Aggressive reductions through efficiency in systems, devices, and behavioral changes

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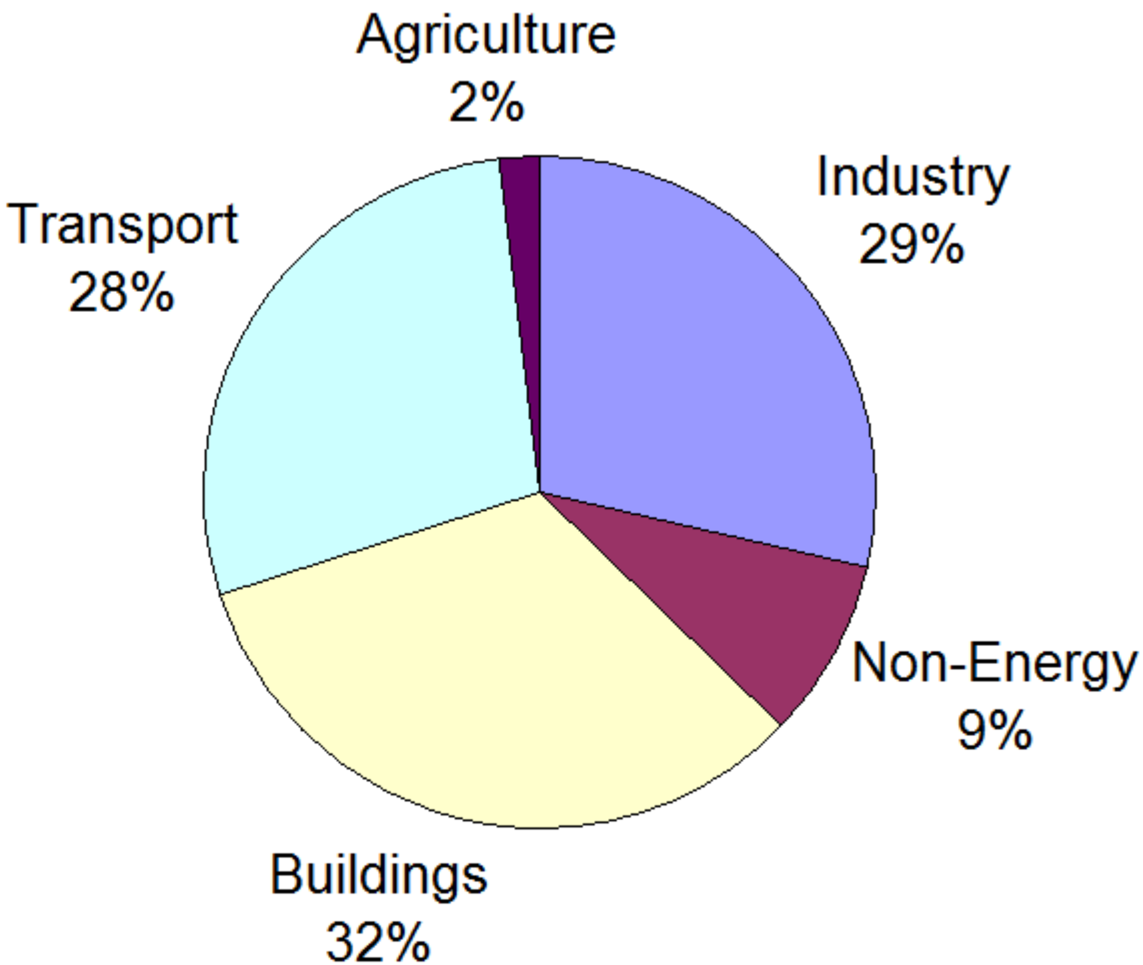
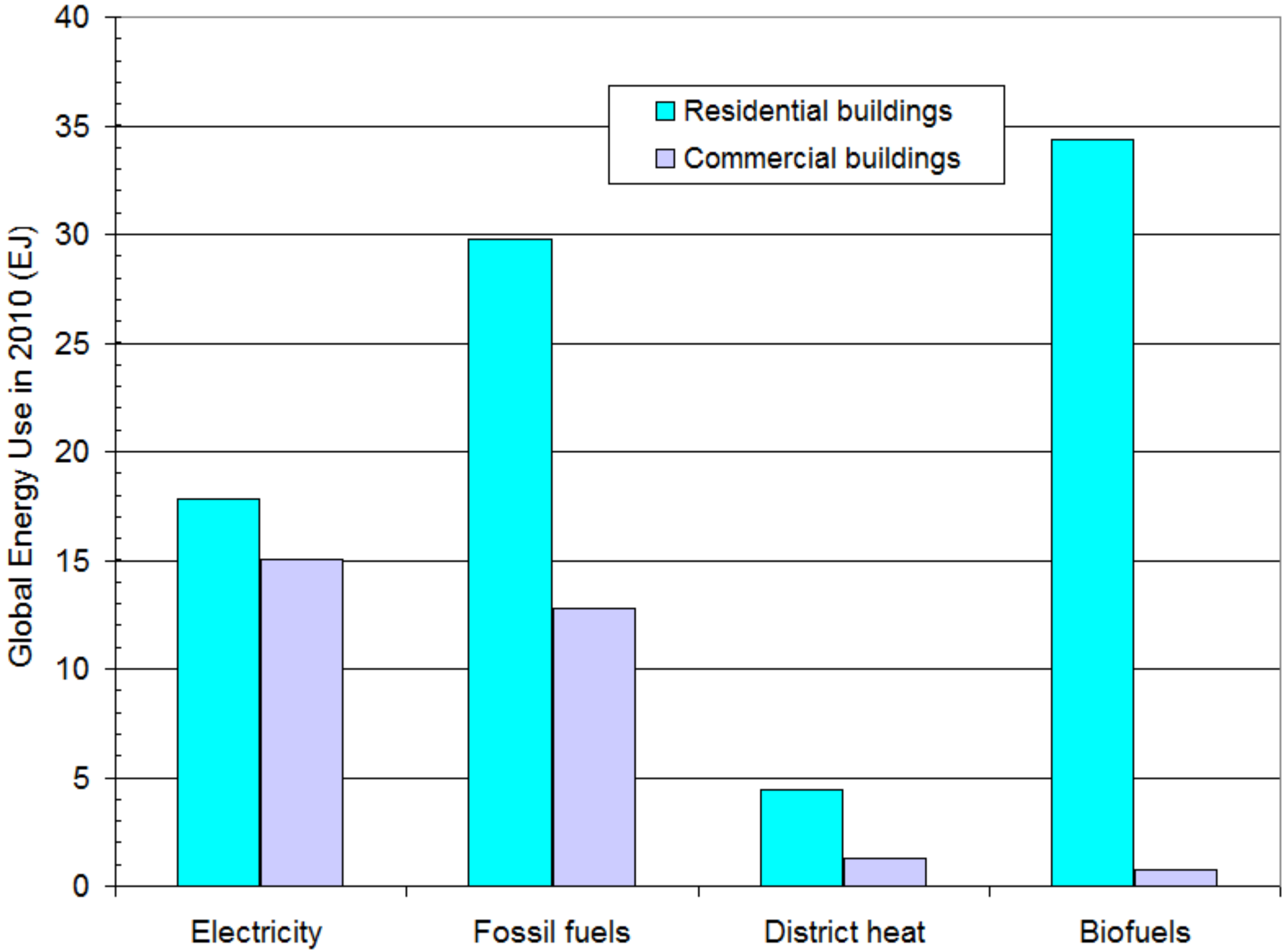
Aspen Global Change Institute Workshop

25 February 2014

Breakdown of global end-use energy in 2010



Global energy use in buildings in 2010



Sources for the savings and cost estimates given in the following slides are:

