

Polyester Use and Recycling in California — from Bottles to Fleece

Brandon Kuczenski and Roland Geyer
Department of Environmental Science and Management, University of California, Santa Barbara

June 21–24 2009

Please send questions or comments by email: bkuczenski@bren.ucsb.edu



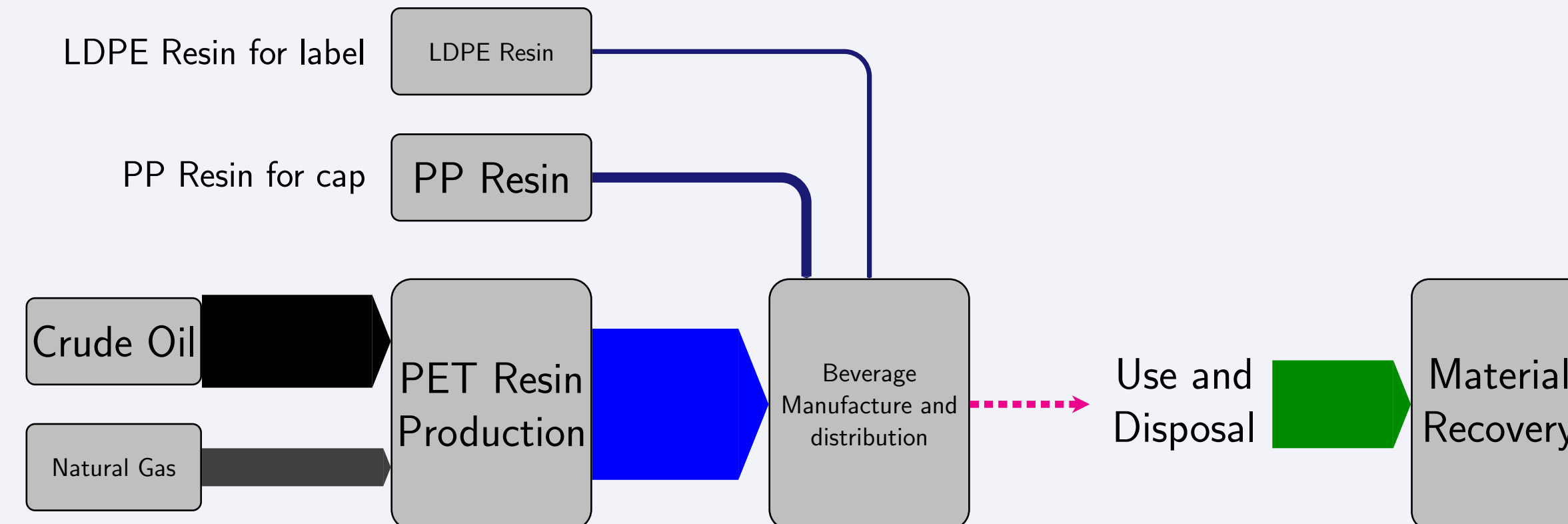
1 Abstract

In an era of increased consumer consciousness of environmental issues, recycling of post-consumer waste has gained prominence as a means for individuals to contribute to a sustainable society. Disposable plastic packaging products are among the most visible candidates for recycling, owing to their ubiquity in the consumer market, their high embodied energy content, and their longevity in landfills and the environment. The plastic soda bottle, made from polyethylene terephthalate (PET), is presently the single most-recycled plastic product in the US.¹ Even so, in 2007 fewer than 25% of PET containers nationwide were recycled. Domestic reclaiming capacity is inadequate to handle even this low recycling rate, and the majority of recycled PET collected is reclaimed overseas.²

In industrial ecology, recycling is a viable strategy for reducing the environmental impacts of consumption only to the extent that the recycled material has the capacity to replace primary production. In principle, plastics could be recycled indefinitely through chemical processes. In practice, however, most plastic is recycled through mechanical means which introduce contamination and reduce the quality of the feedstock.³ These technical obstacles, combined with regulatory challenges, limit the use of post-consumer PET in food and beverage packaging (closed-loop or “bottle-to-bottle” recycling). Instead, most PET is down-cycled into fiber, non-food packaging, and industrial applications, where it is unlikely to be collected for another cycle.

We investigated the life cycle of PET bottles consumed in California, one of eleven US states with legislated container deposit programs to encourage recycling of beverage bottles. Our study period was the years 2000–2007.

