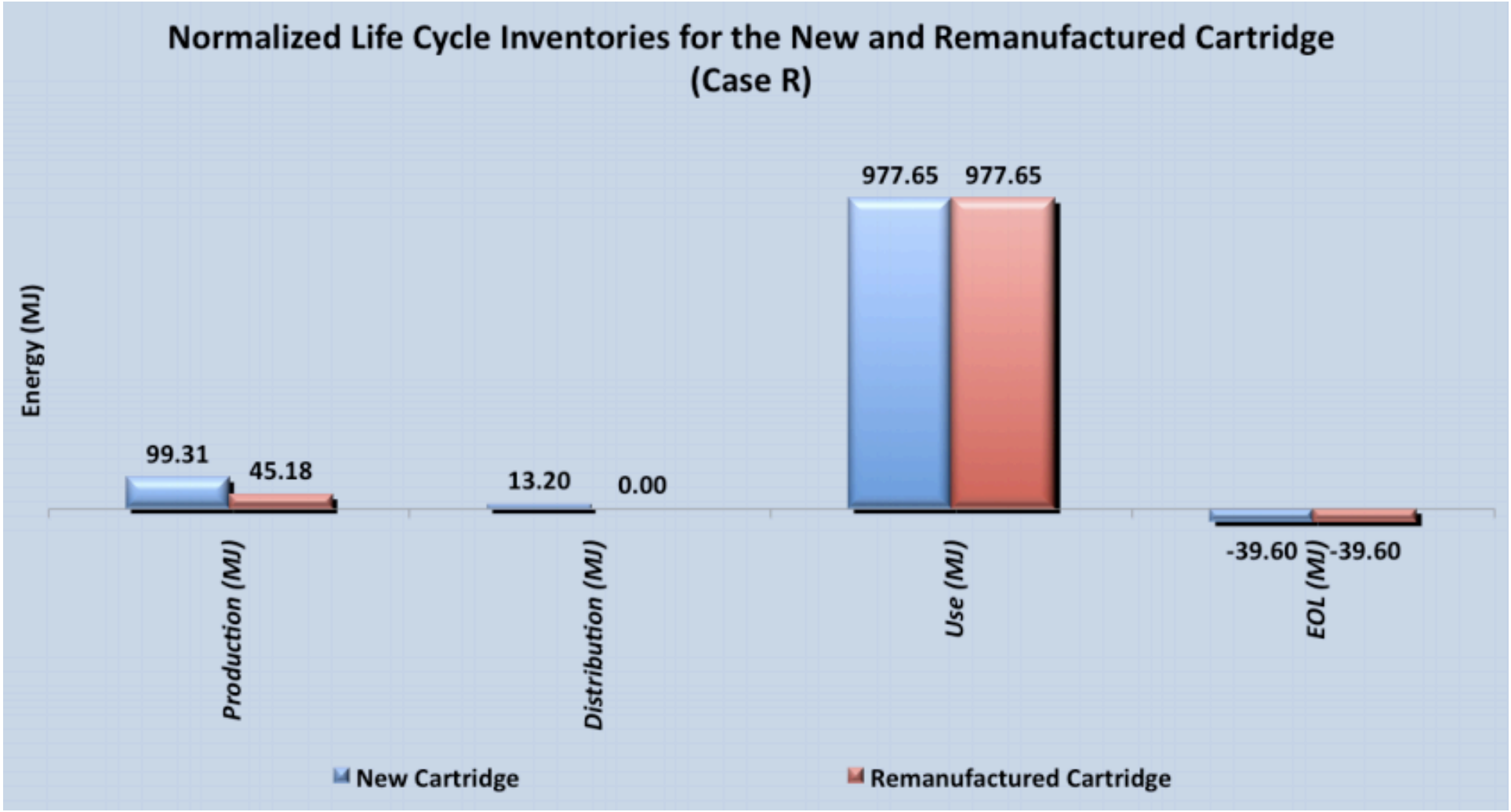
Cartridge - CED



What about Use Phase?