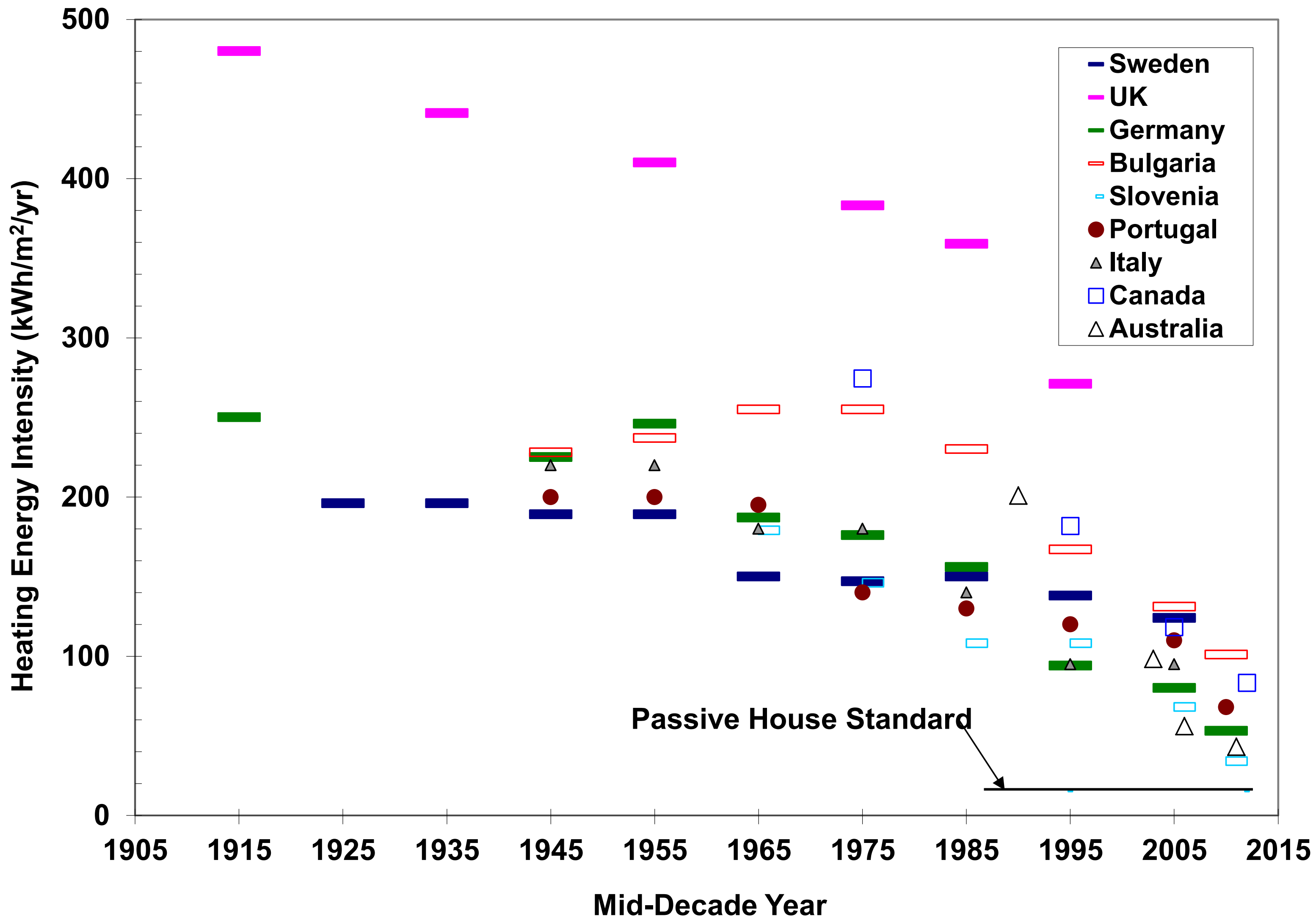
- Harvey LDD (2010) Energy and the New Reality, Volume 1: Energy Efficiency and the Demand for Energy Services, Earthscan
- Harvey LDD (2013a) Recent advances in sustainable buildings: Review of the energy and cost performance of the state-of-the-art best practices from around the world. Ann Rev Env Resources 36:281-309.
- Harvey LDD (2013b) Global climate-oriented transportation scenarios. Energy Policy 54:87-103
- Harvey LDD (2014) Global climate-oriented building energy use scenarios. Energy Policy 55

Buildings

Table 1. Savings in off-site energy requirements of buildings (given as a percent) or factor by which off-site energy use can be reduced, for various end uses in buildings, due to on-site active solar energy systems or due to improvements in device or system efficiencies, or due to behavioral changes, relative to typical 2010 energy use.

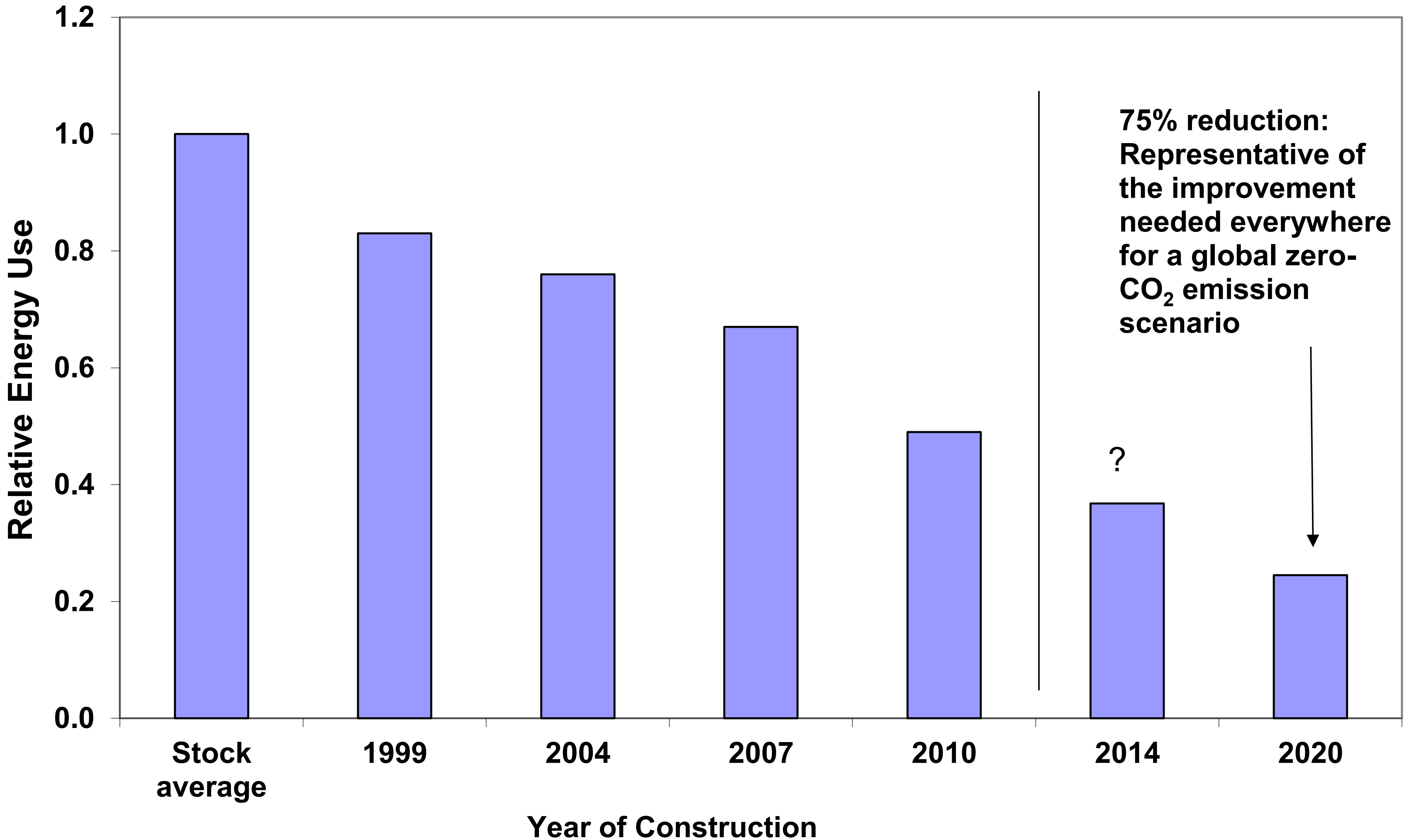
End Use	On-site C-Free Energy Supply[1]	Device Efficiency	System Efficiency	Behavioral Change
Heating	20-95% solar space heating[2]	Up to 30%[3] Up to factor of 5[4]	Up to factor of 10[5]	10-30% typical[6] 1/3 in Denmark[7]
Hot water	50-100% solar water heaters[8]	Up to 35%[9] Up to factor of 4[10]	Up to 40%[11]	Up to 50%[12]
Cooling	50-80% solar air conditioning and dehumidification[13]	Up to factor of 2[14] Up to factor of 4[15]	Up to factor of 3[16]	Factor of 2-3[17]
Cooking	0-30% solar cooking[18]	25-75%[19] Up to factor of 7-10[20]	Factor of 2[21]	Up to 50%[22]
Lighting	10-30% active solar tracking[23]	Up to factor of 4[24] Up to factor of 6-10[25] Up to factor of 600[26]	Factor of 5-15[27]	Up to 70%[28] Up to factor of 5[29]
Refrigerators		40%[10]		Up to 30%[30] Factor of 2[31]
Dishwashers		≥17%[10]		Up to factor of 4[32]
Clothes washers		~ 30% by 2030[10]		60-85%[33]
Clothes dryers		≥50%[10]		10-15%[34] Up to 100%[35]
Office computers & monitors		40%[10]		
General electrical loads	10-120%[36]			

Heating energy requirements of residential buildings built at different times in the past in various countries, in comparison with the Passive House standard



Source: Harvey (2013a)

Trends in energy use of new commercial buildings in California, complying with various versions of the ASHRAE-90.1 building code