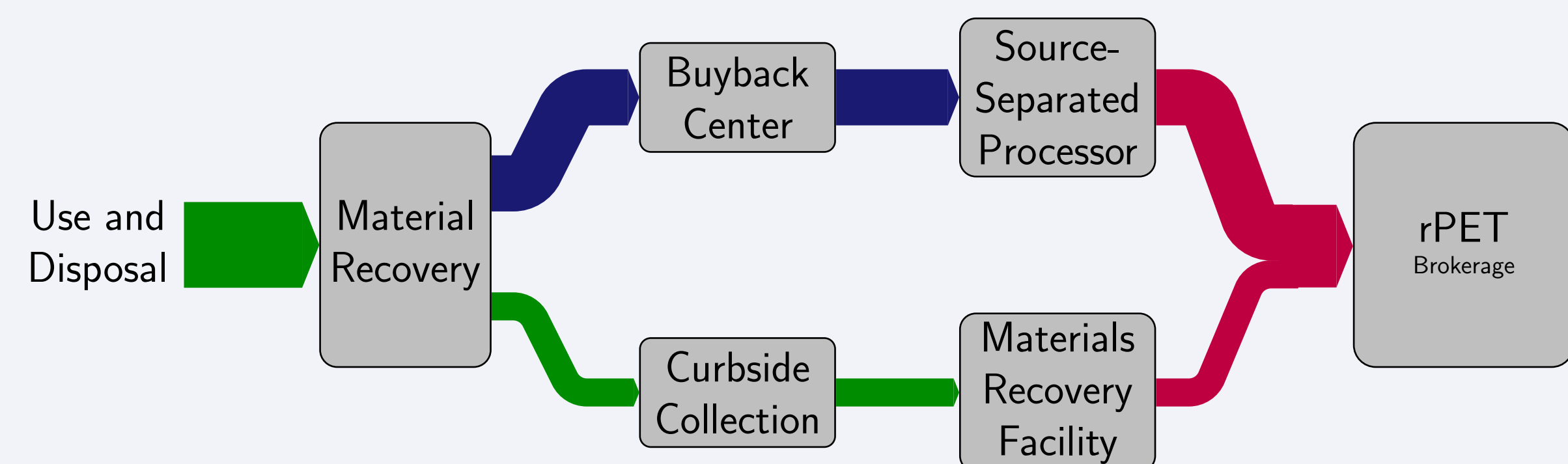
2 The Life Cycle of PET Bottles



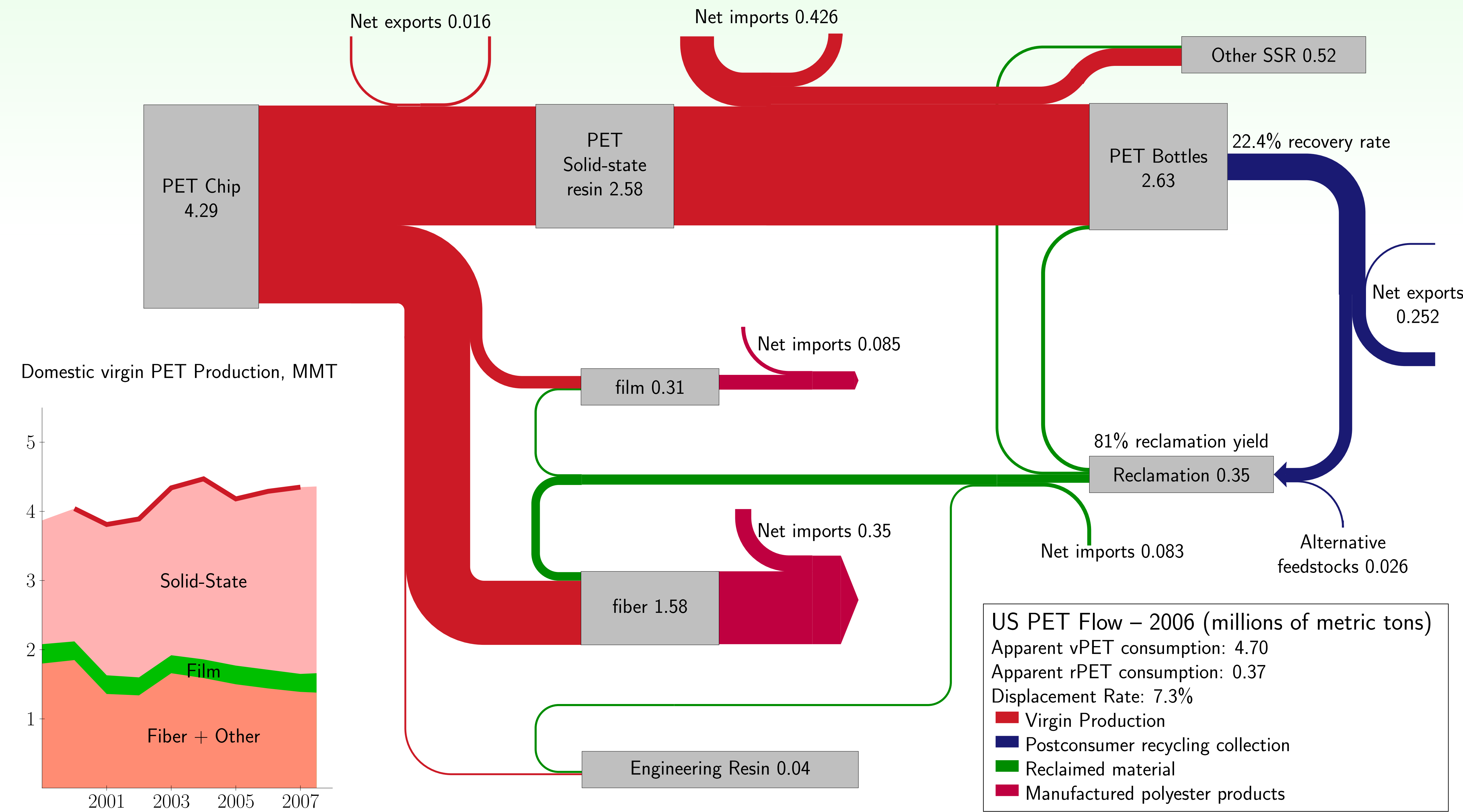
PET is manufactured from the polymerization of two precursor substances, terephthalic acid and ethylene glycol, which are produced from crude oil and natural gas. The process inventory for PET production is available from numerous sources including the US LCI database and PlasticsEurope. The majority of energy consumed in the production process is in the form of thermal energy from natural gas combustion. Total energy for the resin production process: about **20.1 MJ net / 30 MJ primary** per kg of PET.

PET beverage bottles are produced by injection-stretch-blow molding. A bottle preform is produced by injection molding, which is then heated and inflated with compressed air inside a chamber. When the resin is cooled rapidly, it takes the form of the chamber. The process uses electric power. Energy for bottle manufacture: about **15.1 MJ net / 36 MJ primary** per kg of PET.