http://web.mit.edu/ebm/www/Publications/MITEI-1-b-2010.pdf

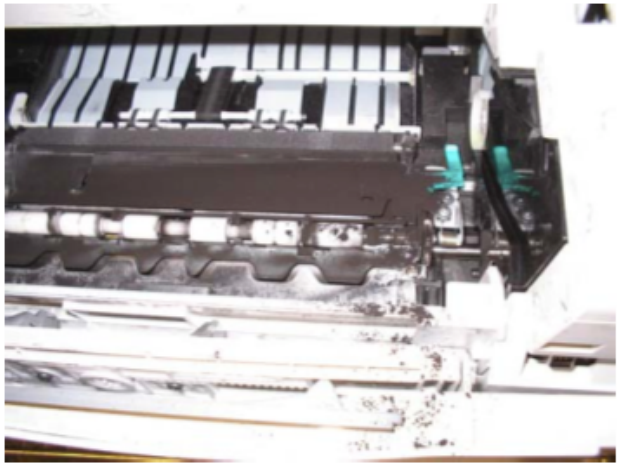
Cartridge – New or Refilled?



New & Refilled: 101 print out pages to obtain 100 useful print outs

http://web.mit.edu/ebm/www/Publications/MITEI-1-b-2010.pdf

Refilled Toner Cartridge - Use

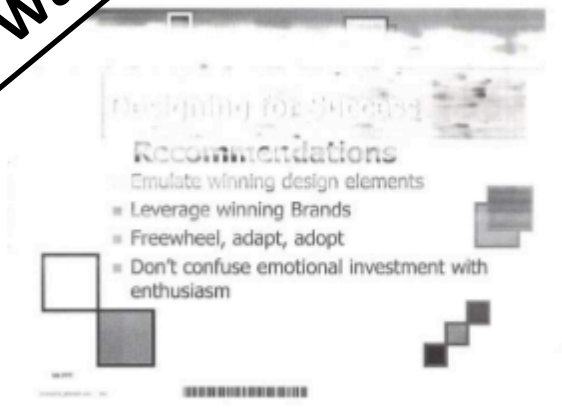


Cartridge Leak