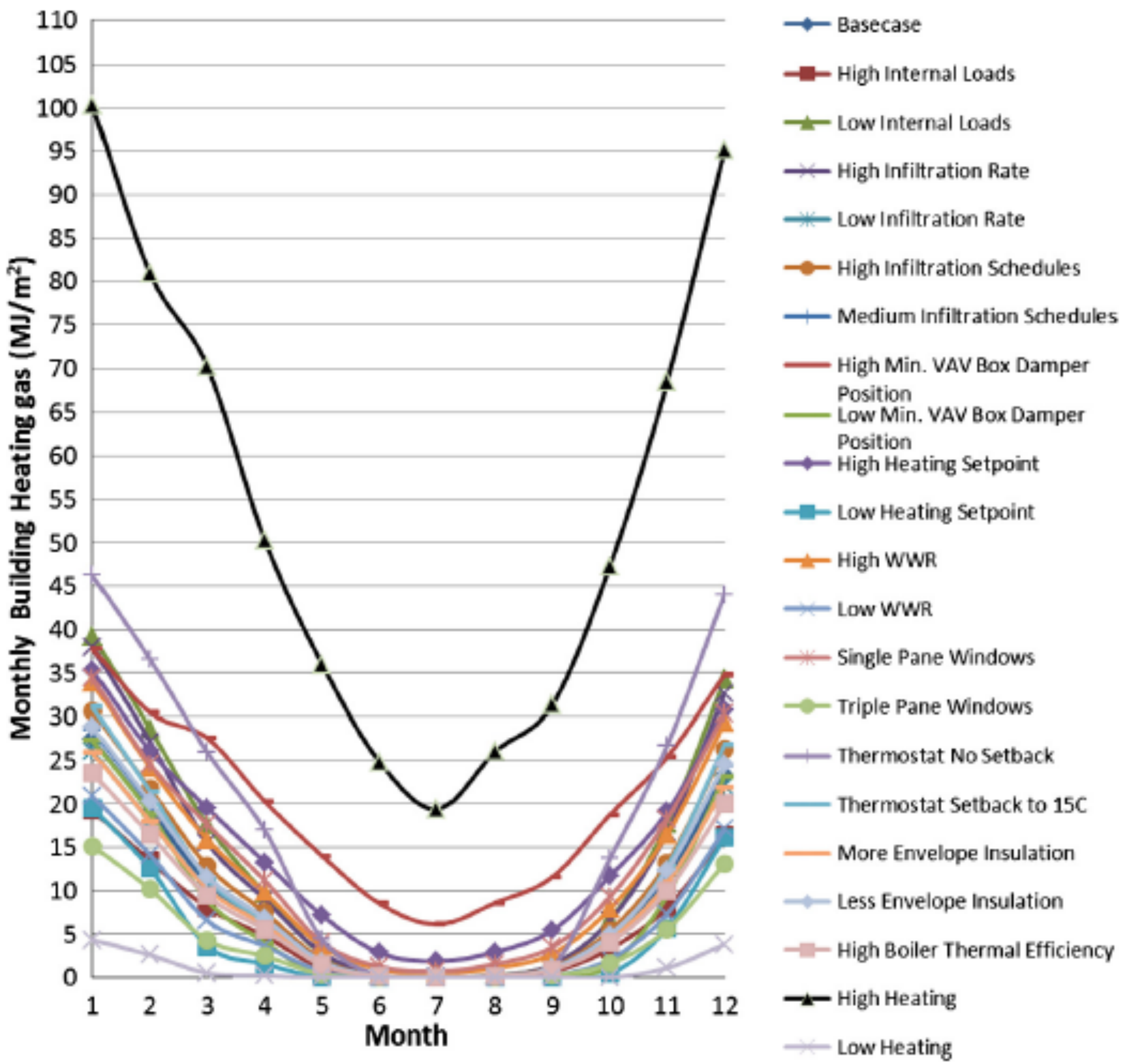
Pending improvements, New Buildings:

- Europe, EU-level Energy Performance in Buildings Directive: all new public buildings to be "nearly zero-energy" by 31 December 2018, and all other buildings to be nearly zero-energy by 31 December 2020"
- The California Energy Commission (which sets building standards) and the California Public Utility Commission (which regulates utilities) are pursuing the goal that all new residential construction be net zero-energy by 2020 and all new commercial construction be net zero-energy by 2030
- Section 422 of the 2007 *Energy Independence and Security Act* lead to the establishment of the *Zero-Net-Energy Commercial Buildings Initiative* with the goals of developing and disseminating technologies, practices and policies with the goals that (i) any new commercial buildings in the US be net zero by 2030, 50% of the commercial building stock be net zero by 2040, and the entire commercial building stock be net zero by 2050
- Architecture 2030 initiative, supported by the American Association of Architects – promoting goal of all new buildings to be net-zero energy by 2030. Local chapters through-out the US, training programs for practicing architects, establishment of 2030 Districts

Some illustrative factoids

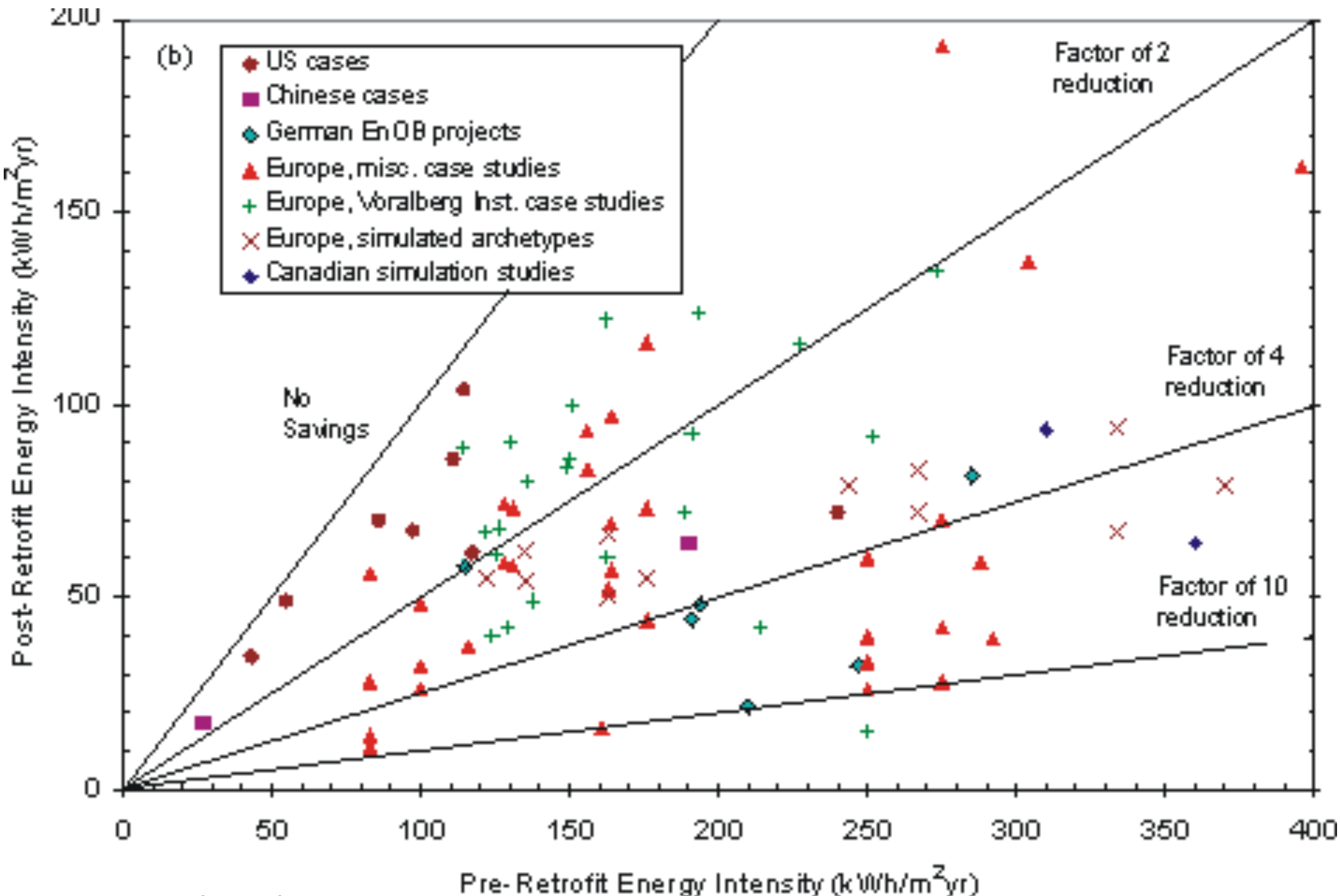
- The average energy intensity of Canadian and northern US hospitals is about 850 kWh/m^{2}yr; that of the most efficient new hospital in Sweden is 150 kWh/m^{2}yr
- Under current regulations, the heating energy requirement for an office building in Atlanta is 80% that of the same building in Chicago
- In Chicago, the heating energy requirement in *winter* of a high-performance office building is ¾ that of the *summer* heating requirement of the worst legal design and 1/6 that of the winter heating requirement of the worst design

Simulated heating Energy Use in a Chicago office building



Source: Lin and Hong (2013, Applied Energy 111:515-528)

Energy savings from building retrofits



Source: Harvey (2013a)