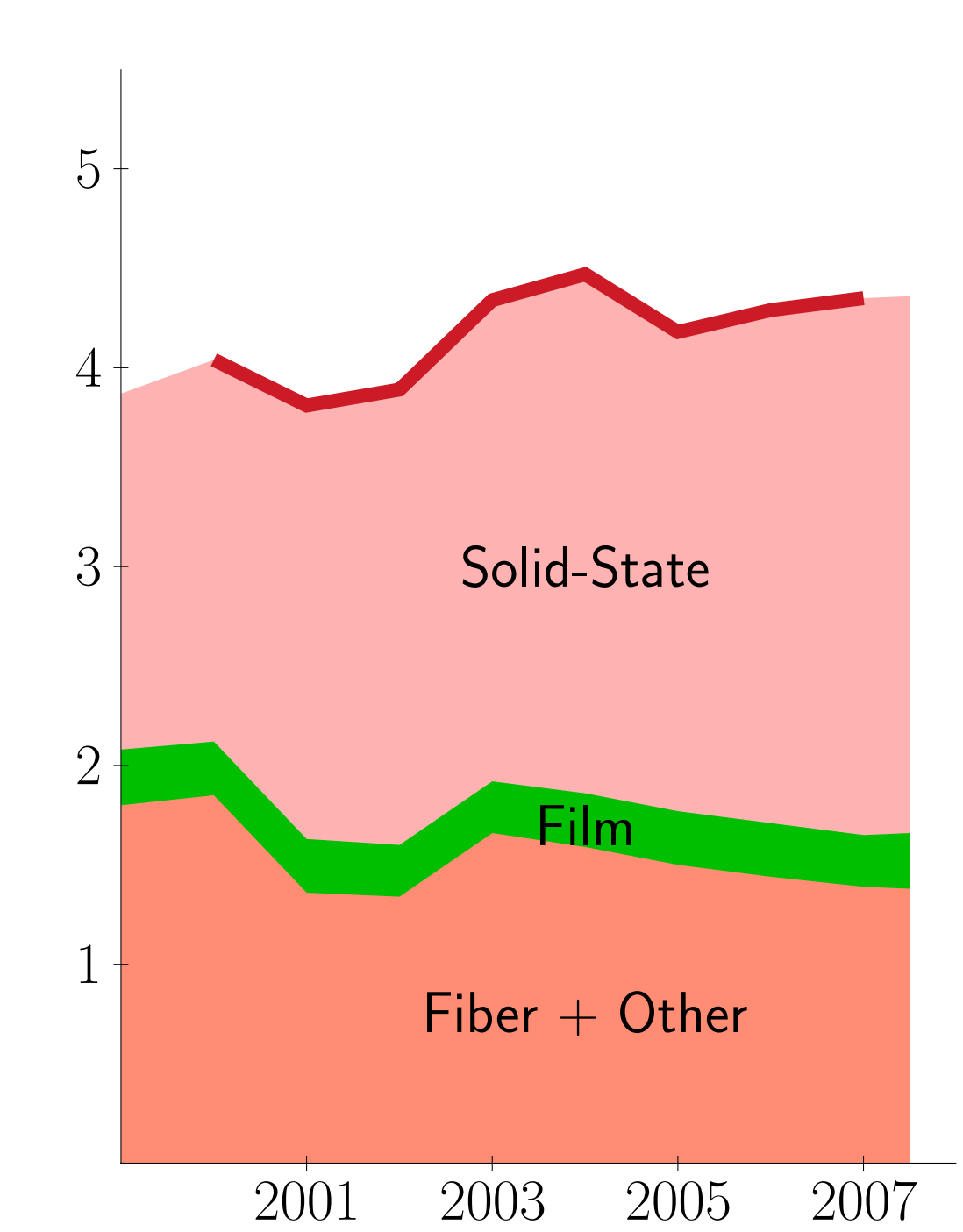
One kilogram of PET allows the transport of approximately **10.8 L** of beverage.



PET bottles in California are collected via two main routes: buyback facilities at which consumers return their bottles for a refund of the deposit amount, or residential curbside programs. The end-of-life collection and sorting process is not energy intensive (around 1–2 MJ / kg), and primarily requires the use of diesel fuel to operate the curbside collection fleet. After being sorted and crushed into bales of around 0.25–0.5 MT, the post-consumer bottles are sold on the market.



