

Drivers for sustainable systems: mobility, buildings, and food

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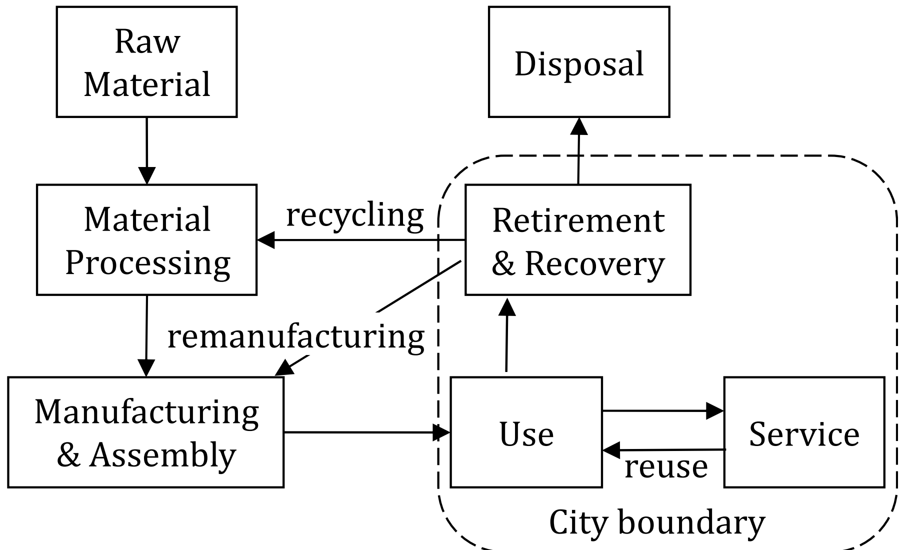
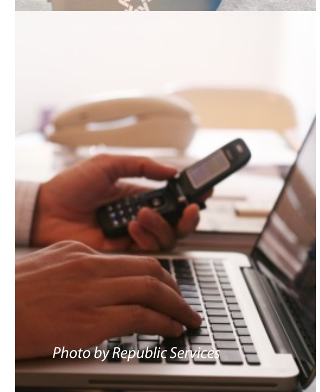
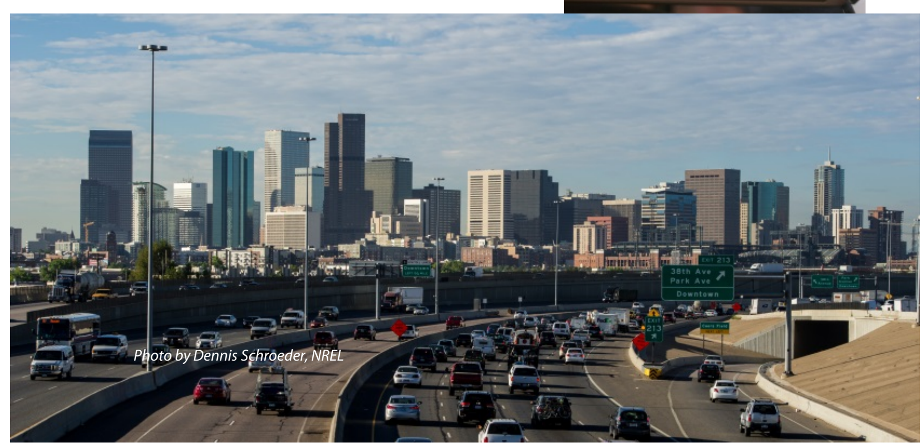
CENTER FOR SUSTAINABLE SYSTEMS
UNIVERSITY OF MICHIGAN

Nexus of Industrial and City Metabolisms





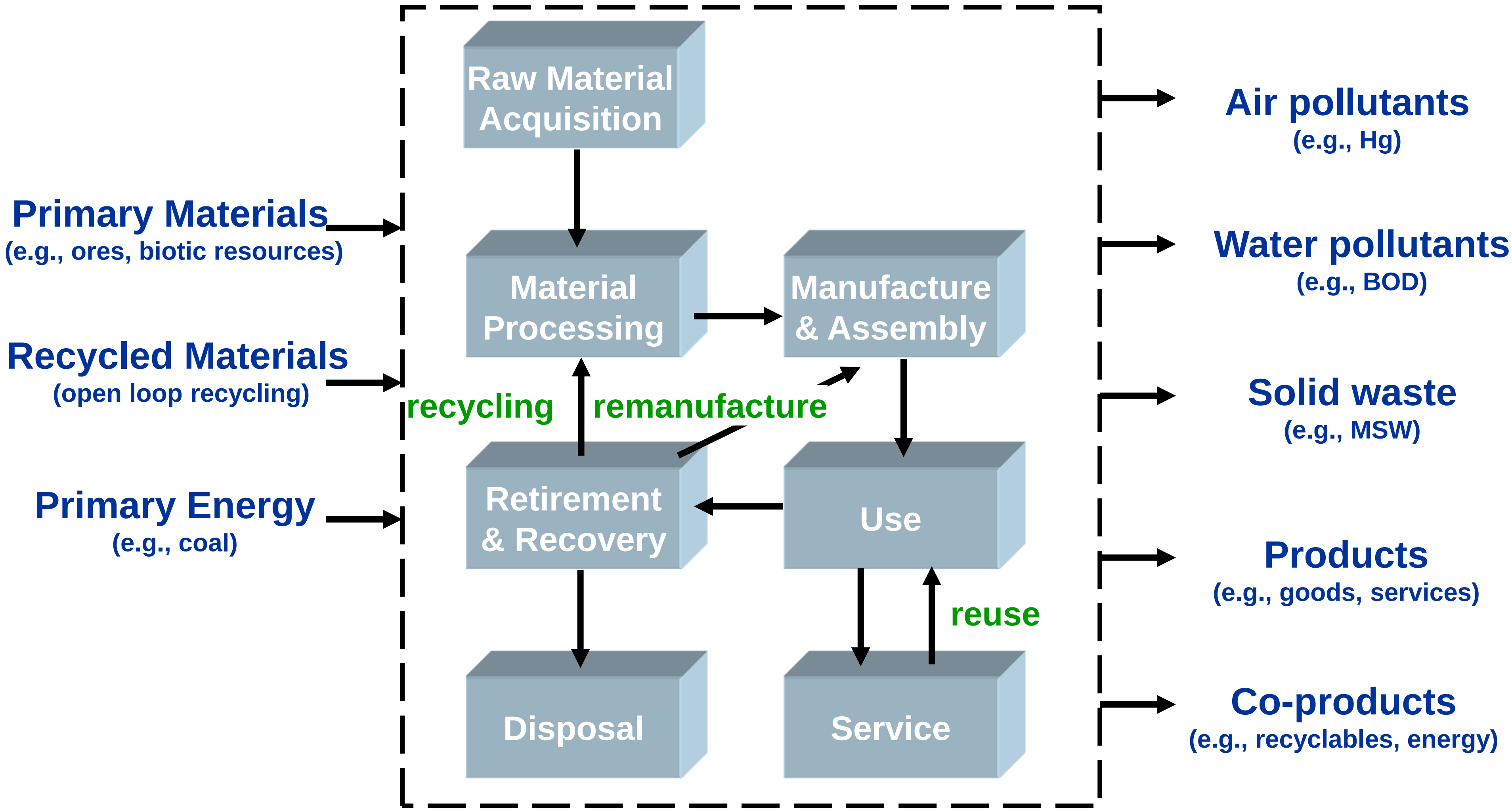


Agenda

- **Sustainable Systems Analysis**
  - **Life Cycle Assessment linking production (industrial metabolism) and consumption (city metabolism)**
    - **More in-depth analysis of consumption patterns with IPAT**
- **Systems studied:**
  - **Mobility**
  - **Buildings**
  - **Food**
- **Recommendations**
  - **Highlight key drivers impacting sustainability**
  - **Identify improvement strategies for system transformations**

Life Cycle Assessment

- **metrics for evaluating environmental sustainability**



Life Cycle Inventory of a Generic Vehicle

System: Mid-sized 1995 Sedan

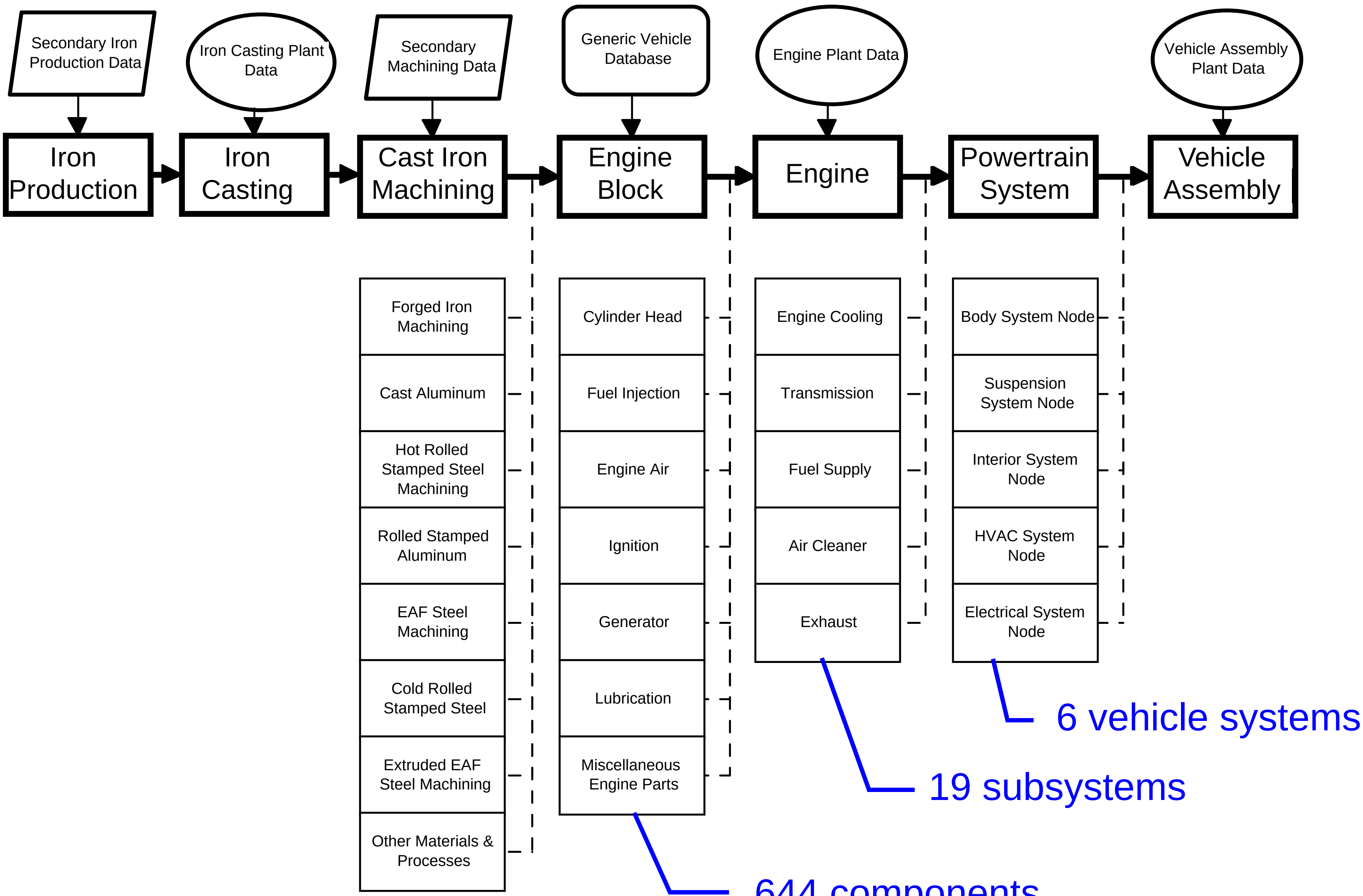
identify a set of metrics to benchmark the environmental performance