Scenarios for future building energy use: inputs

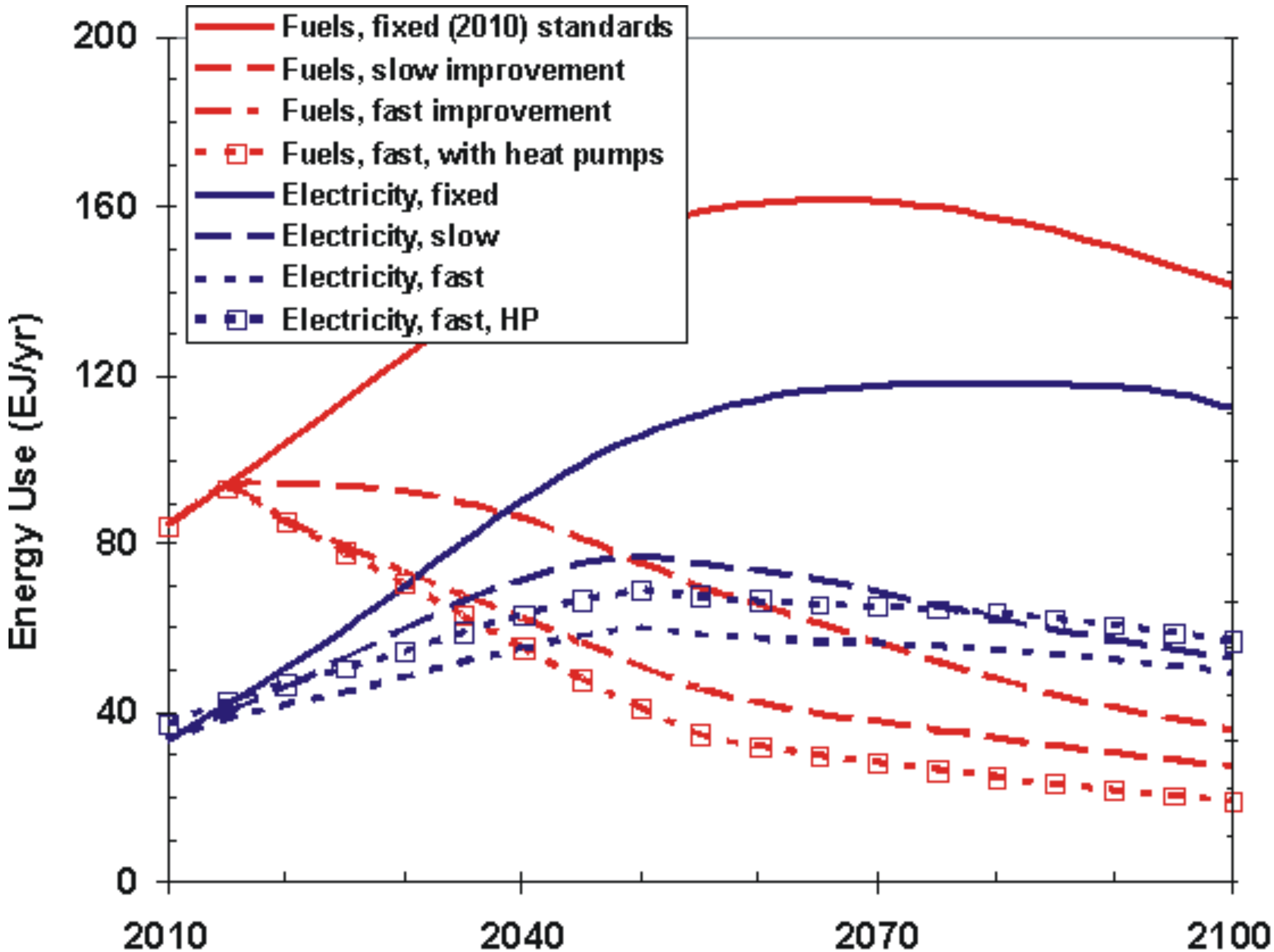
- Estimated starting data on: commercial and residential floor areas and energy intensities by end use and energy types in 10 different world regions
- Growth in residential and commercial floor areas in each regions as population and GDP/P increase, and increase in heating and cooling energy use per m^2 floor area as income increases in regions where indoor temperatures are currently not comfortable
- Stock turnover model to account for effects of renovation and demolition with replacement
- More stringent standards for new buildings and for renovations of existing buildings gradually implemented over time
- Acceleration in the rate of renovation

Specifically, it is assumed that

- Energy intensity for new buildings drops by a factor of 3-4 compared to the 2010 stock average, by 2020 (fast) or 2030 (slow)
- Renovations of existing buildings achieve a factor of 2-3 reduction in energy use on average by 2020 or 2030
- The entire building stock is renovated by 2055
- 50% of the residual fuel requirement (for space and water heating) is shifted to heat pumps

Full details, along with the spread sheets and Fortran code used for the calculations for what is to follow are in Harvey, L.D.D. 2014. Global climate-oriented building energy scenarios. Energy Policy (in press)

Net result of global buildings fuel and electricity demand, low GDP/P and population growth scenario



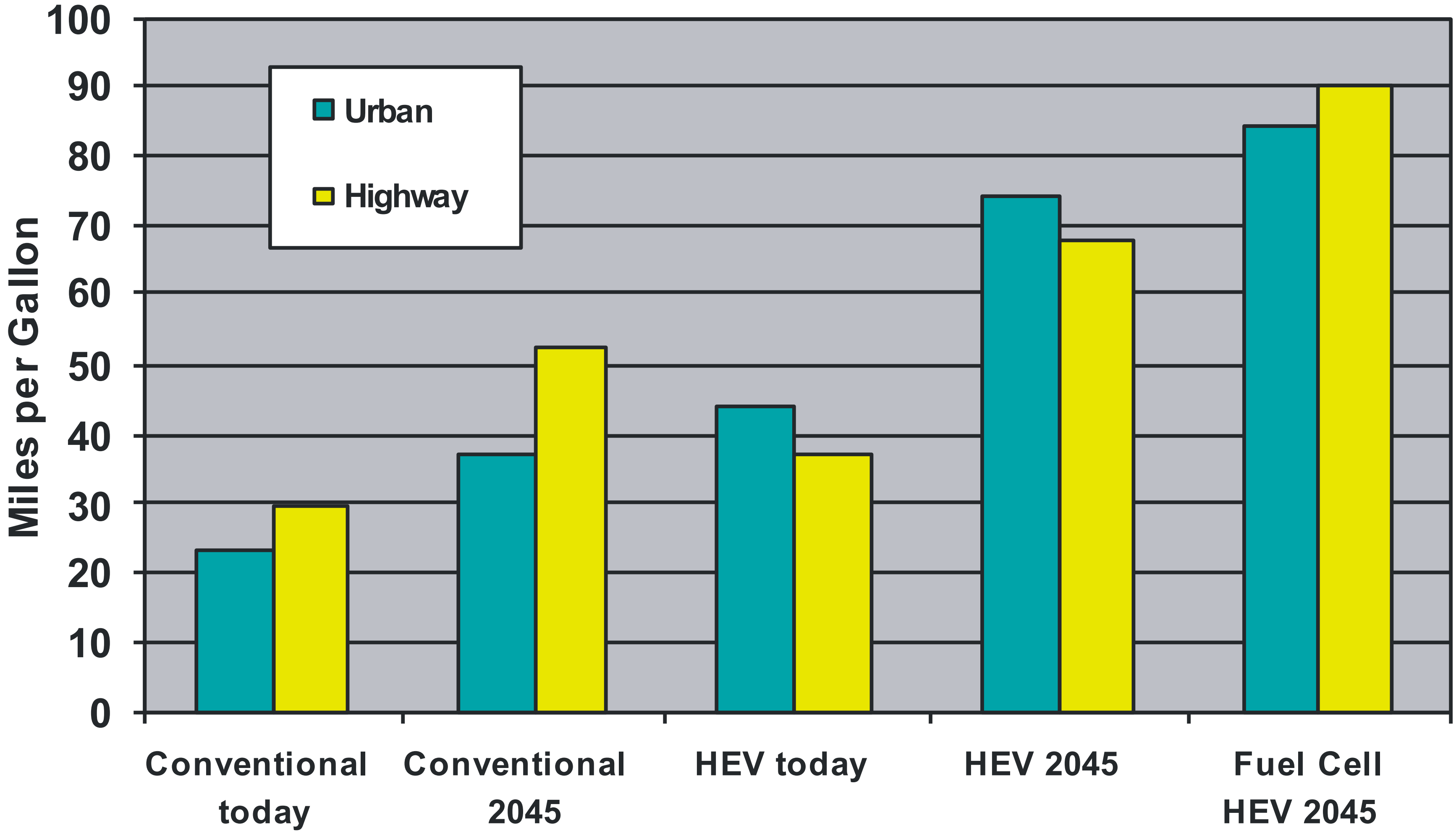
Transportation

Table 2: Potential savings in energy use per pkm from technical measures, or overall reduction in energy demand from system-level and behavioural changes