All uses, including external distribution

Limited u ternal distribution
(Fade i with 'Designing for
Suc

Limited Not for distribution

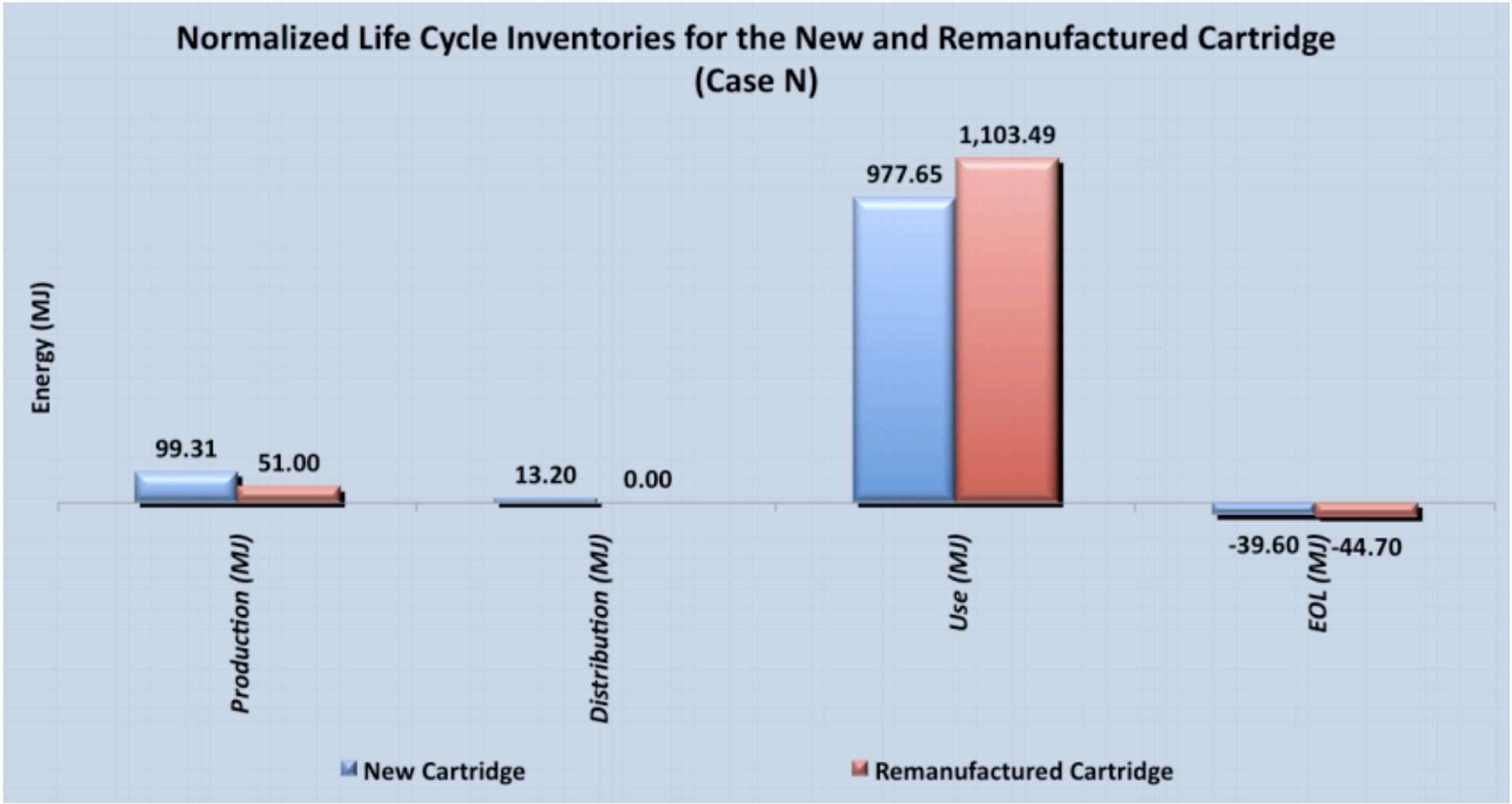


Unusable

Poor Quality Printing – Wasted Paper & Electricity

Quality Logic. Reliability comparison study: HP laserjet toner cartridges vs remanufactured brands. 2008.

Cartridge – New or Refilled?