Sponsors: US Consortium for Automotive Research

- Chrysler
- Ford
- GM

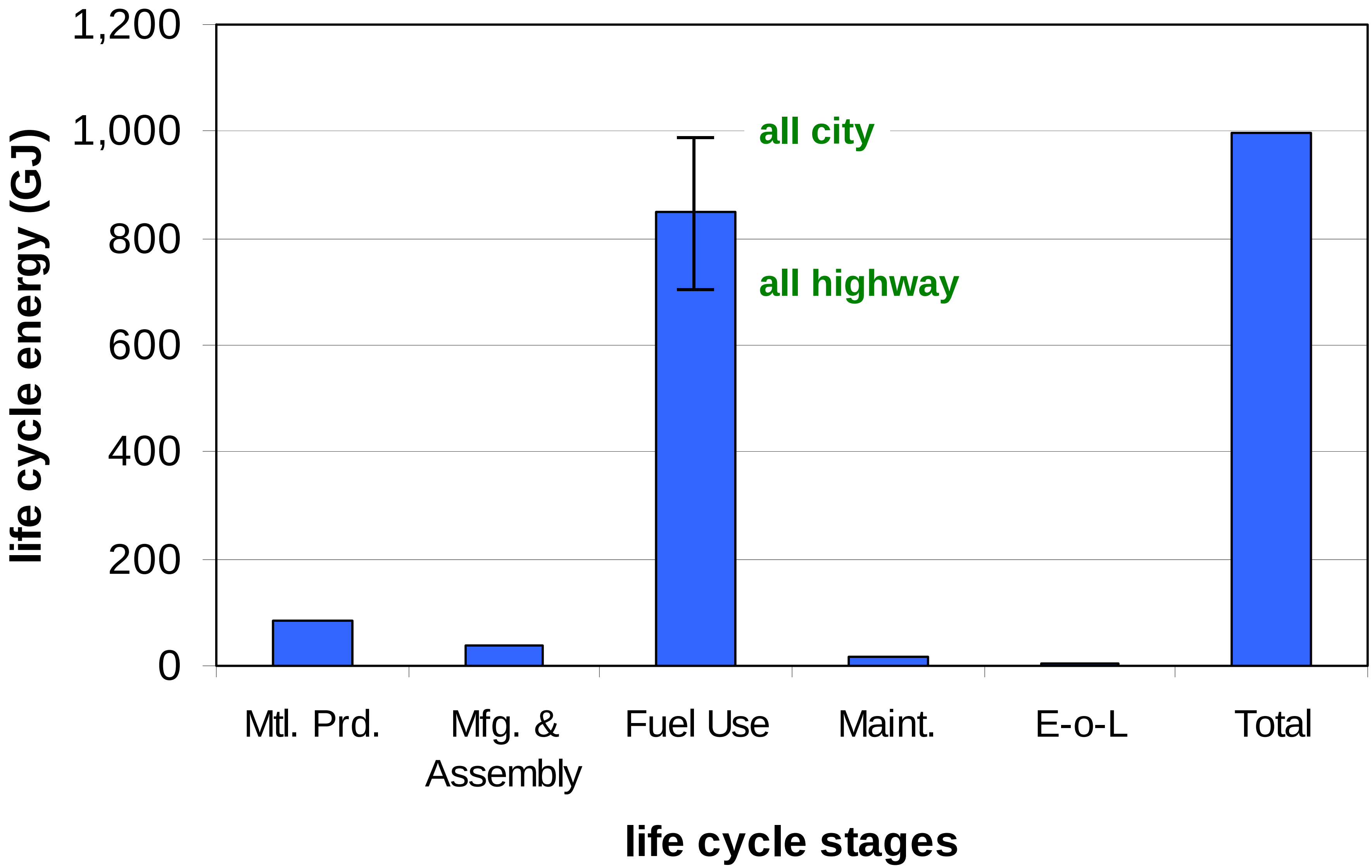
- American Iron and Steel Institute
- Aluminum Association
- American Plastics Council

Vehicle Production



Life cycle energy

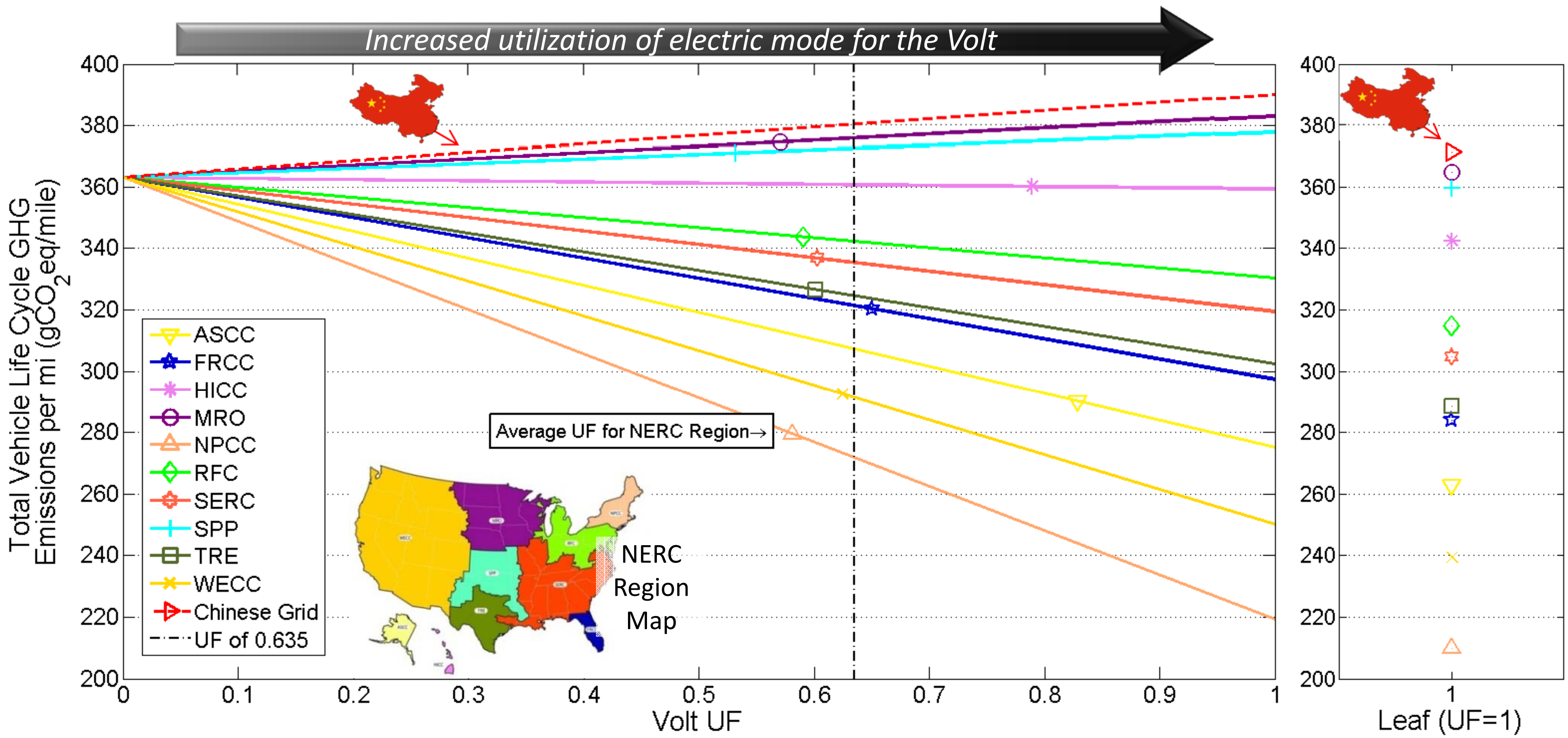
(6 GJ = 1 barrel of crude oil)



Alternative vehicle technology

U.S.–China Clean Energy Research Center
中美清洁能源研究中心

TA6 Project 3: Fuel Economy and GHG Emissions Labeling and Standards for EVs from a Life Cycle Perspective



MacPherson, N.D., G.A. Keoleian, and J.C. Kelly, "Fuel economy and greenhouse gas emissions labeling for plug-in hybrid vehicles from a life cycle perspective" Journal of Industrial Ecology (2012) 16(5): 761-773.

Key Sustainability Drivers: IPAT Equation

$$I = P \times A \times T$$

I =	total environmental impact from human activities
P =	population
A =	affluence or per capita consumption
T =	environmental damage from technology per unit of consumption

Source: Ehrlich and Holdren (1971)

Impact of Automobiles in U.S.