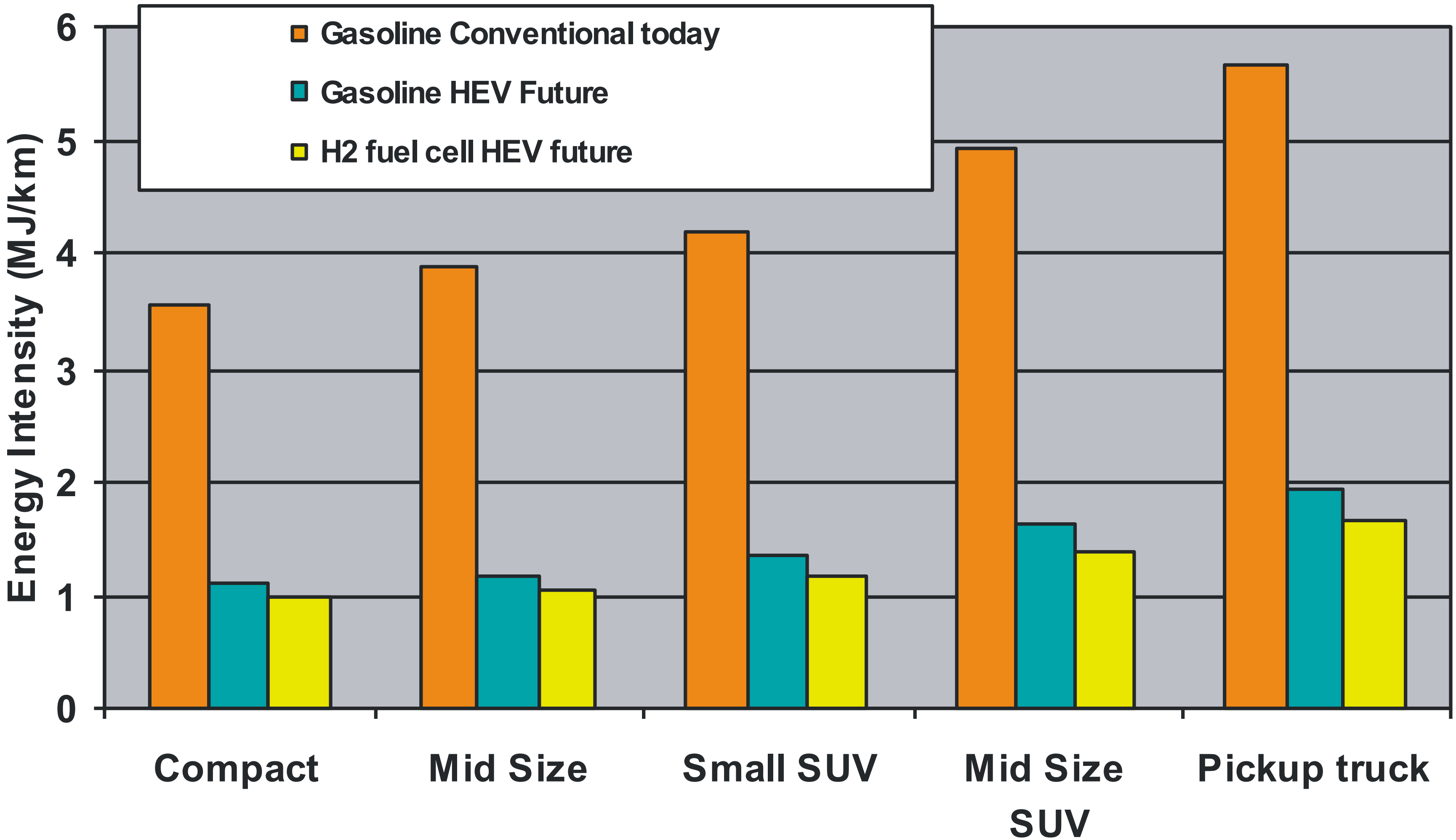
Mode	Technical measures – savings per passenger-km of travel	Behavioural and System Measures
LDVs	65% savings with advanced HEVs in urban driving, 60% in rural 2/3 further reduction in on-board energy use for each km shifted to grid electricity	Factor of two difference in total annual km travelled per person, Houston vs San Francisco Factor of six difference in percentage of trips by car, Houston vs Hong Kong 35% reduction, pickup truck vs midsize car 20% reduction, non-aggressive vs aggressive driving behaviour 10% reduction through car pooling
Bus	50% savings urban buses, 30% inter-city	
Rail	50% savings in diesel trains, 75% savings in shift from diesel to electric	
Air	40% reduction by 2050 relative to 2010	

Source: Harvey (2013b)

Argonne National Lab 2011 study, potential improvements in the fuel economy for compact cars (adjusted from standardized tests to reflect real-world driving conditions, including aggressive driving behaviour)



Impact of vehicle choice



Argonne National Lab study, fuel and electricity energy intensity for compact cars

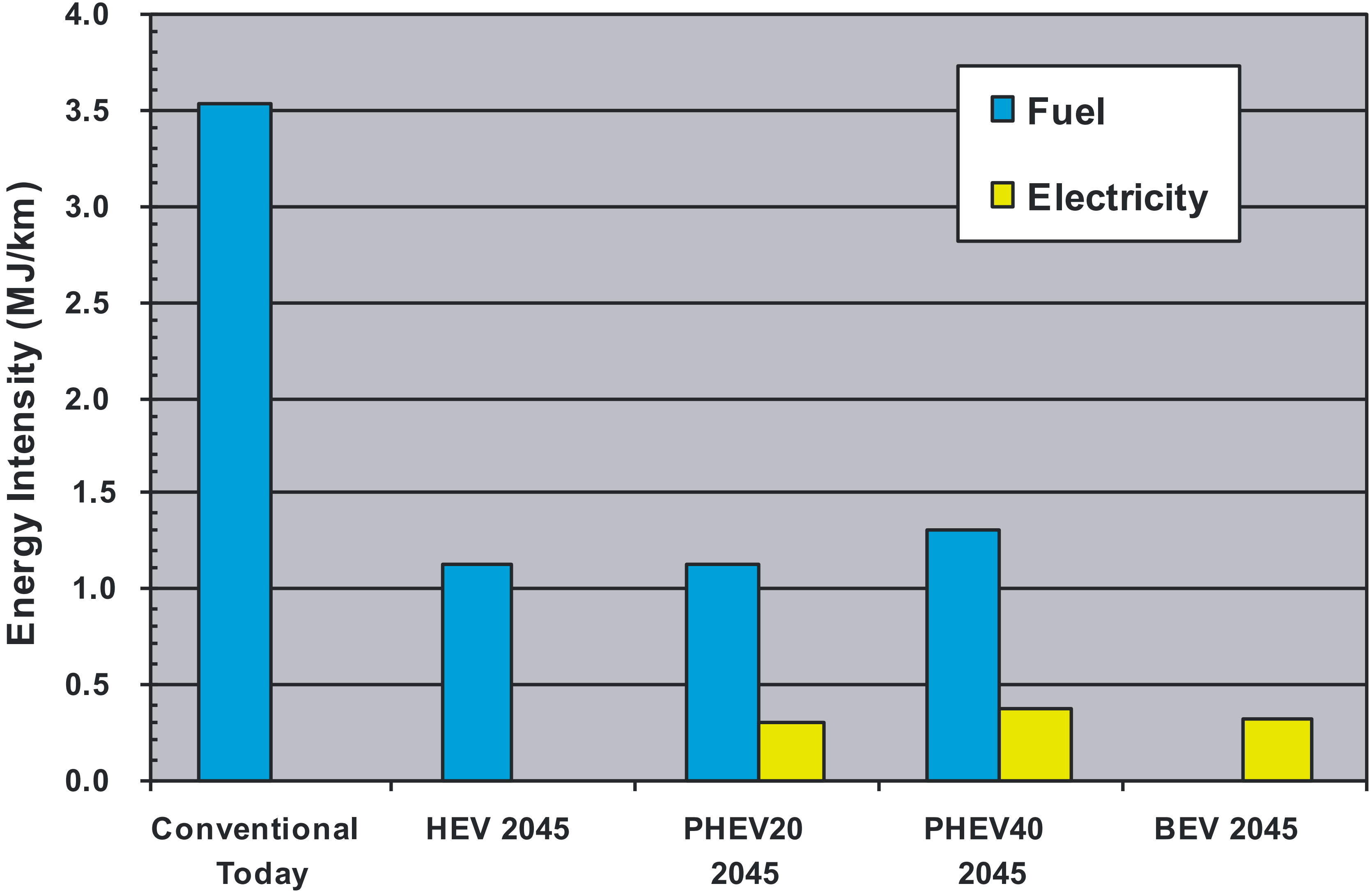
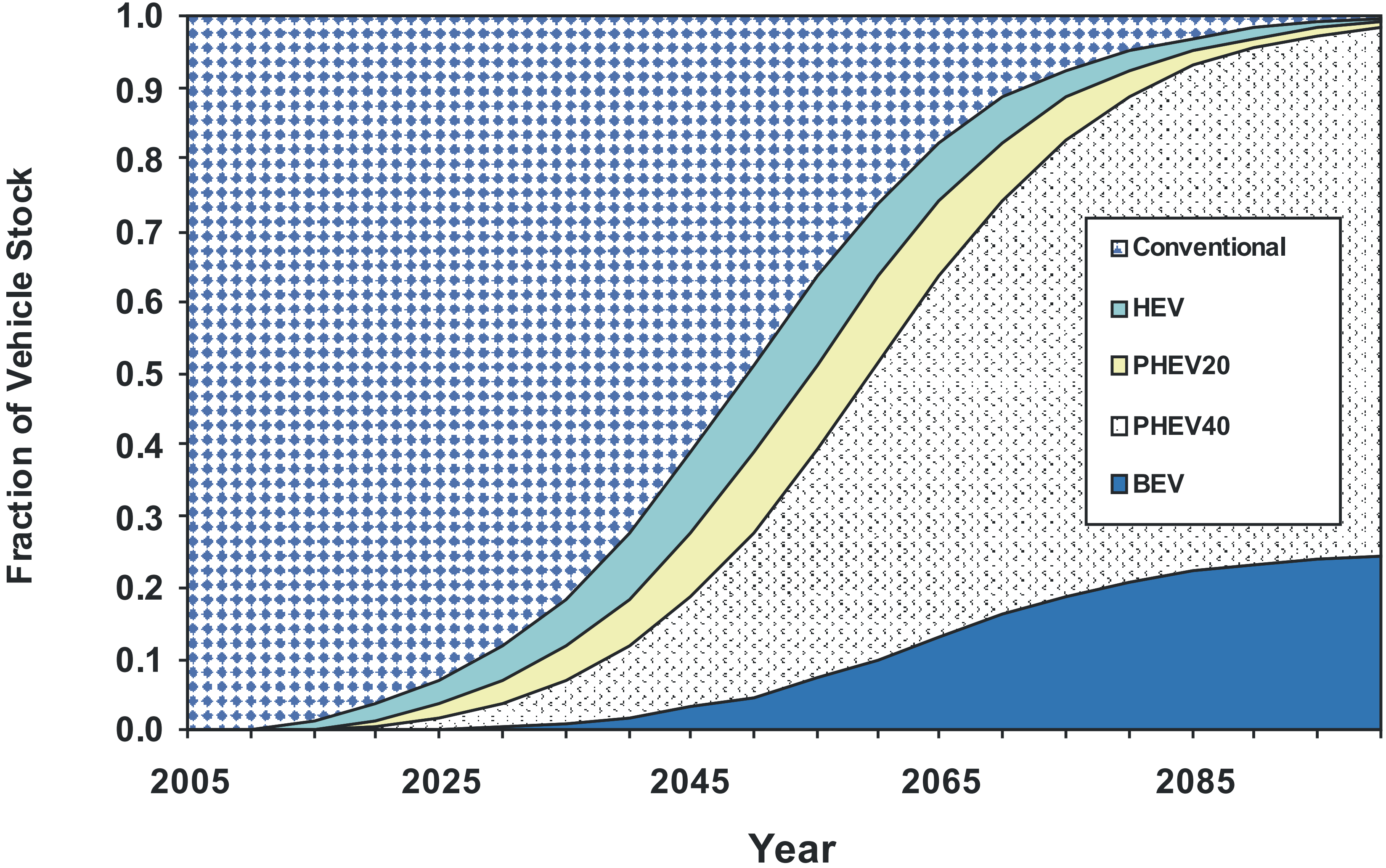