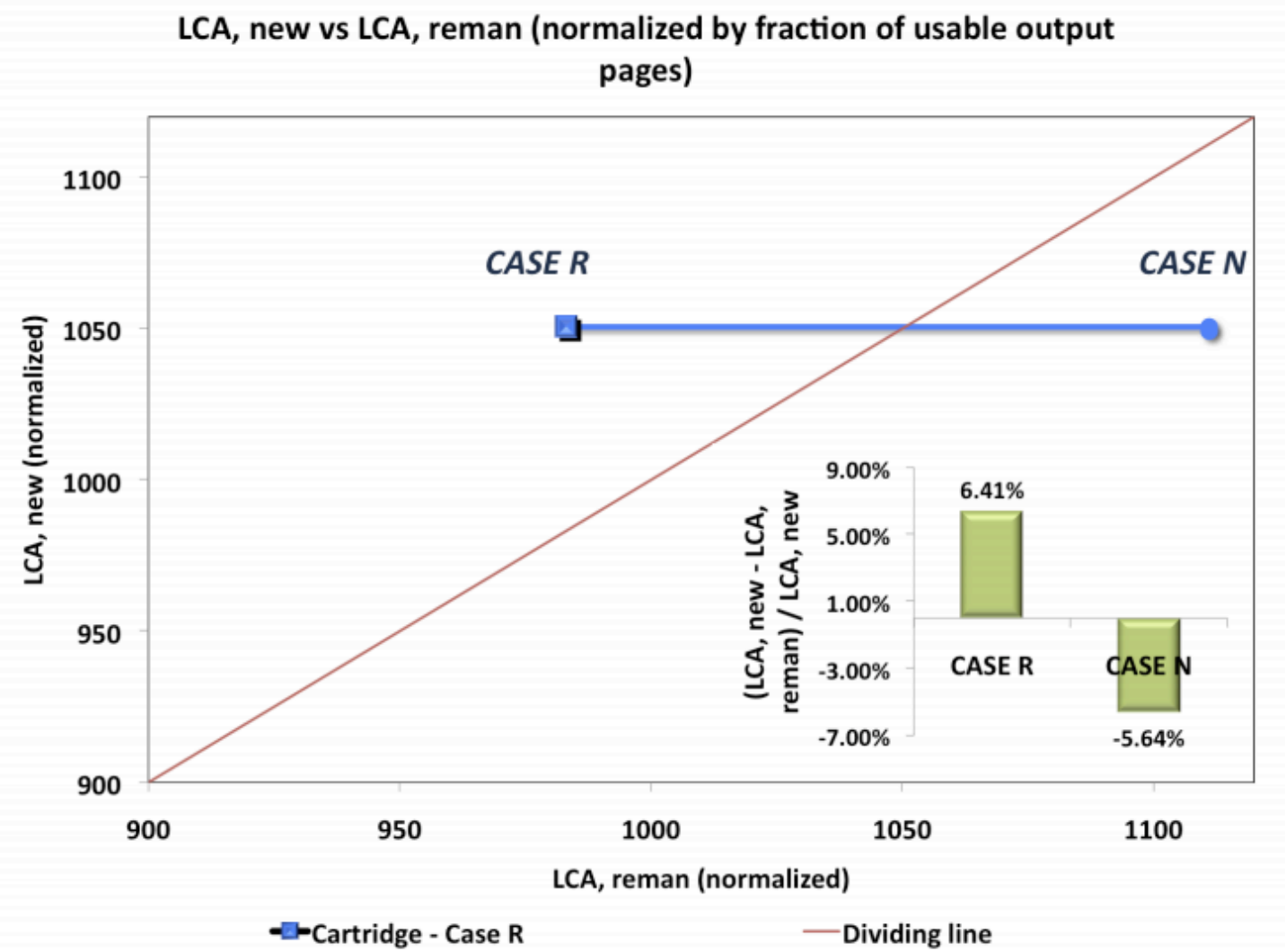


New: 101 print out pages to obtain 100 useful print outs

Refilled: 114 print out pages to obtain 100 useful print outs

http://web.mit.edu/ebm/www/Publications/MITEI-1-b-2010.pdf

Cartridge – New or Refilled?



http://web.mit.edu/ebm/www/Publications/MITEI-1-b-2010.pdf

Competition in Remanufacturing

- OEMs sometimes remanufacture even if they don't want to, to avoid competition from third-part remanufacturers
- Lexmark employed a Prebate system (contractual agreement)
  - Buyer must return or discard spent ink cartridge
  - US Court of Kentucky barred this practice
- Rapid design changes by OEM
  - HP has over 1000s of printer and printer cartridge designs

Other Products

- **Tires (Retreading)**
  - 44% of all replacement tires are retreaded (Michelin)
  - Improving performance (reducing rolling resistance)
  - Transformational change: Biasply to Radial to advanced radial
  - Empirically observed up to 8% increase in rolling resistance in retreaded tires, enough to overcome production phase savings

- **Electric Motors (rewinding)**
  - Use Phase dominates
  - Stricter standards in the efficiency of performance
  - EPA software estimate 1% decrease in efficiency for small motors and 0.5% for large motors after rewinding, enough to overcome production phase energy savings from rewinding

- **Engines**
  - Use phase strongly dominates
  - Historically changing efficiency with earlier and new CAFE standards

Timothy Gutowski, Sahil Sahni, Avid Boustani, Stephen Graves, *Environmental Science and Technology (2011)*