Domestic virgin PET Production, MMT

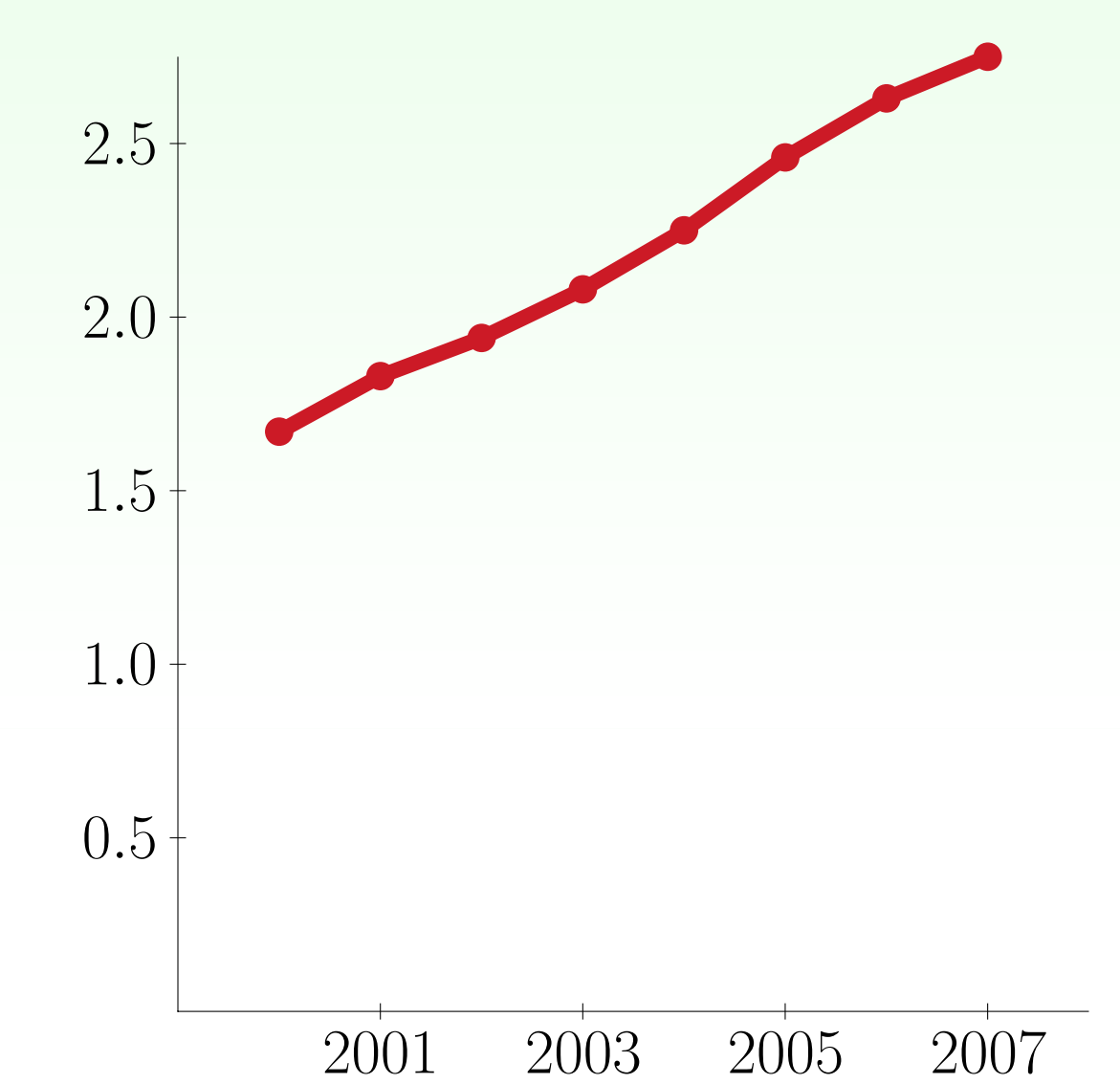


Sankey diagram showing the flow of Polyethylene Terephthalate (PET) resin in the manufacture and post-consumer recycling of disposable beverage bottles. PET Solid-state resin (SSR) has a higher intrinsic viscosity than PET chip, making it tougher and more durable for packaging applications. Beverage bottles are the dominant and fastest-growing use of PET, driven largely by the growth of the bottled water industry. Other applications, including polyester fiber and film, have been in decline.

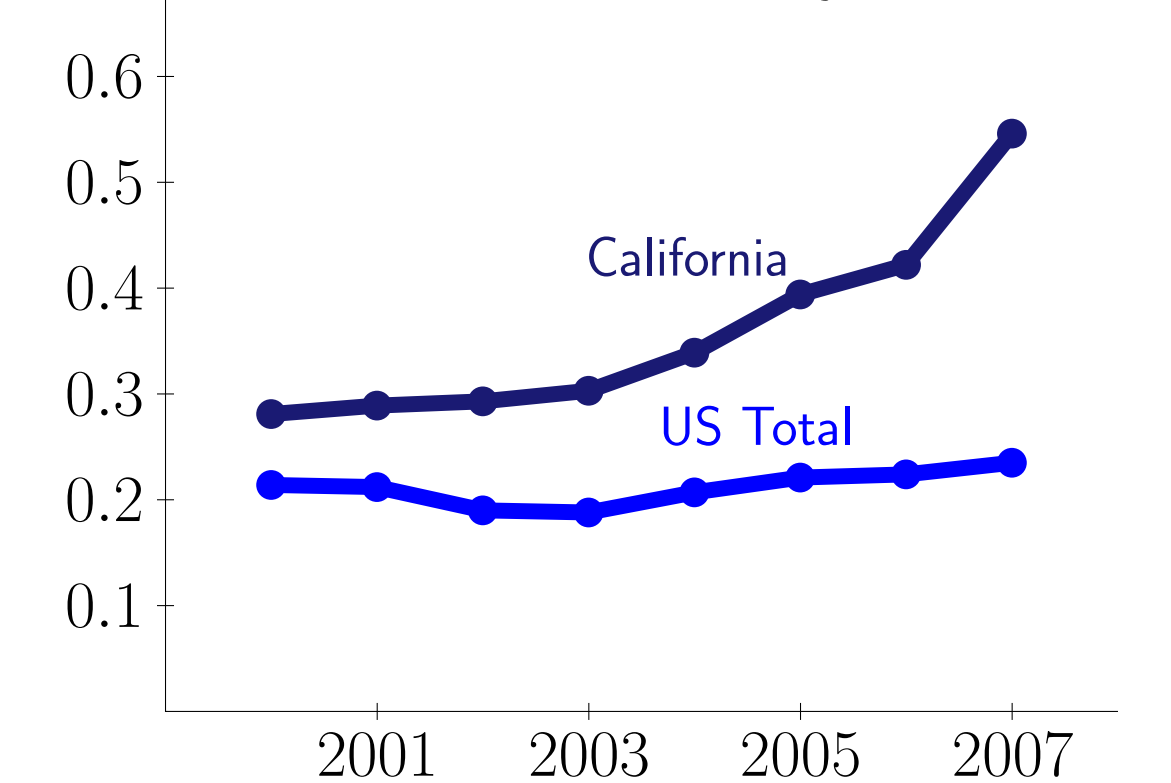
Although PET bottle collection has kept pace with increased consumption, the capacity of domestic reclamation facilities has not increased, and so the increasing volume of postconsumer bottles is exported, mostly to Asia. Meanwhile, reclaimed PET (rPET) is imported from Mexico and South America. Most of the rPET used in the US is down-cycled into fiber or film. There is still substantial consumption of vPET in these areas, so increased bottle reclamation has the potential to considerably reduce virgin fiber and film production. At the same time, the long-term decline of these sectors diminishes the effectiveness of this strategy.