Table 3: Potential savings in freight energy use per tkm from technical measures, or overall change due to changes in modal split

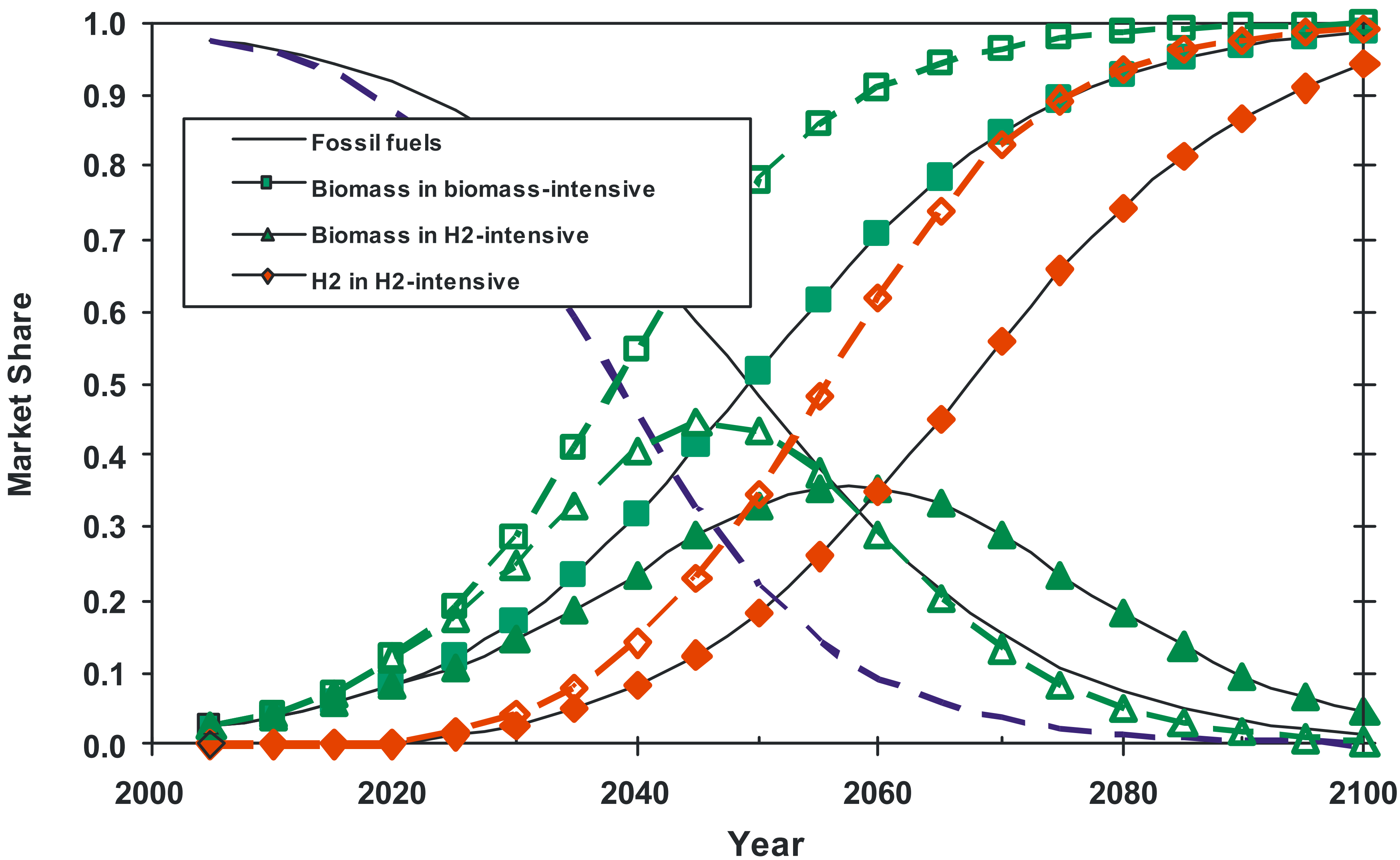
Mode	Technical measures and reduce ship speed – savings per passenger-km of travel	System-scale effects
Truck	45-50% reduction through engine improvements 60% reduction with additional aerodynamic changes	Tendency for truck modal share to increase
Rail	60% reduction from all measures except electrification 75% reduction with electrification too	
Ship	60% reduction for all shipping modes except container ships 75% reduction for container ships	Tendency for increasing proportion of more energy-intensive ships
All	Another 10% or so savings if H_2 is used in fuel cells	

Source: Harvey (2013b)

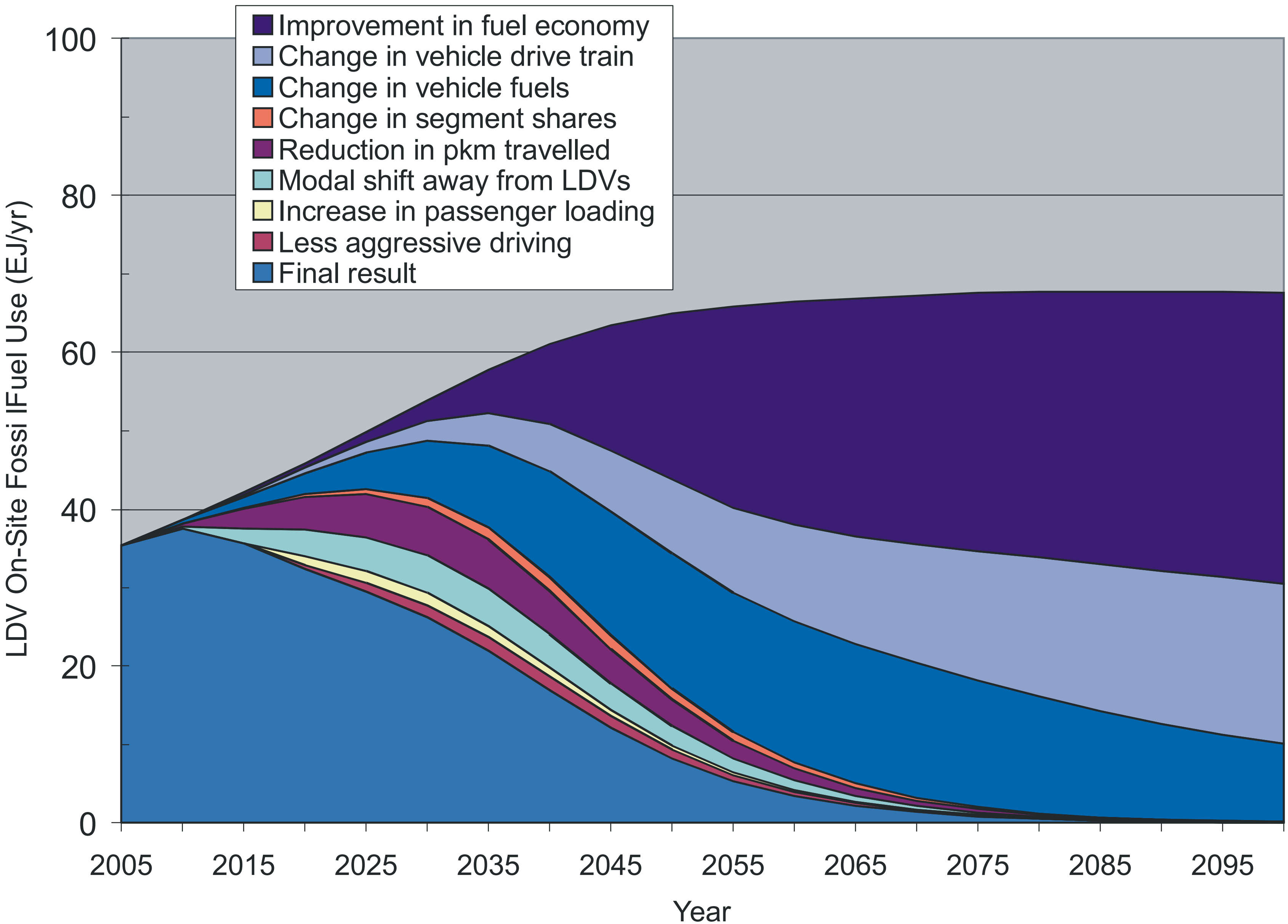
Scenario for changing market share of different LDV drive-trains



