SUPPLEMENTARY INFORMATION

Cross life cycle opportunities for increasing the post-consumer recycled content of automotive aluminum body sheet in the United States

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This supporting information file (S1) provides additional details that complement the main article. In addition to this document (S1), a spreadsheet-based supporting file (S2) is available on the journal's website. The Python linear programming (LP) code used to perform the analysis can be downloaded here.

S1 DEFINITIONS OF PCRC AND PCRR

The outputs of the LP model include, for a given year, the material flows, $R_{s,d}$ and $P_{s,d}$, that result in the minimum virgin metal use in making the ABS ingots and, therefore, the maximum scrap content. Below, the maximum closed-loop post-consumer ABS recycling rate (PCRR) and the maximum closed-loop post-consumer ABS recycled content (PCRC) are defined in terms of $R_{s,d}$ and $P_{s,d}$ and the total quantity of post-consumer (PC) ABS scrap arising from ELVs. For PCRC (S1), the numerator is the total quantity of ABS PC scrap in ABS ingots while the denominator is the total quantity of metal in the ingots. Meanwhile for PCRR (S2), the numerator is the total quantity of ABS PC scrap added to furnaces to make ABS ingots while the denominator is the total quantity of ABS PC scrap arising from U.S. ELVs (i.e., scrap generated, not collected). In both cases, the numerator reflects the total quantity of ABS PC scrap used—the main difference is the PCRC accounts for melt losses that occur in the furnace.

$$PCRC = \frac{0.95 \times \sum_{s=16:15+|T|} \sum_{D} R_{s,d}}{Ingot\ Demand} \tag{S1}$$

$$PCRR = \frac{\sum_{s=16:15+|T|} \sum_{D} R_{s,d}}{ABS\ PC\ Scrap\ Arising} \tag{S2}$$

S2 ECONOMIC SCRAP CHARGE CONSTRAINT ON SECONDARY FURNACES

The furnace scrap constraint reflects the reality that recycling becomes economically and environmentally unviable when the scrap fraction in the furnace charge is too low. As the scrap charge decreases, the cost and greenhouse gas (GHG) emissions from purchasing and remelting primary aluminum begin to outweigh the benefits of displacing only a small portion of primary material. For recycling—using a furnace charge that blends scrap with primary aluminum—to result in lower emissions than direct alloying with 100% primary aluminum, the scrap charge α must exceed a certain threshold. This can be approximated by modeling scrap as emissions-free, highlighting the minimum scrap fraction required for net environmental benefit.

$$Emissions_{primary} \times (1-\alpha) + Emissions_{remelting} < Emissions_{primary} \tag{S3}$$

Using $Emissions_{primary} = 8.072\,\mathrm{kgCO_2e/kg_{ingot}}$ and $Emissions_{remelting} = 0.513\,\mathrm{kgCO_2e/kg_{ingot}}$, the minimum scrap furnace charge for recycling to be competitive from and emissions perspective is $\alpha = 0.064$

The equivalent equation for the economic of recycling is:

$$Cost_{primary} \times (1-\alpha) + Cost_{remelting} < Cost_{primary} \tag{S4}$$

Figure S1 shows the minimum scrap charge fraction required for economically viable recycling, plotted as a function of scrap price and melting cost. Sensible values for these costs—based on energy requirements for remelting and scrap prices relative to primary aluminum, as reported by Schlesinger (2006)—highlight how economic feasibility depends on the scrap type. If the scrap input consists entirely of Twitch (the relatively inexpensive, aluminum-rich stream from ELV recycling), the required scrap charge can be as low as 20%. In contrast, if the input is exclusively Tooth (higher-cost, segregated alloy clippings and solids), the minimum viable scrap charge maybe as large as 52%. Given that today's scrap stream is primarily production scrap and future streams will likely include a mix of production and post-consumer scrap, a baseline scrap charge fraction (α) of 0.35 is used as a reasonable assumption in the model, which was vetted by our ABS sheet mill industrial collaborator.

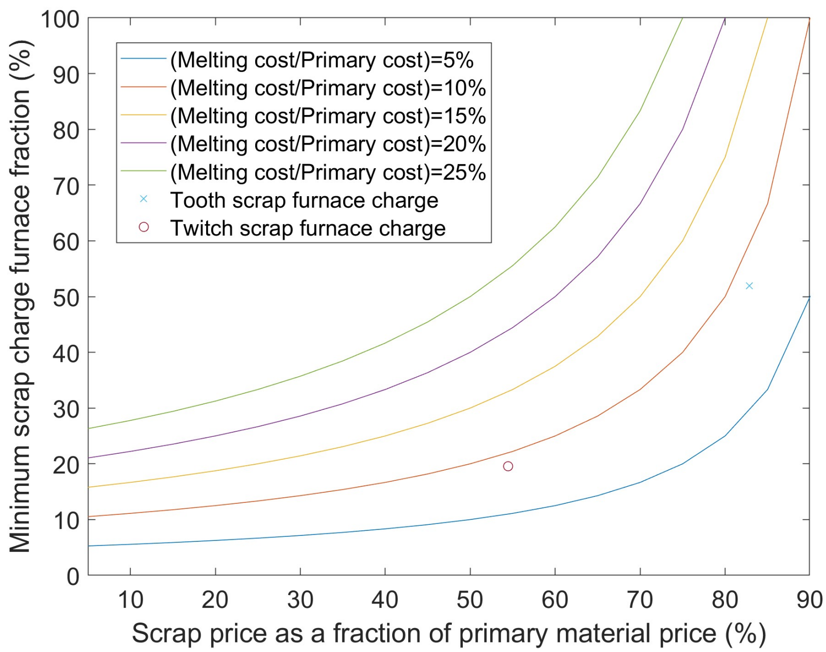

Figure S1. Minimum fraction of scrap charge in secondary furnace (α) required for economically viable recycling