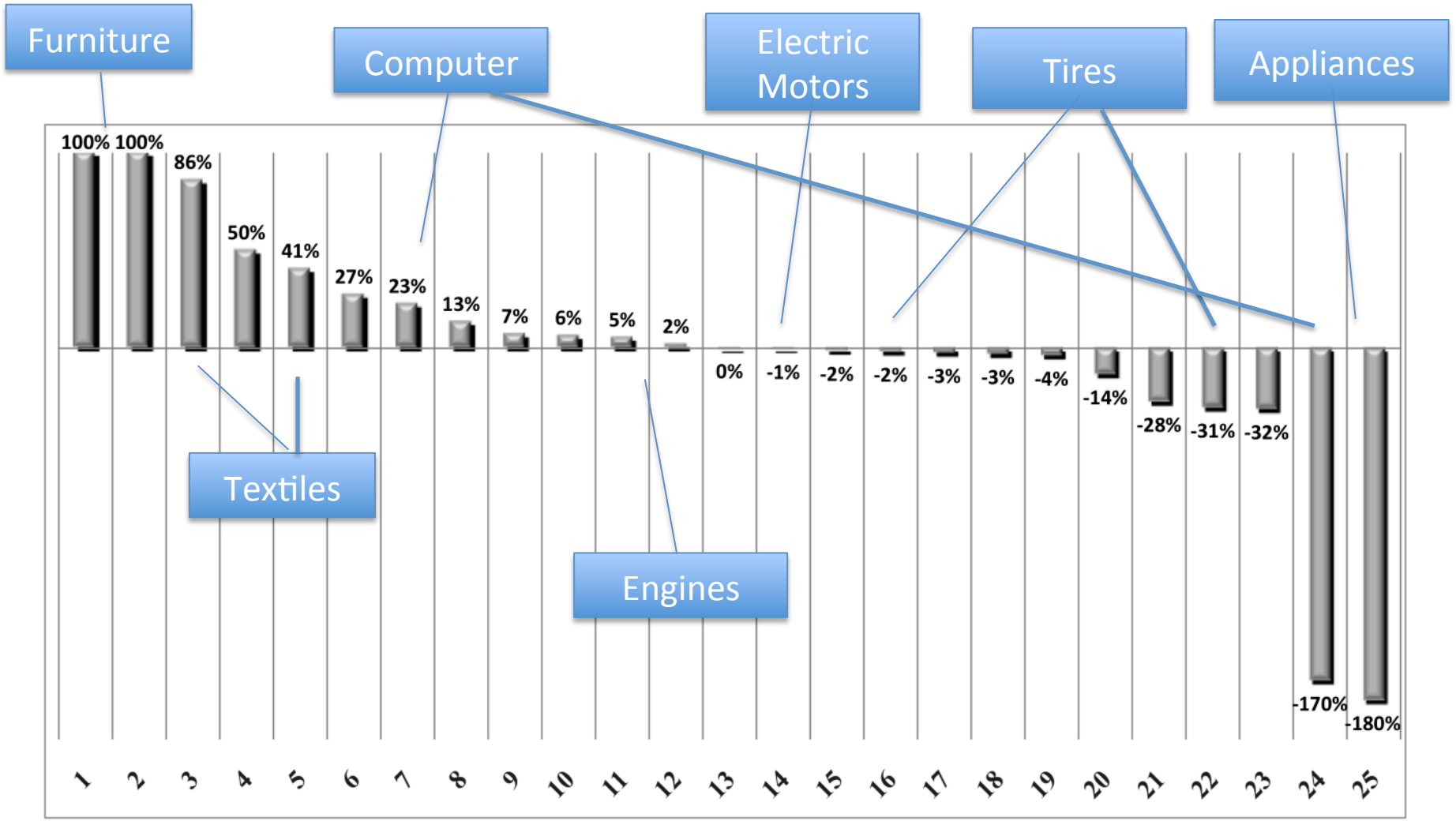
25 Case Studies

		New		Remanufactured			
Category	**Ref # for Figure 2 and 3**	**Product Details**	**Year of Mfg**	**Product Details**	**Year of Mfg**	**Scenario**	**Normalized Unit for Energy**
Appliances	20	Dishwasher	2008	Dishwasher	1998	Remanufacture	MJ/unit product
	23	Refrigerator	2008	Refrigerator	1994	Remanufacture	MJ/m^3
	25	Washing Machine (front-load)	2008	Washing Machine (top-load)	1997	Remanufacture	MJ/m^3
Computers	7	Desktop Control Unit	2005	Desktop Control Unit	2001	Reuse/Upgrade	MJ/unit product
	4	Laptop	2005	Laptop	2001	Reuse/Upgrade	MJ/unit product
	6	CRT Monitor	2005	CRT Monitor	2001	Reuse	MJ/unit product
	8	LCD Monitor	2005	LCD Monitor	2001	Reuse	MJ/unit product
	24	Laptop	2005	Desktop w/ CRT Monitor	2001	Reuse/Upgrade	MJ/unit product
	21	LCD Monitor	2005	CRT Monitor	2001	Reuse	MJ/unit product
Furniture	2	Office Desk	-	Office Desk	-	Reuse	MJ/unit product
	1	Office Chair	-	Office Chair	-	Reuse	MJ/unit product
Textiles	5	Cotton T-shirt	-	Cotton T-shirt	-	Reuse	MJ/unit product
	3	Viscose Blouse	-	Viscose Blouse	-	Reuse	MJ/unit product
Toner Cartridge	10	Toner Cartridge	-	Toner Cartridge	-	Refill	MJ/fraction of usable pages