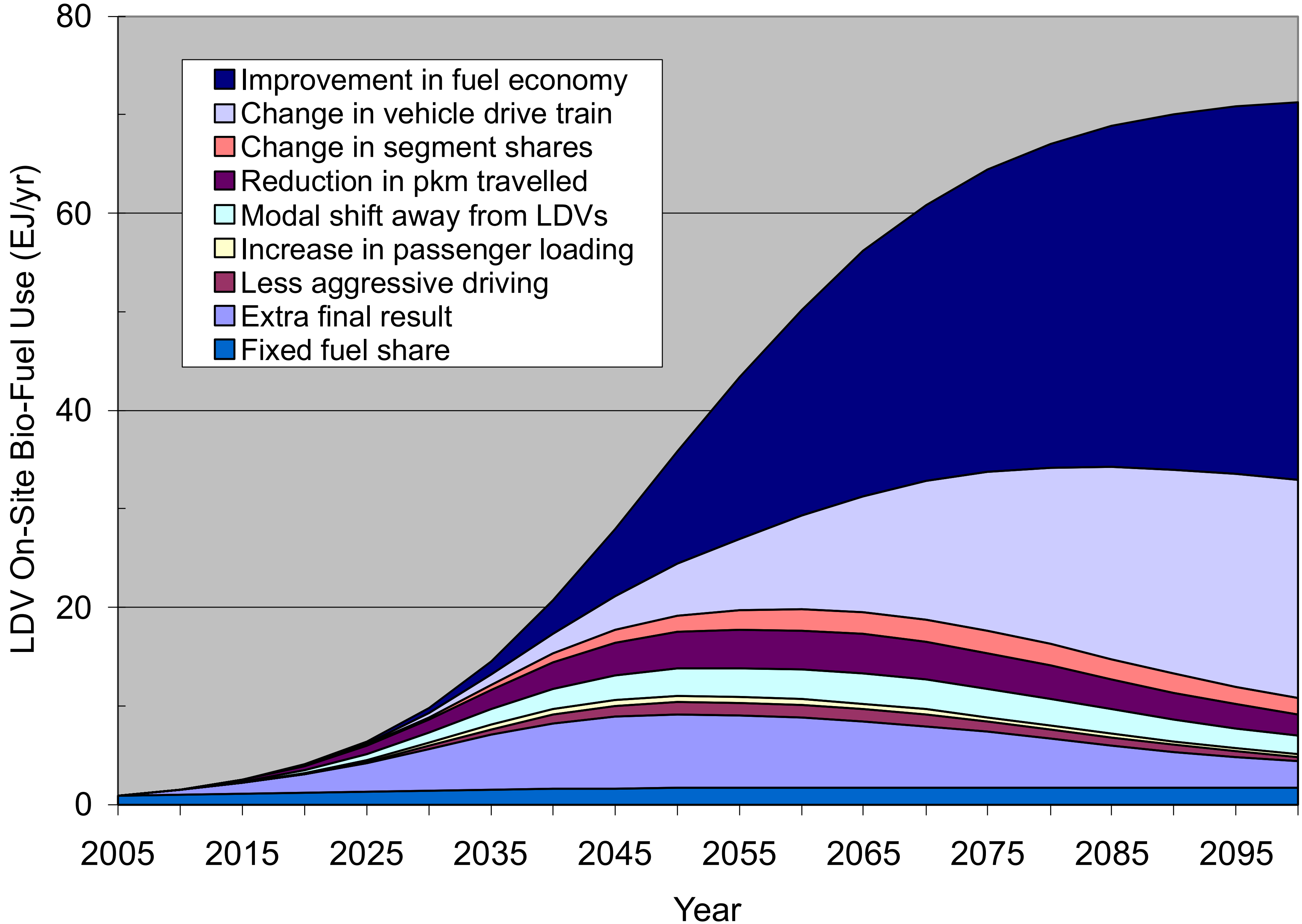
Changing Market Share for Different Fuels for LDVs



Global fossil fuel use by LDVs, Low GDP scenario, Fast Transition



Reductions in global biofuel use by LDVs, Low GDP scenario



Industry

Breakdown of global industrial energy use in 2005

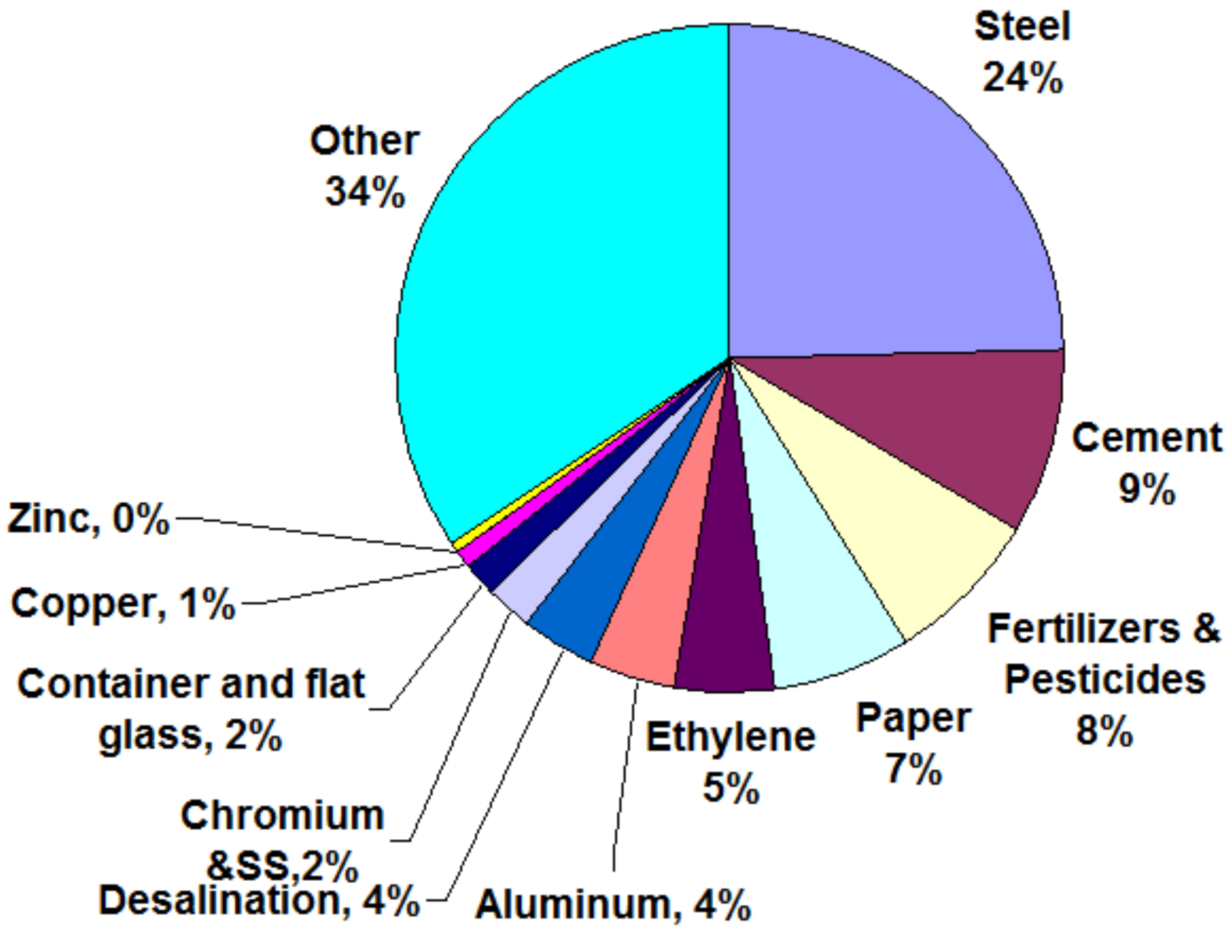


Table 4: Energy intensity for the production of primary and secondary (recycled) steel.

	Primary Steel				Secondary Steel			
	Fuels	Electricity		Total	Fuels	Electricity		Total
	GJ/t	kWh/t	GJ/t	GJ/t	GJ/t	kWh/t	GJ/t	GJ/t
Average today	30.0	450	1.6	**31.6**	1.2	650	2.3	3.5
Present best	16.4	290	1.0	17.4	1.2	475	1.7	2.9
Future best	11.8	115	0.4	12.2	1.2	395	1.4	**2.6**

Source: Harvey (2010, Table 6.6)

Table 5: Energy intensity for the production of primary and secondary (recycled) aluminum.