	I^1 = (impact)	P x (population)	A x (affluence)	T (technol.)
	gallons (billion)	pop. (million)	vmt/ capita	gallons/ mile
1970	80.1	204	5098	1/13.0
2009	133.1	307	8833	1/20.4
change	+66%	+51%	+73%	-36%

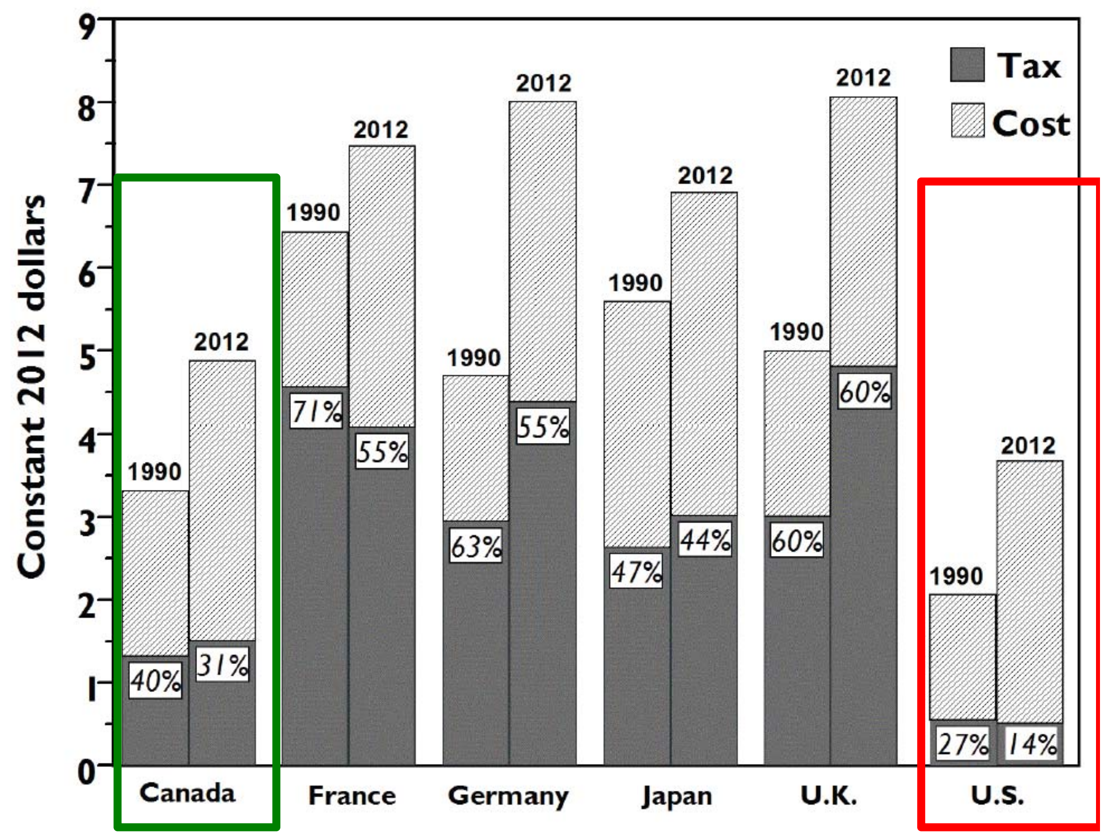
2025 Fuel Economy Standards: 54.5 mpg

Source data from TRANSPORTATION ENERGY DATA BOOK: EDITION 30–2011

Policy matters

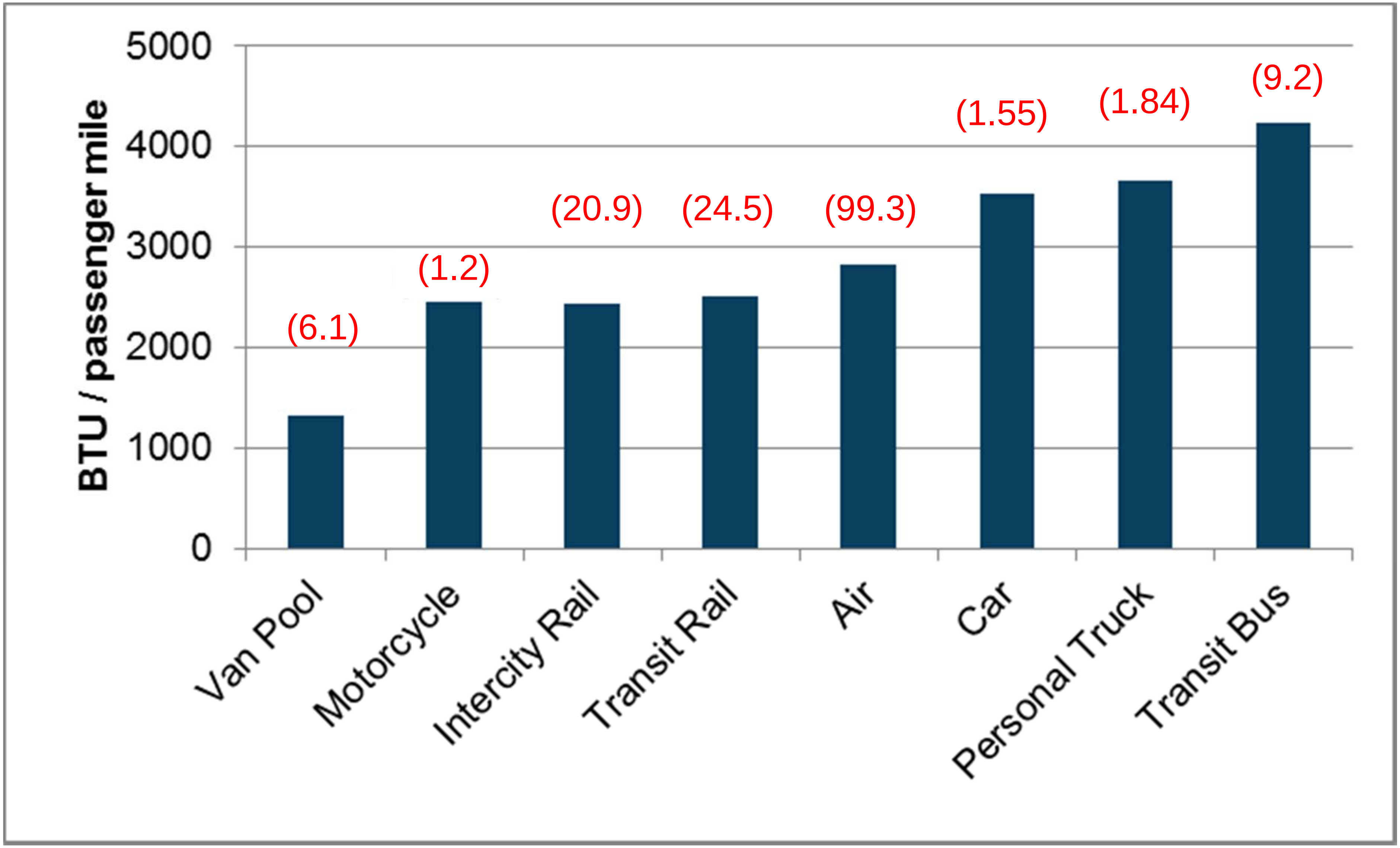
	VMT per capita
China	569
Brazil	1,393
Russia	1,788
European Union**	3,812
Japan	4,379
Germany	4,383
Australia	4,508
Italy*	NA
United Kingdom	5,082
France	5,291
Canada	6,072
United States	9,557

Figure 10.2. Gasoline Prices for Selected Countries, 1990 and 2012



Source:
Table 10.1 and International Energy Agency, *Energy Prices & Taxes, Fourth Quarter, 2012*, Paris, France, 2013. (Additional resources: www.iea.org)

Energy Intensity of U.S. Passenger Travel in 2009
(Average Vehicle Occupancy)



Source: ORNL (2011) *Transportation Energy Data Book*

Mobility Drivers

- Use phase dominates life cycle impacts
- More efficient modes are underutilized (low occupancy) – e.g., trains, buses
- Technology improvements are insufficient to address population growth and consumption
  - CAFE driven technology improvements significant but will be inadequate for addressing global challenges
  - Carbon price on energy is required
  - Shift in behavior is critical
    - Development patterns
    - Modes and occupancy

Life Cycle Analysis of a Residential Home in Michigan

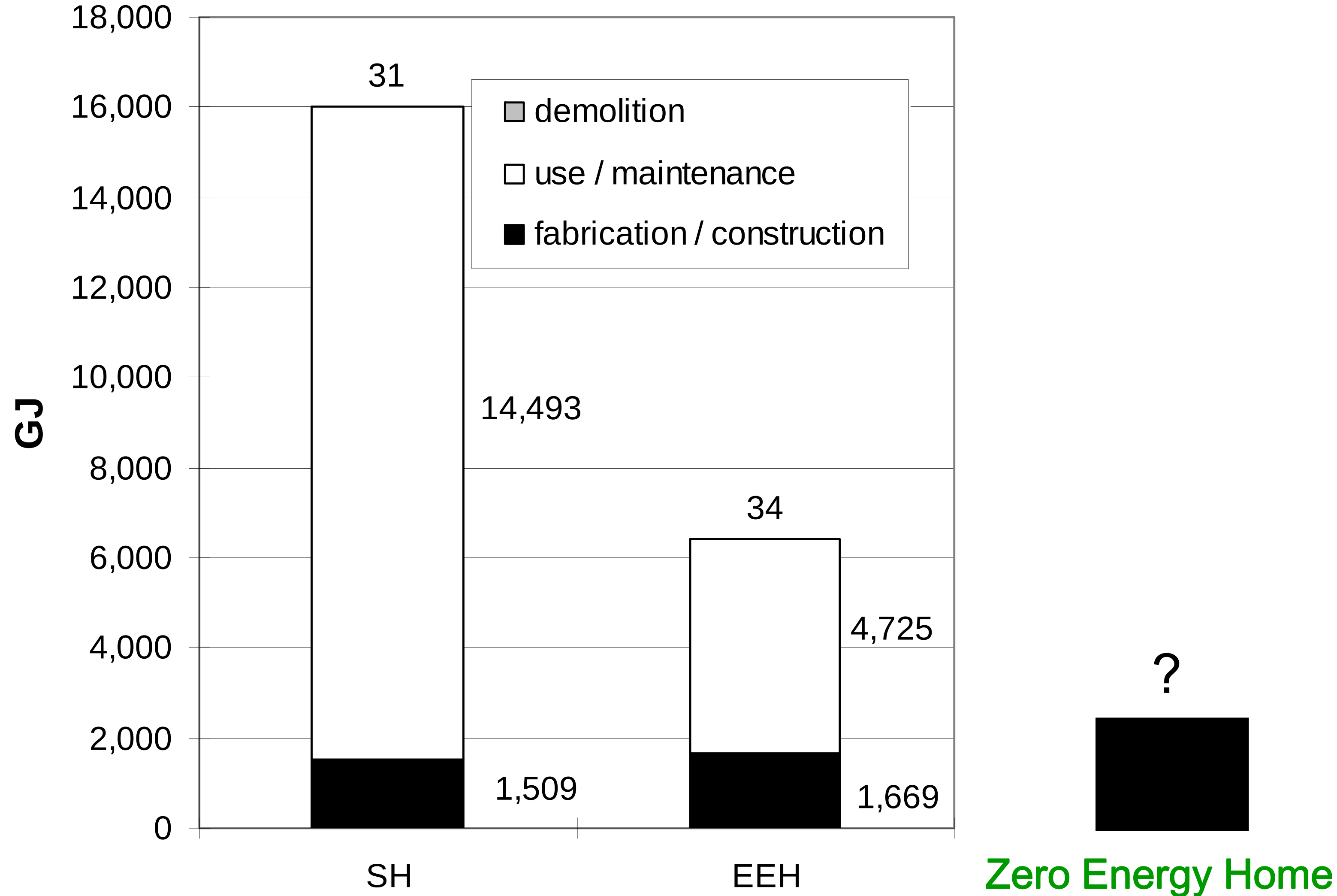
Keoleian, G.A., S. Blanchard, and P. Reppe "Life Cycle Energy, Costs, and Strategies for Improving a Single Family House" *Journal of Industrial Ecology* (2000) 4(2): 135-156.