Engines	12	Passenger Car Gasoline Engine	1999	Passenger Car Gasoline Engine	1987	Remanufacture	MJ/unit product
	11	Combination truck Diesel Engine	1999	Combination truck Diesel Engine	1987	Remanufacture	MJ/unit product
Electric Motors	19	22 kW Electric Motor Energy Efficient	-	22 kW Electric Motor Standard Efficient	-	Rewind	MJ/unit product
	14	22 kW Electric Motor Energy Efficient	-	22 kW Electric Motor Energy Efficient	-	Rewind	MJ/unit product
	15	22 kW Electric Motor NEMA Premium	-	22 kW Electric Motor Energy Efficient	-	Rewind	MJ/unit product
	18	22 kW Electric Motor NEMA Premium	-	22 kW Electric Motor NEMA Premium	-	Rewind	MJ/unit product
	17	200 kW Electric Motor NEMA Premium	-	200 kW Electric Motor Standard Efficiency	-	Rewind	MJ/unit product
	13	200 kW Electric Motor NEMA Premium	-	200 kW Electric Motor NEMA Premium	-	Rewind	MJ/unit product
Tires	22	Heavy-Duty Truck Tires Radial	-	Heavy-Duty Truck Tires Bias-ply	-	Retread	MJ/unit product
	9	Heavy-Duty Truck Tires Radial	-	Heavy-Duty Truck Tires Radial	-	Retread	MJ/unit product
	16	Heavy-Duty Truck Tires Advanced Radial	-	Heavy-Duty Truck Tires Radial	-	Retread	MJ/unit product

Timothy Gutowski, Sahil Sahni, Avid Boustani, Stephen Graves, *Environmental Science and Technology (2011)*