	Primary Aluminum				Secondary Aluminum			
	Fuels	Electricity		Total	Fuels	Electricity		Total
	GJ/t	kWh/t	GJ/t	GJ/t	GJ/t	kWh/t	GJ/t	GJ/t
Average today	42.5	15900	57.24	**99.7**	11.2	380	1.4	12.6
Future best	13.8	11430	41.15	54.9	8.4	285	1.0	**9.4**

Source: Harvey (2010, Table 6.9)

Table 6: Energy intensity for the production of primary and secondary (recycled) copper. RG designates energy use with future reduced ore grade due to depletion of high-quality ores, while RG+IP includes the impact of future improved practice

	Primary Copper				Secondary Copper			
	Fuels	Electricity		Total	Fuels	Electricity		Total
	GJ/t	kWh/t	GJ/t	GJ/t	GJ/t	kWh/t	GJ/t	GJ/t
Average today	34	6000	21.6	**55.6**	15	4200	15.1	30.1
RG	46	9300	33.5	79.5	15	4200	15.1	30.1
RG+IP	39	7500	27.0	66.0	10	2800	10.1	**20.1**

Source: Harvey (2010, Table 6.13)

Table 7: Energy intensity for the production of primary and secondary (recycled) zinc. RG designates energy use with future reduced ore grade due to depletion of high-quality ores, while RG+IP includes the impact of future improved practice

	Primary Zinc				Secondary Zinc			
	Fuels	Electricity		Total	Fuels	Electricity		Total
	GJ/t	kWh/t	GJ/t	GJ/t	GJ/t	kWh/t	GJ/t	GJ/t
Average today	9.3	4290	15.4	**24.7**	2.5	1100	4.0	6.5
RG	10.4	4740	17.1	27.5	2.5	1100	4.0	6.5
RG+IP	8.1	4420	15.9	24.0	2	800	2.9	**4.9**

Source: Harvey (2010, Table 6.15)

Range of energy intensities in the production of cement

- Highest national average: 6.1 GJ/t
- Lowest national average: 3.1 GJ/t
- Global average: 4.8 GJ/t
- Theoretical minimum: 1.76 GJ/t to produce clinker, + 0.2 GJ/t crushing and grinding
- If the future world average can be brought to 20% below the current best (to 2.5 GJ/t), the reduction in global average energy intensity would be about 50%

Source: Harvey (2010, Section 6.7.2)

Potential unit energy savings in the manufacture of glass

- 30-35% savings from improved furnaces
- 10% possible savings from recycling hot gases
- 15% savings by increasing average cullet (recycled) fraction from 25% to 60%
- Over potential reduction of 45-60% per unit of production

Source: Harvey (2010, Section 6.8.4)

Energy Intensity of Paper Production

- Paper mills using virgin wood should become energy self-sufficient or net energy exporters (by using primary and secondary wastes to cogenerate heat and electricity)
- Production of new paper by recycling of old paper entails a primary energy requirement (excluding collection energy use) of about 20 GJ/t, but use of the saved forest biomass for cogeneration of heat and electricity yields a net primary energy gain of about 37 GJ/t

Source: Harvey (2010, Section 6.9.7)

Plastics - Ethylene

- Cracking step: 25-30 GJ/t average today
  20-25 GJ/t best practice
  17-22 GJ/t (30% savings) future
- Cooling and fan energy use: 30-85% savings
- Mechanical downcycling saves 40-50%

Source: Harvey (2010, Section 6.10.2)

Fertilizer Energy Use

Depends on

- Demand for crops – influenced by diet (most of the corn grown, for example, is fed to animals and turned into food for people with a very low conversion efficiency)
- Efficiency of fertilizer use (kg nutrient in edible crops over kg of nutrient applied to field)
- Energy intensity of producing fertilizer (GJ/t)

N fertilizer energy intensity

Savings in production of ammonia:

•40% for future best practice compared to average today using natural gas

•60% for future best practice compared to average today using coal

•75% best practice today using coal vs mid 1990s average in India using coal

Savings in production of nitric acid and ammonium nitrate

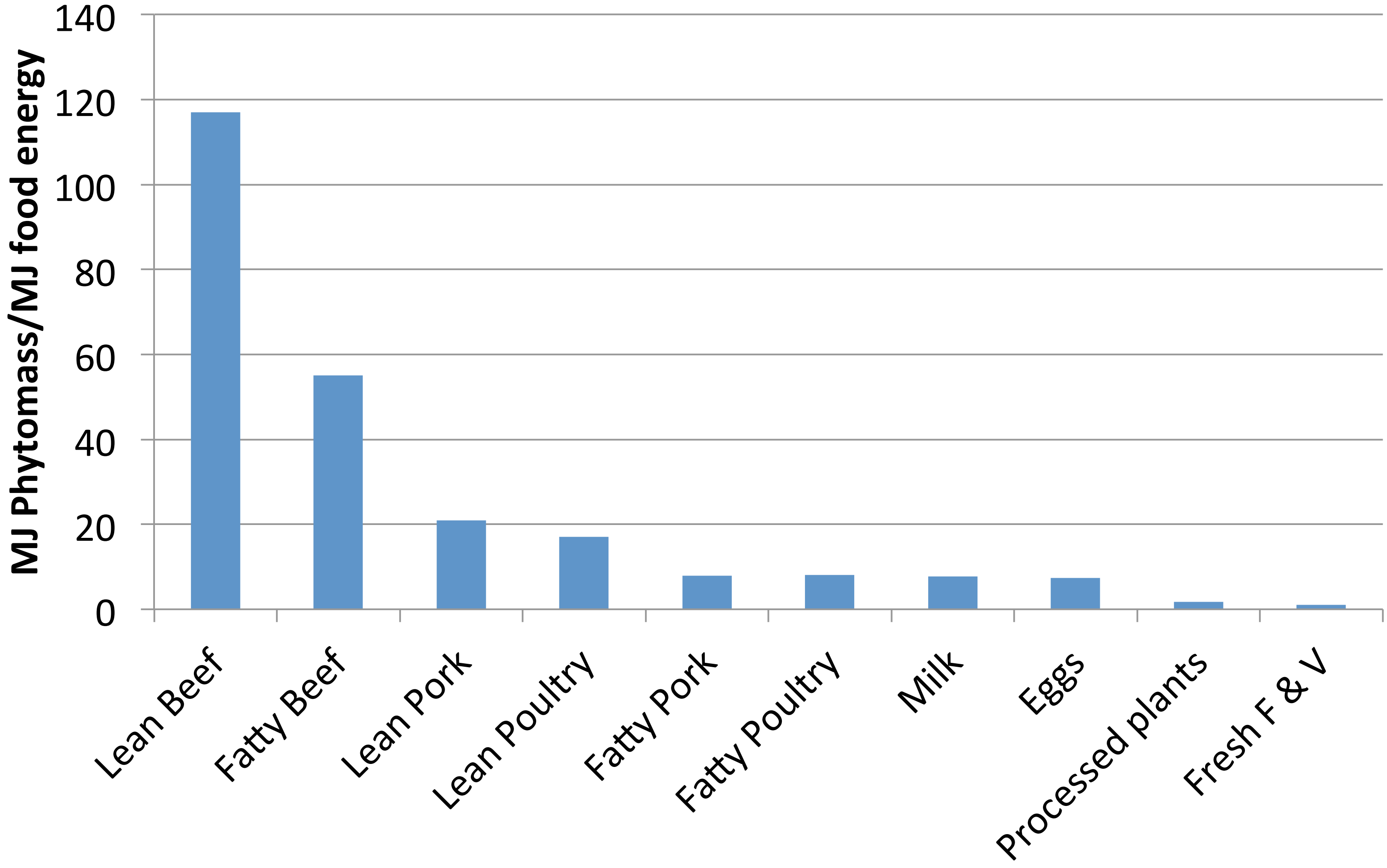
•50% identified future best practice vs mid 2000s best practice

Source: Harvey (2010, Section 6.9.7)

Nitrogen use efficiency

- 30-45% reduction in N use with no reduction in crop yield estimated for The Netherlands
- Factor of 4 variation in average kgRice/kgFertilizer for various rice-producing countries

Ratio of MJ of phytomass feed to animals, to MJ of human-metabolizable energy in animal products



For fertilizers, and some other agricultural inputs, we can envisage

- A factor of two reduction in demand through modest reversal of the trend toward more meat consumption in many parts of the world, and through a continuation of the shift away from beef
- A factor of two reduction in fertilizer use per unit of crop production
- A factor of two reduction in the energy intensity of fertilizers

This amounts to a factor of reduction in fertilizer energy use compared to the reference case

Summary: Energy savings potential

- New buildings – factor of 2- 3 reduction in energy intensity (kWh/m^{2}yr) compared to recent practice for new buildings, achieved by 2020-2025
- Existing buildings – retrofit to reduce average energy use of the entire stock by a factor of 2-3 by 2055
- Double to triple fuel efficiency of new LDVs (depending on the country and starting conditions) by 2025-2035; largely phased into the fleet by 2040-2050
- Shift a further ½ to 2/3 of fuel demand to grid electricity by 2055 (at 1/3 the energy intensity (MJ/km))
- 50% reduction in energy intensity of buses and passenger rail, and 40% reduction of passenger air, by 2025 for new equipment, and by 2045 for the entire stock

Energy Savings Potential (continued)

- 60-75% reduction in freight energy intensity (MJ/tkm)
- Reduction in energy intensity of primary materials: steel, 60%; aluminum, 45%; copper and zinc, none; cement, 50%; glass, 45-60%; plastics, 50%
- Reduction in fertilizer energy demand relative to BAU: factor of 4-8
- Savings when recycling is possible (excluding incremental collection energy use, and based on advanced secondary production compared to current average primary production): steel, factor of 12; aluminum, factor of 10; copper, factor of 2; zinc, factor of 5; plastics, factor of 2 (in at least some cases).