Energy Efficient Strategies Utilized

• Increase wall insulation (R-35 double 2x4)	Use-phase
• Reduce air infiltration (Caulking)	Use-phase
• Increase ceiling insulation (R-60 cellulose)	Use phase
• Insulation in basement (R-24)	Use-phase
• High perfomance windows (lowE-coating, argon fill)	Use-phase
• Energy-efficient electrical appliances	Use-phase
• All fluorescent lighting	Use-phase
• Building-integrated shading (overhangs)	Use-phase
• Waste hot water heat exchanger	Use-phase
• Air-to-air heat exchanger	Use-phase
• Recycled-materials roof shingles	Embodied Energy
• Wood foundation walls/cellulose insulation	Embodied Energy

Summary of Life Cycle Results

Life Cycle Inventory of:	Unit	Standard Home	Energy Efficient Home
MASS	Metric Tons	306	325
ENERGY	GJ	16,000	6,400
GLOBAL WARMING GASES	Metric Tons	1,010	370



Initial construction/ total life cycle energy	9%	26%	100%

Figure 3. Life cycle energy consumption for SH and EEH

“Use phase” dominates life cycle energy for many durables

Product System (functional unit)	**Average Life Cycle Energy/ Year**	**Use Phase (%)**
Mixed Use Commercial Building (75 years, 78,500ft^2)	3,100	98%
Residential Home (50 years, 2450 ft^2)	320	91%
Passenger Car (120,000 miles, 10 years)	100	85%
Household Refrigerator (20 ft^3, 10 years)	11	94%
Desktop Computer (3 years, 3300 hrs)	5.6	34%
Office File Cabinet (one cabinet, 20 years)	0.12	0%

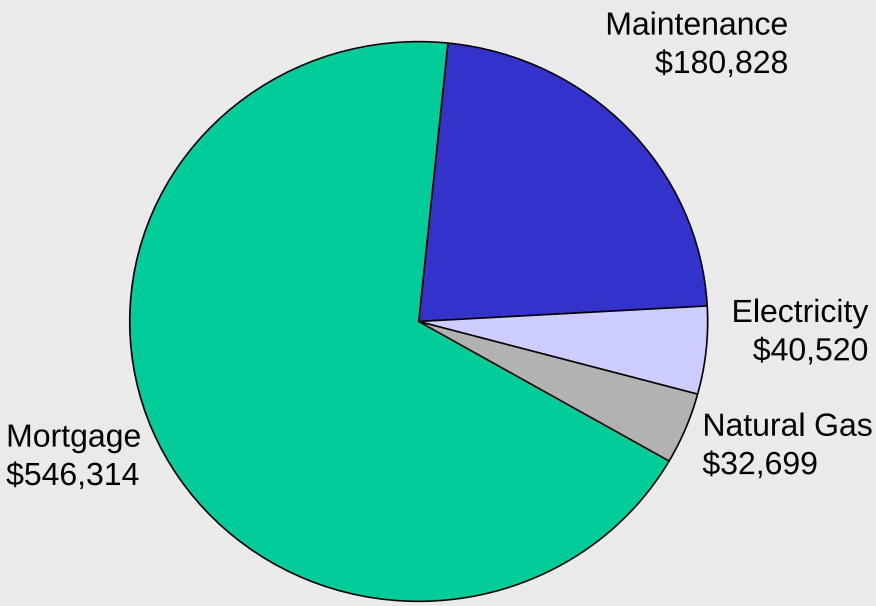
Source: Keoleian, G.A. and D.V. Spitzley. “Life Cycle Based Sustainability Metrics”, Chapter 2.3 in *Sustainability Science and Engineering, Volume 1: Defining Principles*, M. Abraham, Ed. Elsevier, 2006.

Life Cycle Costs

1998 Energy Prices

Standard Home

Total Cost = $800,361

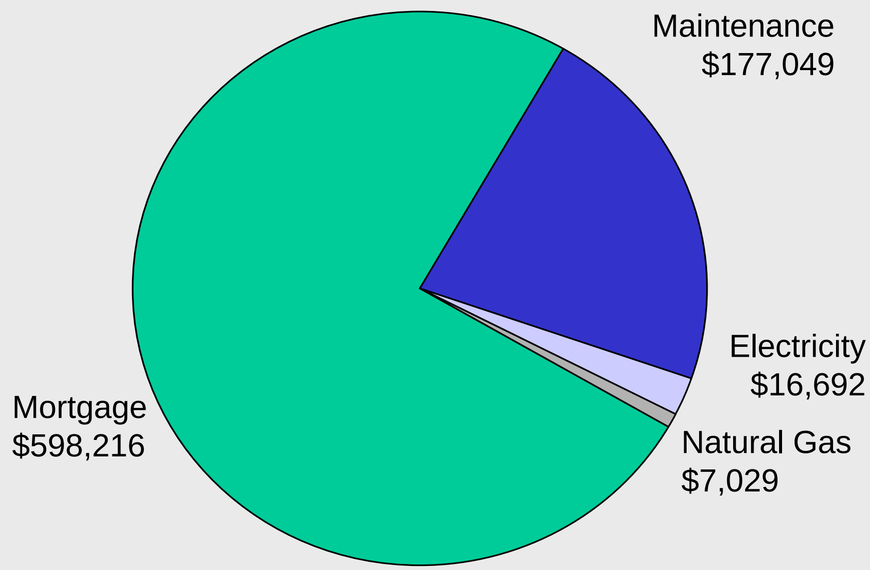


Price = $240,000 **Mortgage = 30 years, 7%**

10,130 kWh Annual Electricity Usage
141,554 kBtu Annual Gas Heating Usage
Cost of Energy Constant over 50 years

Energy Efficient Home

Total Cost = $798,986



Price = $262,800 **Mortgage = 30 years, 7%**

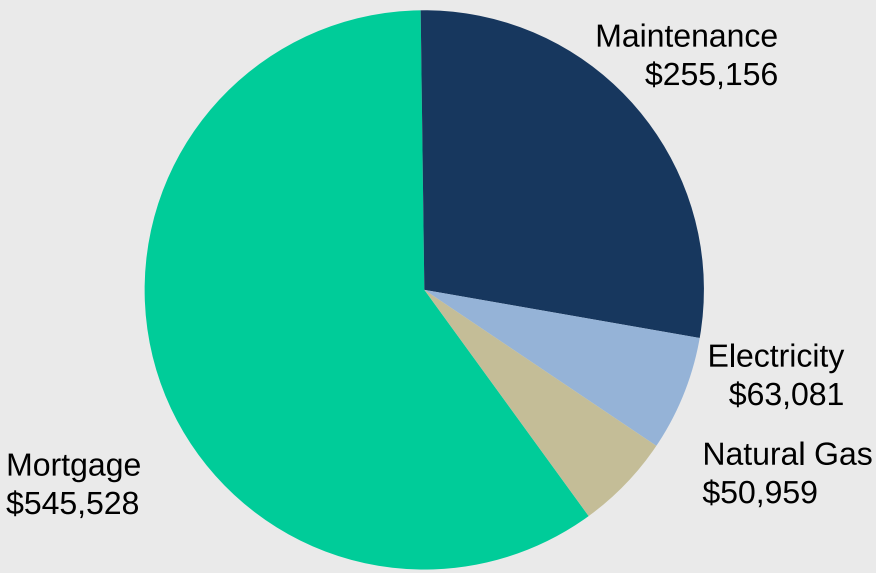
4,1730 kWh Annual Electricity Usage
30,400 kBtu Annual Gas Heating Usage
Cost of Energy Constant over 50 years

Life Cycle Costs

2012 Energy, Home, Mortgage Prices

Standard Home

Total Cost = $914,724

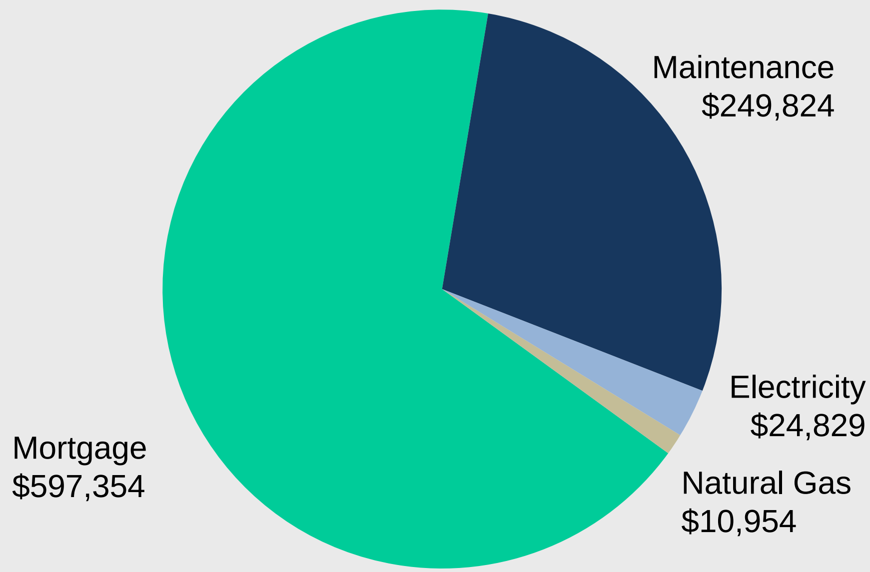


Price = $338,650 Mortgage = 30 years, 4%

10,130 kWh Annual Electricity Usage
141,554 kBtu Annual Gas Heating Usage
Cost of Energy Constant over 50 years