The low rate of rPET production means that recycled PET has the capacity to displace only a small amount of virgin material production. The displacement rate here is defined as rPET consumption over total apparent consumption: $rPET / (vPET + rPET)$. Net imports of PET-SSR are included in this measurement, though net imports of manufactured fiber and film products are not. Our estimates suggest that PET bottle recycling presently displaces only about 6–8% of domestic production of PET, and this rate has been roughly constant over the study period. Less than 3% of domestic bottle production uses recycled feedstock (closed-loop recycling rate).

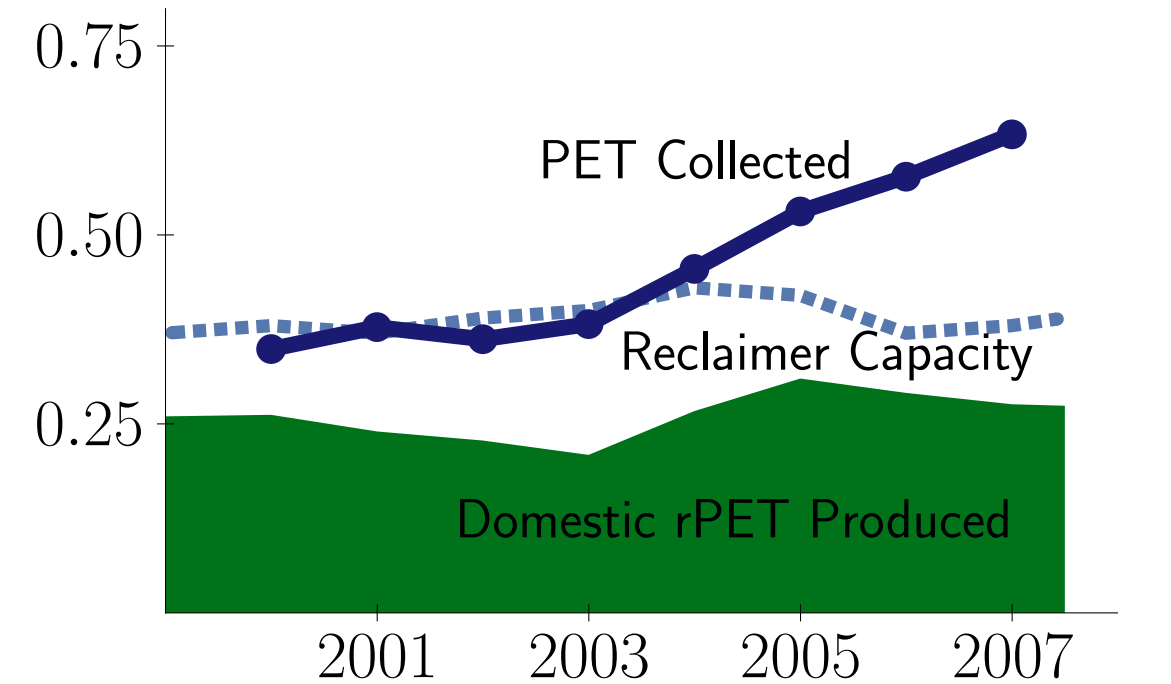
Solid-State PET in bottles, MMT



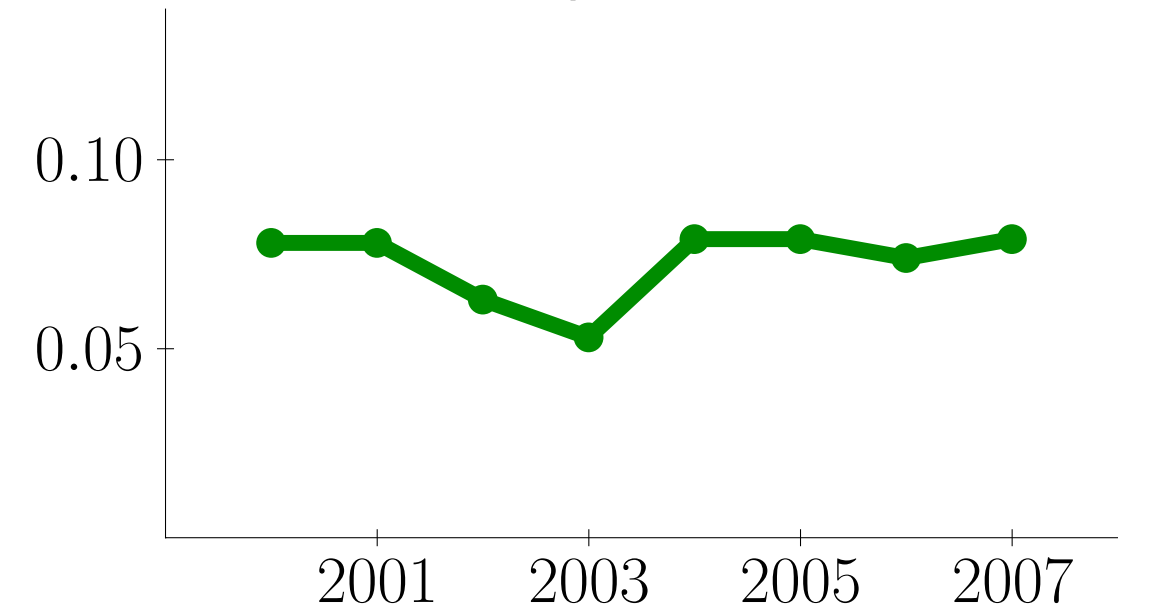
PET Bottle Recovery Rate



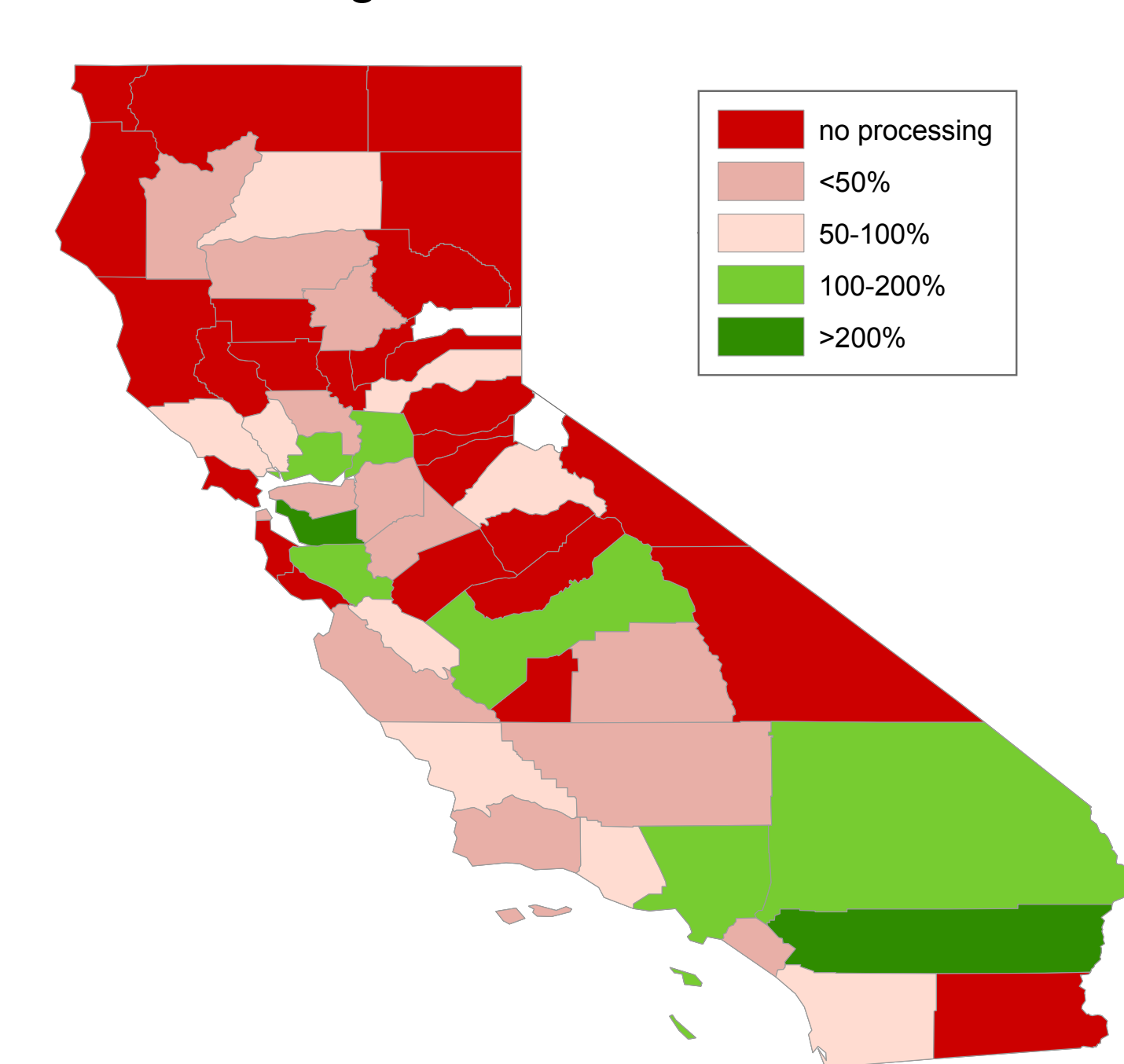
Domestic PET Reclamation, MMT



vPET Displacement Rate



Processing as Percent of Collection – 2007



3 Reverse Logistics