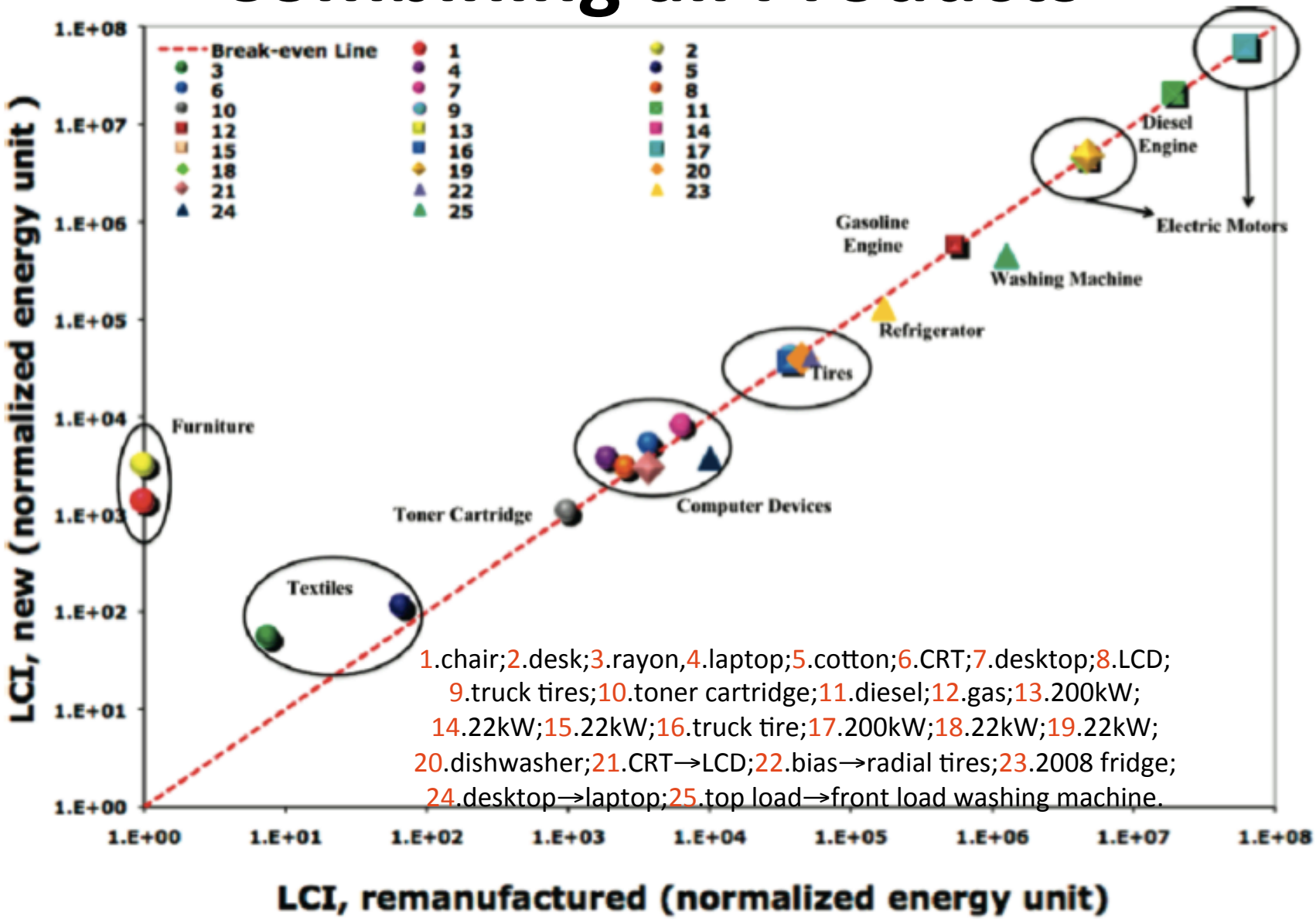
Combining all Products

% Life-Cycle Energy Savings for Remanufactured wrt New



Timothy Gutowski, Sahil Sahni, Avid Boustani, Stephen Graves, *Environmental Science and Technology (2011)*

Combining all Products



Timothy Gutowski, Sahil Sahni, Avid Boustani, Stephen Graves, *Environmental Science and Technology (2011)*

References

T.G. Gutowski, S. Sahni, A. Boustani, and S.C. Graves. ''Remanufacturing and Energy Savings,'' Environmental Science and Technology Vol. 45, pp. 4540-4547, 2011. (click here for pdf)

http://web.mit.edu/newsoffice/2011/remanufacturing-0516.html

Product Category	Report #	Hyperlink
Appliances	MITEI-1-a-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-a-2010.pdf
Toner Cartridge	MITEI-1-b-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-b-2010.pdf
Electric Motor	MITEI-1-c-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-c-2010.pdf
Engines	MITEI-1-d-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-d-2010.pdf
Furniture	MITEI-1-e-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-e-2010.pdf
Computers	MITEI-1-f-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-f-2010.pdf
Textiles	MITEI-1-g-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-g-2010.pdf
Tires	MITEI-1-h-2010	http://web.mit.edu/ebm/www/Publications/MITEI-1-h-2010.pdf

What about the Economics of Remanufacturing?