Energy Efficient Home

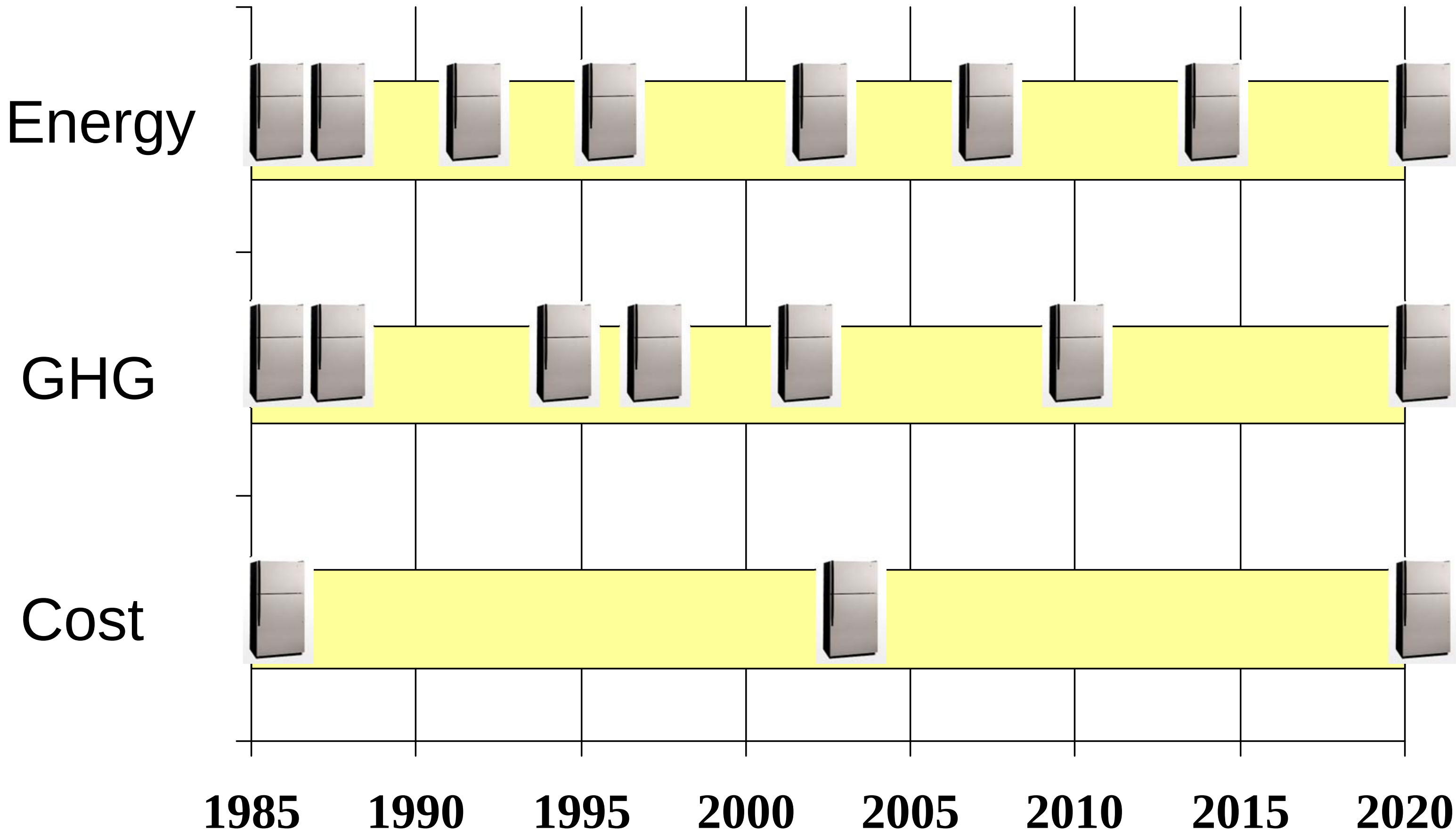
Total Cost = $882,962



Price = $370,822 Mortgage = 30 years, 4%

4,173 kWh Annual Electricity Usage
30,400 kBtu Annual Gas Heating Usage
Cost of Energy Constant over 50 years

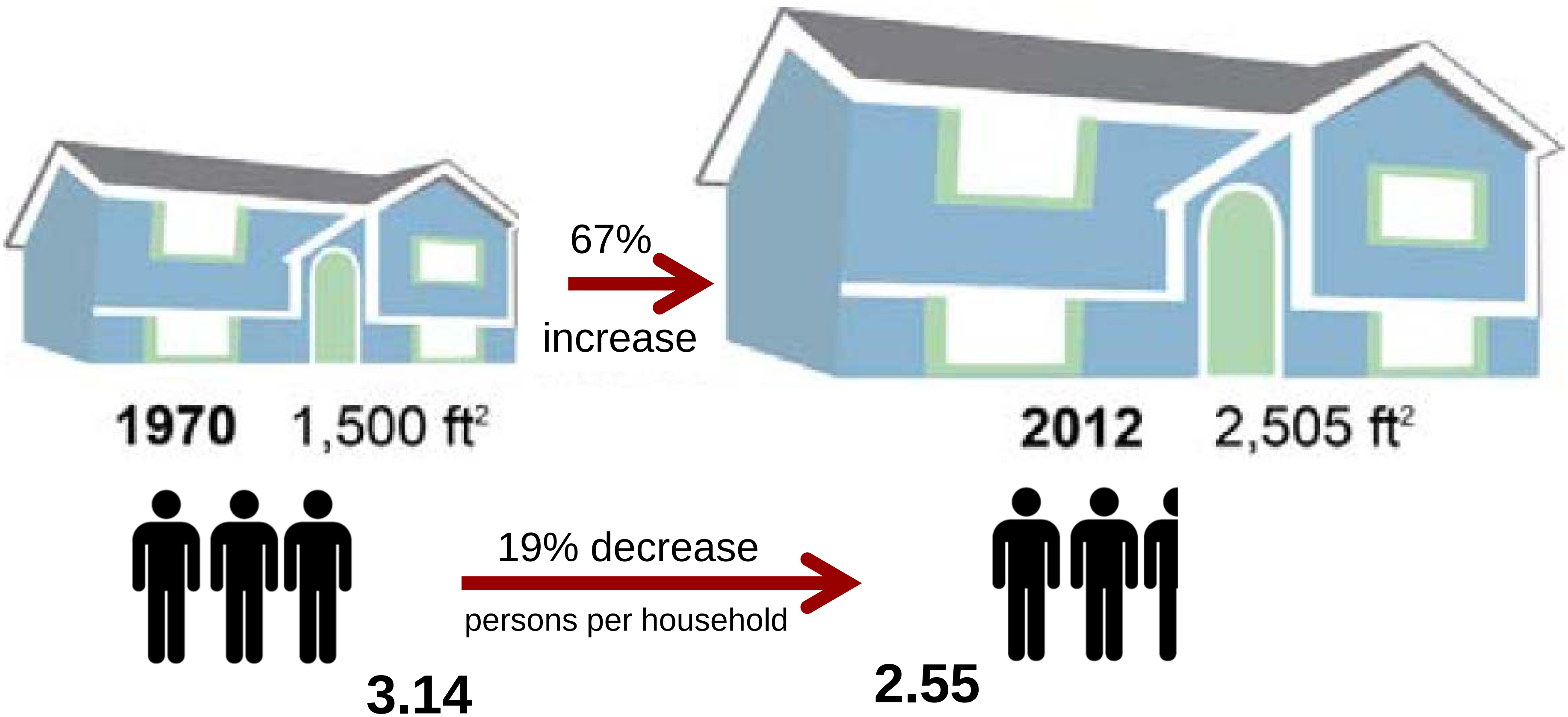
Optimal Replacement Policy



- Replace refrigerators that consume more than 1000 kWh/year of electricity (typical mid-sized 1994 models and older – original study)
  - would be an efficient strategy both cost and energy standpoint.

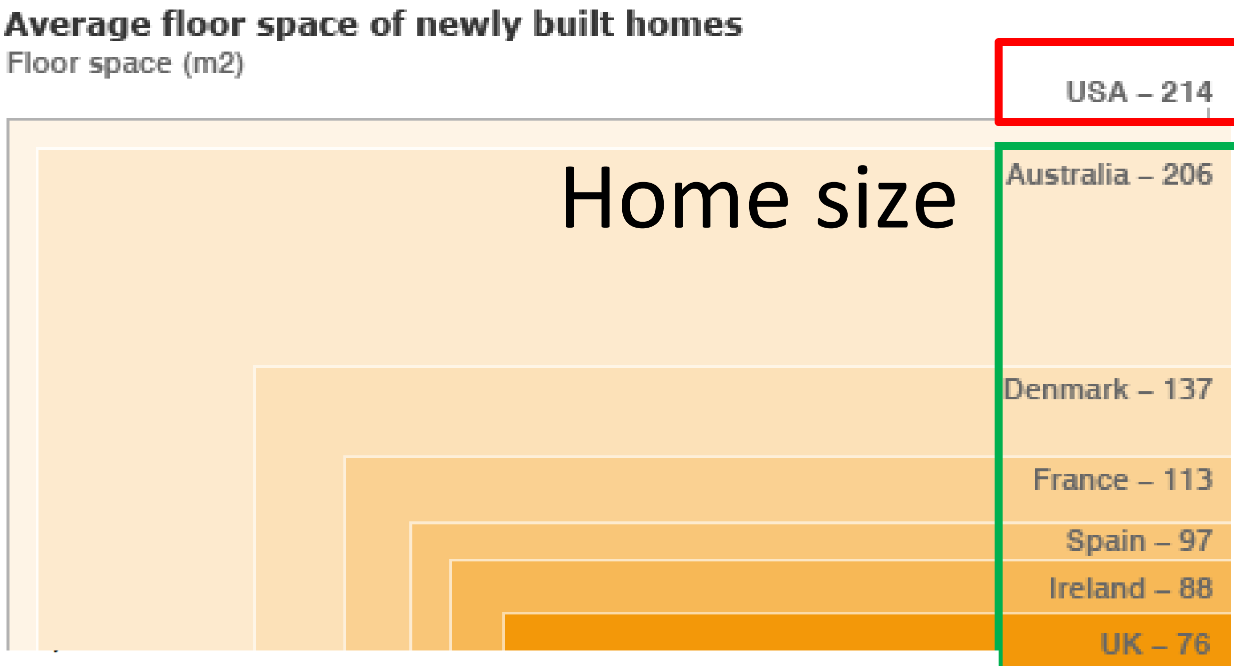
Kim, H.C., G.A. Keoleian, Y.A. Horie, "Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost" *Energy Policy* (2006) 34(15): 2310-2323.