California's regulations specify a two-stage system for bottle end-of-life: collection and processing. Collection is widely dispersed throughout the state, but processing is more centralized near urban areas and ports. We used the volumes of PET collected and processed in each county to estimate the freight involved with postconsumer bottle collection.

- 8 counties processed more PET than they collected in 2007.
- Assume efficient allocation:
 - Local capacity used up first;
 - Excess distributed to surplus counties according to their capacity.
- Distances measured between county centroids.
- Mean distance between collection and processing: 127 km
- Total freight: 22 MMT·km.

We can conclude that reverse logistics do not contribute significantly to lifecycle environmental impacts. However, transport distances between processing and reclamation add a substantial financial cost which favors overseas reclaimers over facilities on the US East Coast.

4 Current Work

We are working to interrelate the time-dependent MFA with life cycle inventory data to develop a comprehensive model of resource consumption and environmental impacts associated with PET material cycling. We plan to use the model to demonstrate the potential benefits and limitations of improved end-of-life materials management in achieving sustainable consumption.

Our study currently only includes recycling of solid-state PET. In the future we plan to expand the analysis to include recycling of lower-grade polyester fiber, usually in the form of textiles and often by chemical means.

5 Acknowledgments

The authors wish to acknowledge the support of the California Department of Conservation, Division of Recycling (Grant #5007-503).

References

- [1] United States Environmental Protection Agency, 2008. Municipal solid waste in the united states: 2007 facts and figures. Online. Available: <http://www.epa.gov/osw/nonhaz/municipal/pubs/msw07-rpt.pdf>, November.
- [2] National Association for PET Container Resources (NAPCOR). 2007 report on postconsumer PET container recycling activity. Online. Available: http://www.napcor.com/pdf/2007PET_Report.pdf, 2008.
- [3] Awaja, F., and Pavel, D., 2005. “Recycling of PET”. *Eur. Polym. J.*, 41, pp. 1453–1477.