Is remanufacturing economically valuable?

Successful Cases - Caterpillar

- Caterpillar diesel engines saved 90% of their production energy from remanufacturing
- 2+ million cores returned in 2010

- Watch Videos:
- http://www.youtube.com/watch?v=LVSMSbwVwjo&feature=relmfu
- http://www.youtube.com/watch?feature=player_embedded&v=nS_p_Nffjng
- http://www.youtube.com/watch?v=2XZIQOFLjXU&feature=relmfu

http://parts.cat.com/parts/cat-reman-products#tab2

Successful Cases - Xerox

In 2004 alone…

- Xerox diverted 128 million pounds of material from entering landfills through parts recycle and part reused
- From reuse alone, Xerox saved approximated 11 million therms of energy (enough energy to light more than 250,000 US homes for a year)
- Xerox remanufactured approximately 70,000 machines

- *Over the past 15 years, this program has given new life to the equivalent of 2.5 million copiers, printers and multifunction systems.*

http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/img_equip/XeroxSlidesRemanufacturing.pdf

Economics for the Remanufacturer

Costs:

- Core cost – often free
- Labor costs - $15-25 per hour
  - Remanufacturing time ~ 2 hours / core
- Overhead costs ~ twice the labor costs
- Replacement parts

Revenue:

- Price of the remanufactured product = 50-70% of the price of New

Refrigerator

Costs:

- Core cost – Free
- Labor costs - $15-25 per hour
  - Remanufacturing time ~ 2 hours / core = $40
- Overhead costs ~ twice the labor costs = $80
- Replacement parts = $30

Revenue:

- Price of the remanufactured product = 50-70% of the price of New = 0.5*500 = $250

Used Core Value = $100

Malima Wolf, Timothy Gutowski, work to be published

Refrigerator

- Recycled material value in the refrigerator = $20-30

- Scrap rate = fraction of appliances that are not refurbished but scrapped = 10 – 50%

If 10%, then UCV = 10%*$100 = $10

➔ Cost of procurement of core < $10

Note: Cost of procurement can be negative as well – people pay to take away their trash

Malima Wolf, Timothy Gutowski, work to be published

Remanufacturing Summary

- Making general energy saving claims about remanufacturing is not right
- For many of the products studied, use phase dominates the life cycle energy needs
- Efficiency improvements bring convenience but reduce reman energy saving potential

- Modular deigns and standardized parts can help upgrade reman product to new
  - Major efficiency improvements have required significant architecture transformation

Design Trends - passive to powered products

1. Lawn rake/blower
2. Clothes drier/line dry
3. Tooth brush
4. Typewriter/printer
5. Books/”Kindle”
6. Slide ruler/calculator
7. Kitchen mixer
8. Hair drier
9. Screw driver
10. Lawnmower
11. Snow blower
12. Board games Vs. Video games
13. Pitch fork/roto tiller
14. Hammer
15. Drill
16. Sun tanning
17. Jogging/treadmill
18. Vibrating sofa w/light and cold beverage storage!
19. Fence/electric fence/invisible fence
20. Door / automatic door opener

Remanufacturing Summary

Energy

- Savings
  - Materials Savings and saving of resources that make materials and manufacture the product
  - local sourcing – lesser transportation
  - Local jobs

- Use Phase Savings are complicated and require careful analysis
  - Efficiency trends
  - Reman product performance degradation

Economics are more favorable especially for consumer