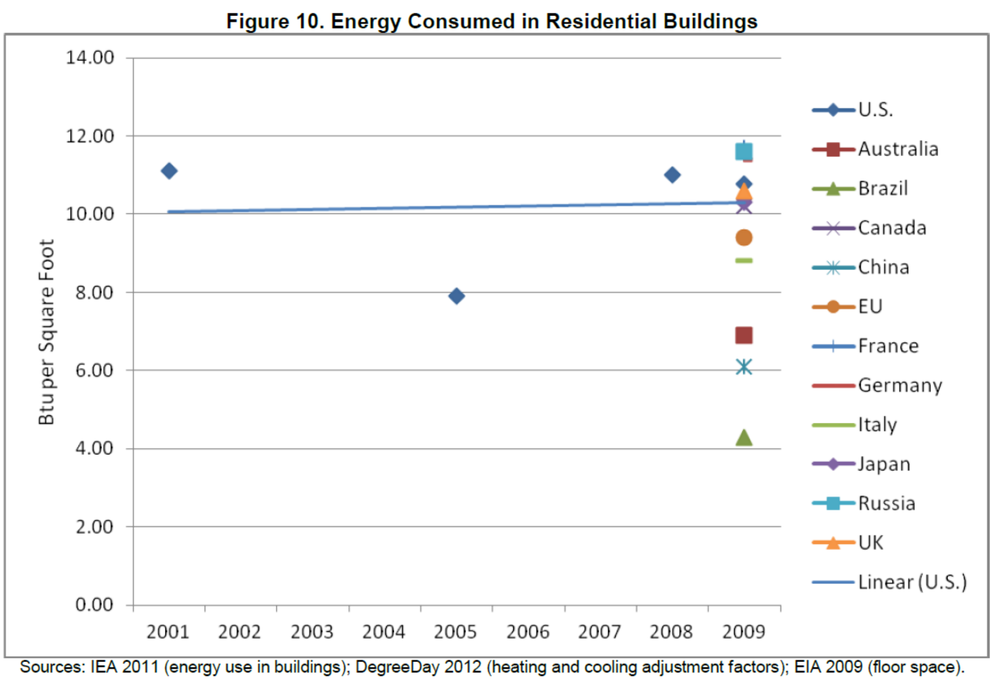
Average Size of a New U.S. Single-Family House



Center for Sustainable Systems, University of Michigan. 2013. “Residential Buildings Factsheet.” Pub. No. CSS01-08. August 2013

Home size





SOURCE: policyexchange, CABE, US Census Bureau

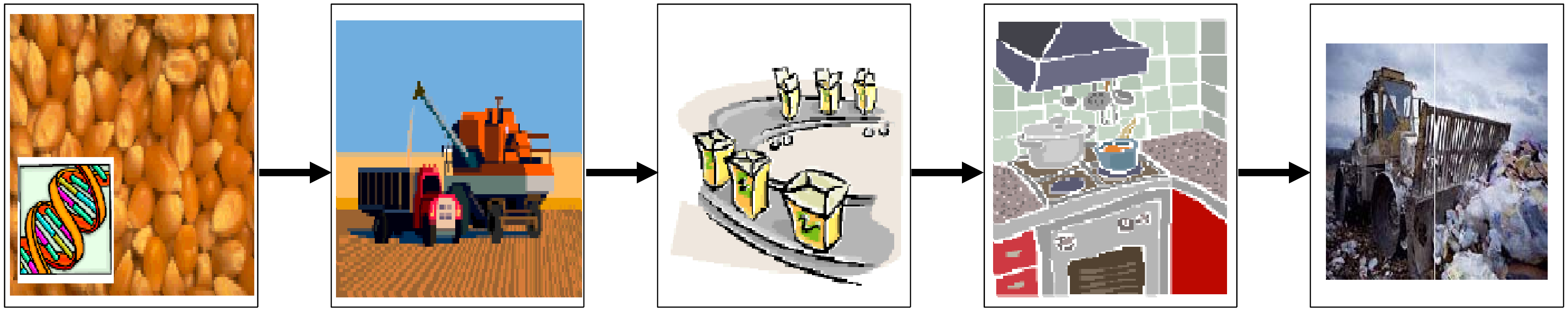
EU households:

- Smaller size homes
- Lower occupancy = 2.4 in 2010

Building Drivers

- Use phase dominates life cycle impacts
- Consumption patterns unsustainable
- Large existing stock should be focus
- Technology exists for transformations
  - Initial cost for adoption of new technology a barrier
- Incentives and policy mechanisms are not aggressive enough
  - Codes are lacking existing stock
  - Few incentive programs

The Food System Life Cycle



Origin of (genetic) resource	Agricultural growing and production	Food processing, packaging and distribution	Preparation and consumption	End of life

production | ***consumption***

total system

Heller, M. and G. Keoleian "Assessing the sustainability of the U. S. food system: A life cycle perspective" *Agricultural Systems* (2003) 76: 1007-1041.

Life cycle stage	SUSTSAINABILITY INDICATORS		
	Economic	**Social**	**Environmental**
Origin of (genetic) resource	•degree of farmer/operator control of seed production/breeding		ratio of naturally pollinated plants to genetically modified/ hybrid plants per acre reproductive ability of plant or animal % of disease resistant organisms
Agricultural growing and production	practices •level of gov't support	a ield and / income vs. other professions rs on farms health benefits. ian community organizations that offer sustainable ag. programs, encourage sustainable practices •# animals/unit, time animals spend outdoors (animal welfare)	rate of soil loss vs. regeneration soil microbial activity, balance of nutrients/acre •quantity of chemical inputs/ unit of production •air pollutants/ unit of production •number of species/acre •water withdrawal vs. recharge rates •# of comtaminated or eutrophic bodies of surface water or groundwater •% waste utilized as a resource •veterinary costs •energy input/ unit of production •ratio of renewable to non•renewable energy •portion of harvest lost due to pests, diseases
Food processing, packaging and distribution	•relative profits received by farmer vs. processor vs. retailer •geographic proximity of grower, processor, packager, retailer	•quality of life and worker satisfaction in food processing industry •nutritional value of food product •food safety	
Preparation and consumption	•portion of consumer disposable income spent on food •% of food dollar spent outside the home		•energy use in preparation, storage, refrigeration •packaging waste/ calories consumed •ratio of local vs. non•local and seasonal vs. non•seasonal consumption
End of life	•ratio of food wasted to food consumed in the US •$ spent on food disposal	•ratio of (edible) food wasted vs. donated to food gatherers	

•Diversity in seed purchasing and seed collecting options

•Rates of agricu land conversion

•level of government support

•Energy requirement for processing, packaging and transportation

•Rates of malnutrition

•rates of obesity

•health costs from diet related conditions

•Amount of food waste composted vs. sent to landfill/incinerator/ waste treatment

Economic indicators

production

($0.40 in 1975)

- Marketing costs up 55% between 1987 to 1997
- Farm-to-retail price spread has increased every year for 30 years
- Retail food prices rose 2.4% from 96 to 97 while farmers received 4.4% less
- ROI: Food manufacturers: 19.8%; food retailers: 17.3%; farmers: often < 4.5%

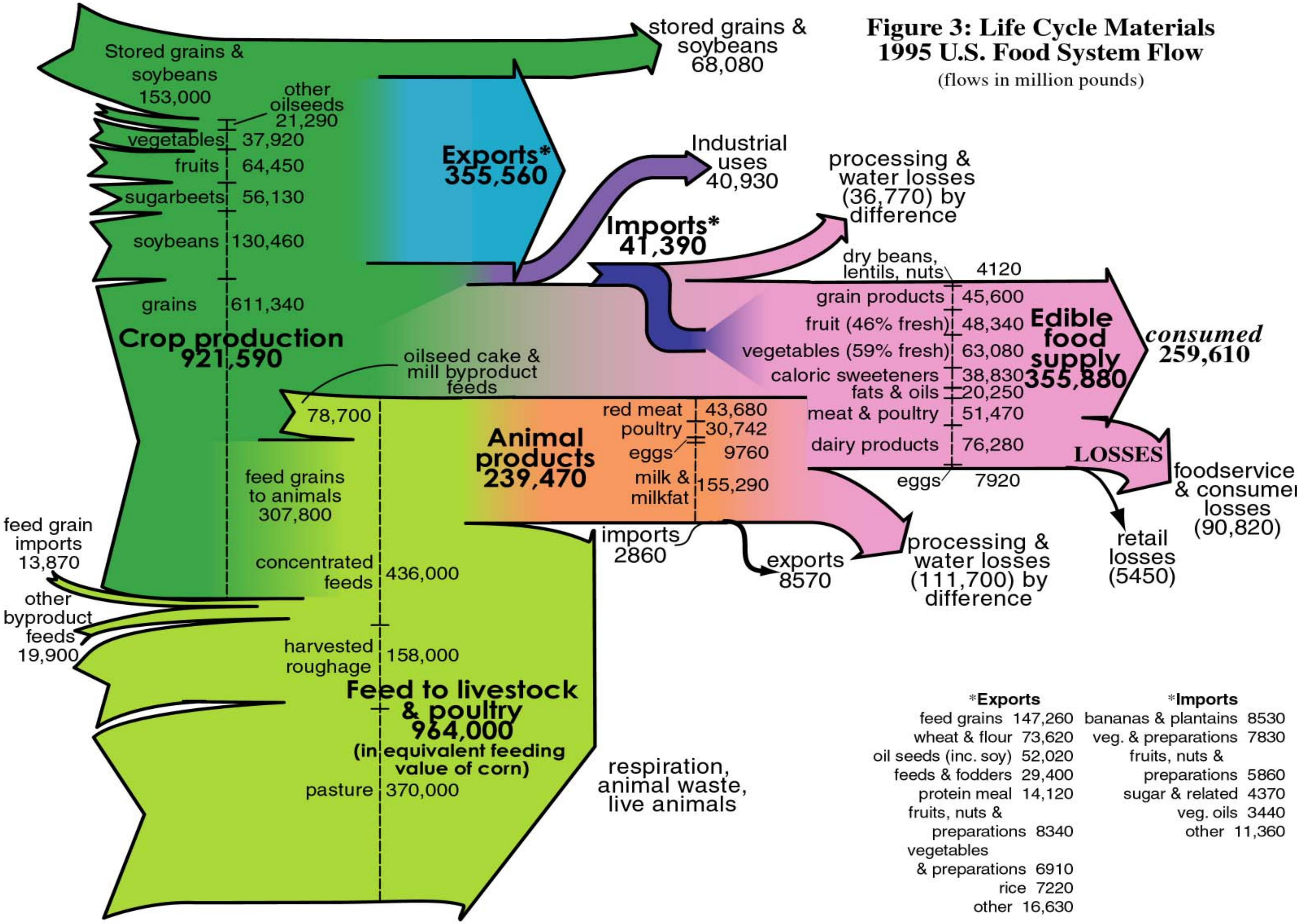
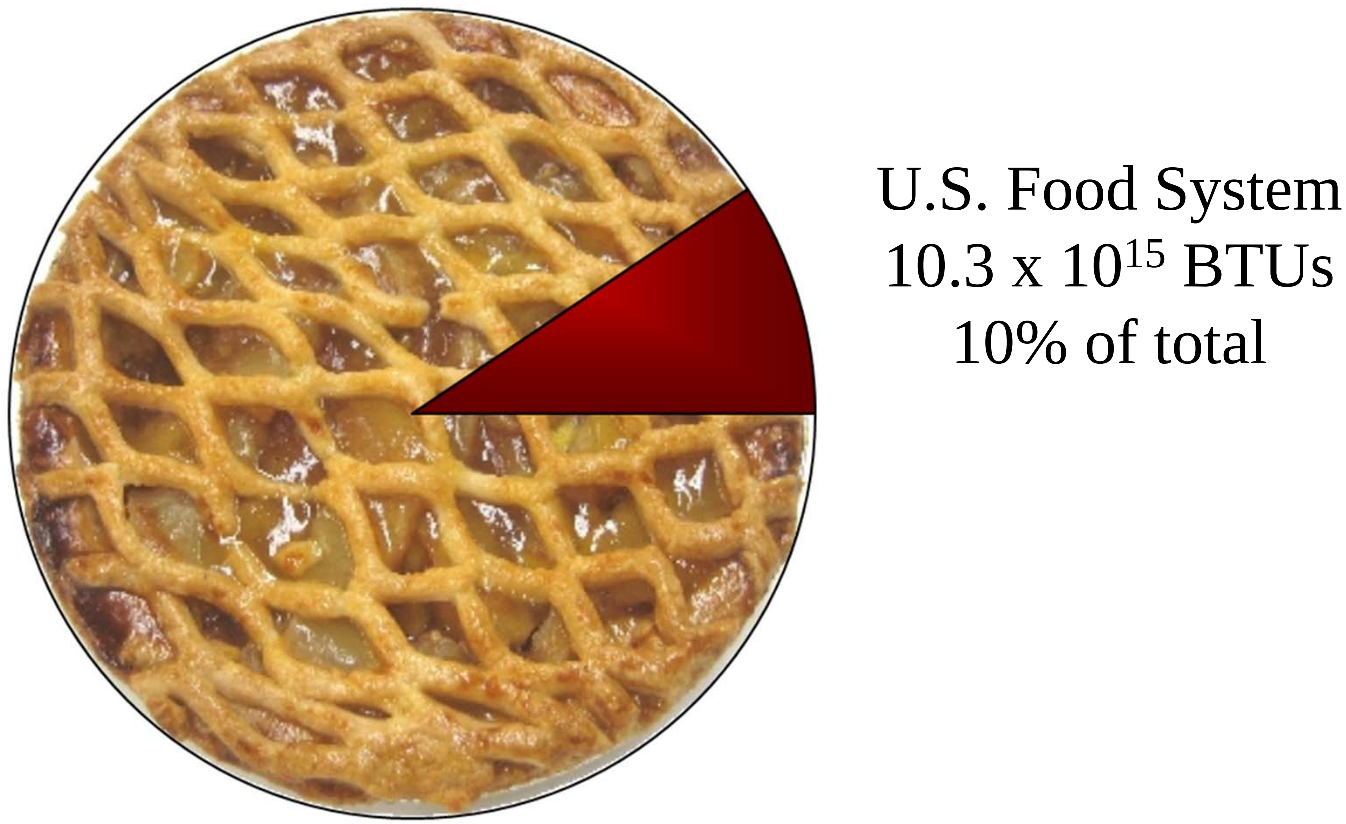


Figure 3: Life Cycle Materials 1995 U.S. Food System Flow

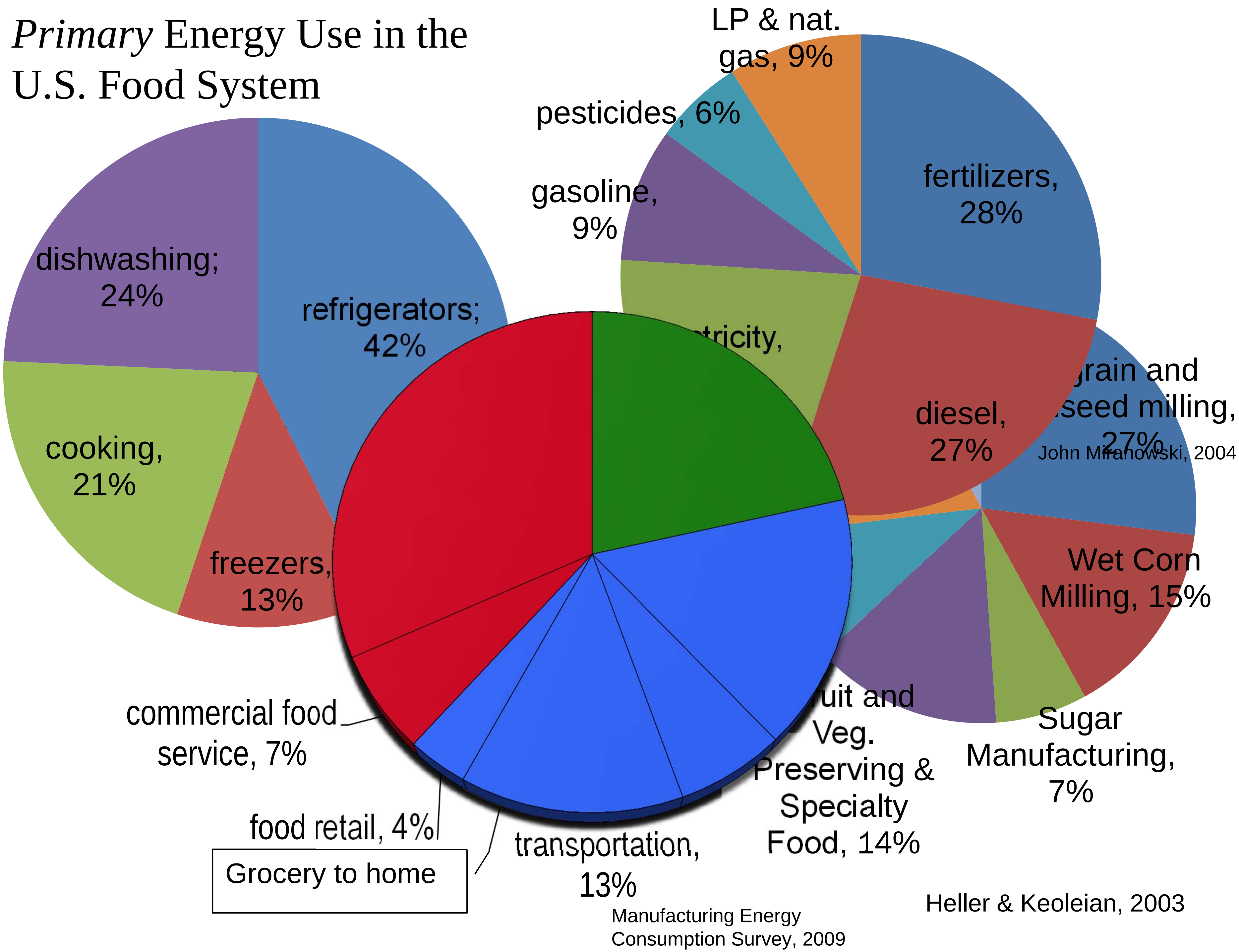
(flows in million pounds)

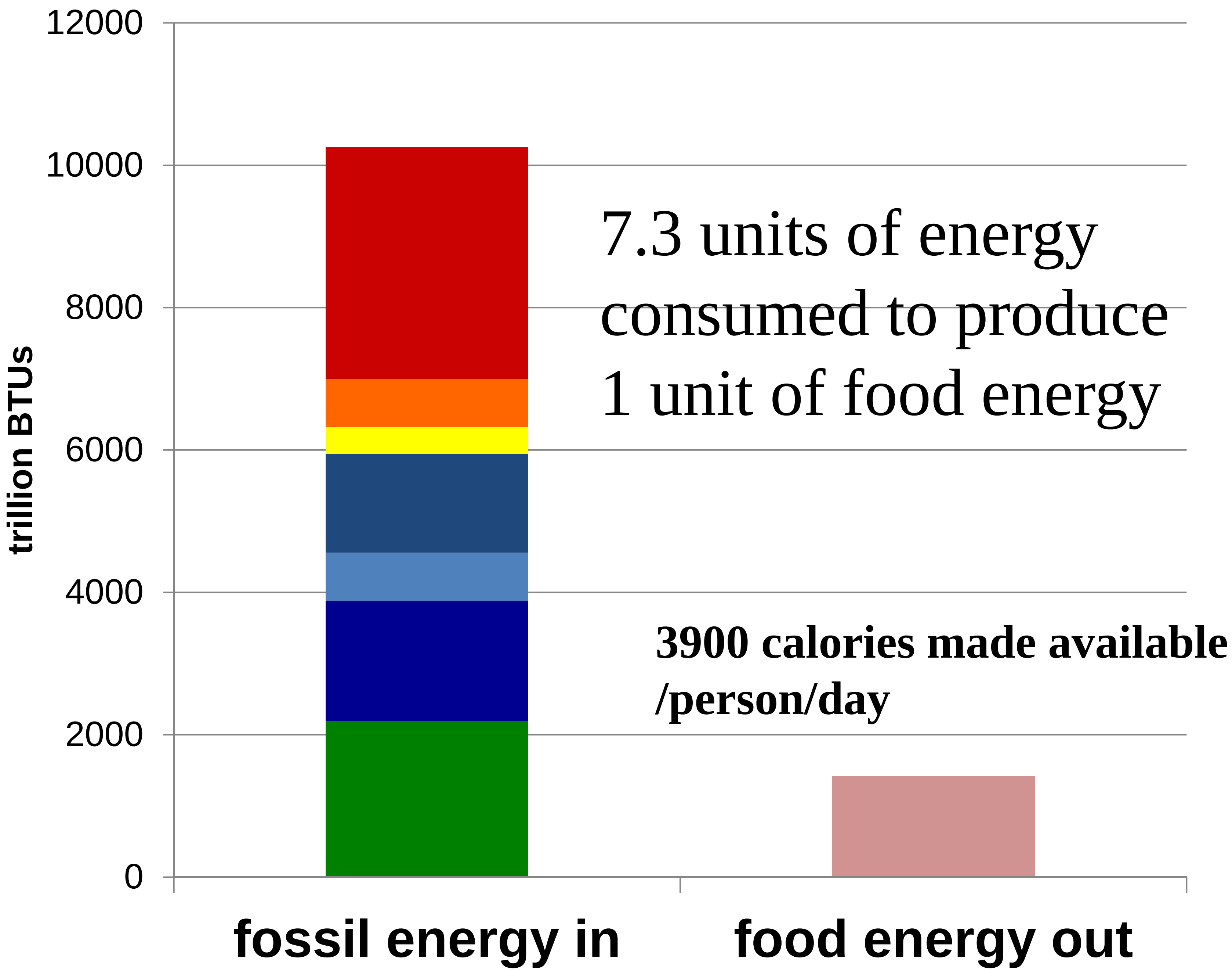
Total Energy Use in United States

99.3×10^{15} BTUs

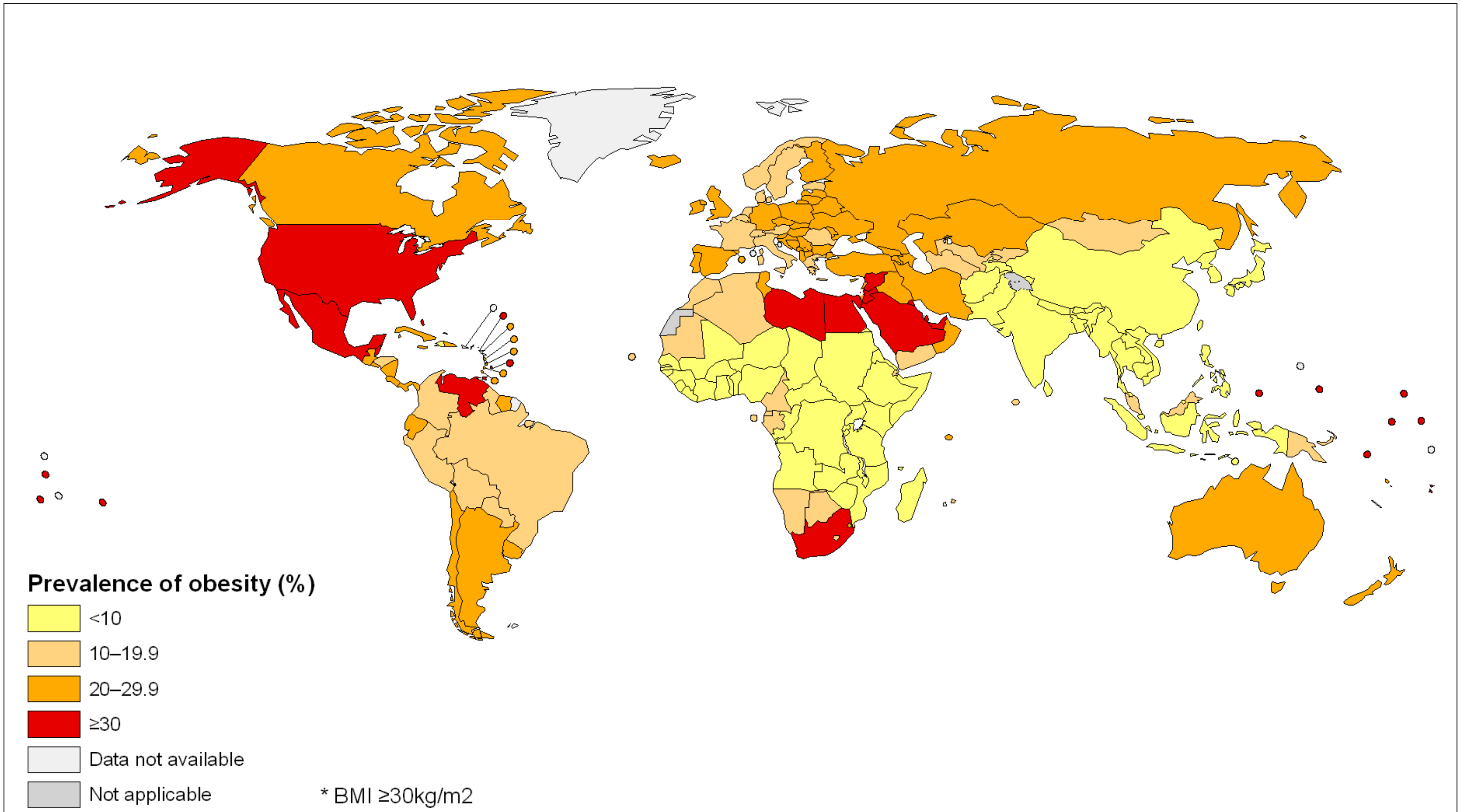


Primary Energy Use in the U.S. Food System




12000
10000
8000
6000
4000
2000
0
trillion BTUs
7.3 units of energy consumed to produce 1 unit of food energy
3900 calories made available /person/day
fossil energy in
food energy out

Prevalence of obesity*, ages 20+, age standardized
Both sexes, 2008



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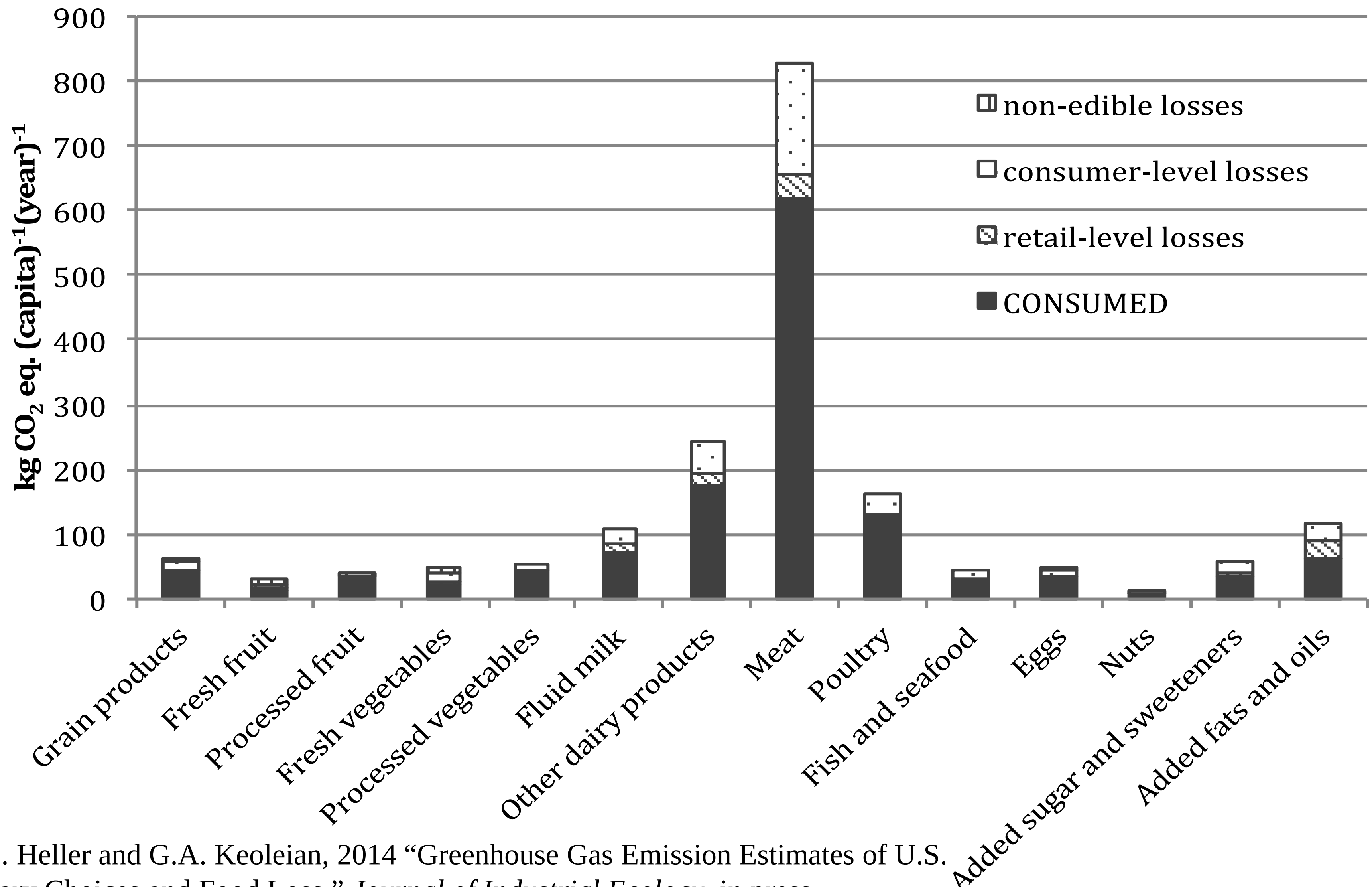
Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization

Carbon intensity of US Diet and Losses



M.C. Heller and G.A. Keoleian, 2014 “Greenhouse Gas Emission Estimates of U.S. Dietary Choices and Food Loss,” *Journal of Industrial Ecology*, in press.

Food Drivers

- Food security vs obesity epidemic
  - Developed and developing countries
- Greatest leverage point in life cycle lies with reducing consumption and waste
  - Reduction by one third is not unrealistic
- Diet shifts in addition to reduction in calories
- Agricultural policy and markets are not focused on delivery the greatest nutritional value

Heller, M.C., G.A. Keoleian, W.C. Willett. "Toward a Life Cycle-Based, Diet-level Framework for Food Environmental Impact and Nutritional Quality Assessment: A Critical Review." *Environmental Science & Technology* (2013) 47(22): 12632-12647.

Thank You!

- Additional resources
  - http://css.snre.umich.edu/

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