Comparative Life Cycle Assessment of Glass Collection and Recycling

Materials Management

December 15, 2022
Updated from Materials List Technical Workgroup Meeting #4

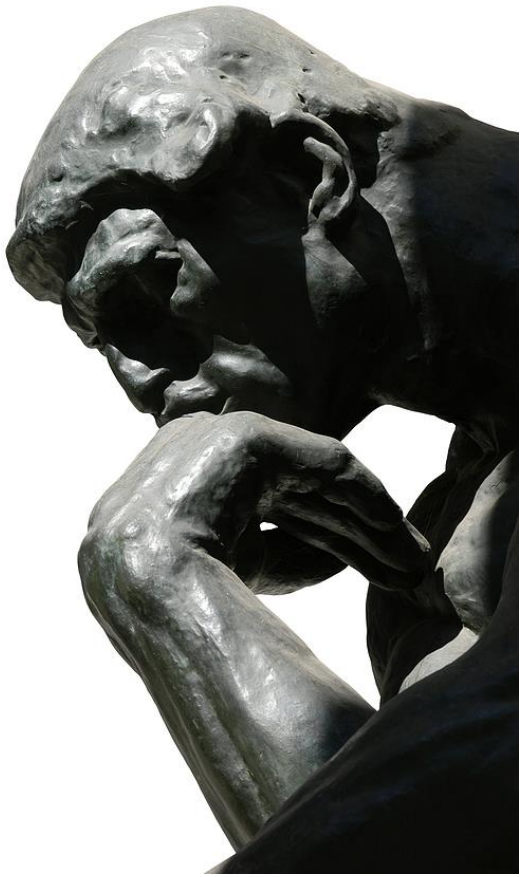
Agenda

- Goal and Scope
- Results
- Interpretation and Limitations

Goal and Scope

Project Goals/Objectives

- Using Comparative Life Cycle Assessment
  - Quantify the environmental impacts of different end of life management scenarios and end markets for container glass to identify trade-offs and key variables.



Scope – Functional (Declared) Unit

- **Function:** Disposition of container glass through different mechanical recycling pathways
- **Magnitude/unit:** 1 us ton (short ton)

Scope – Key Variables Evaluated

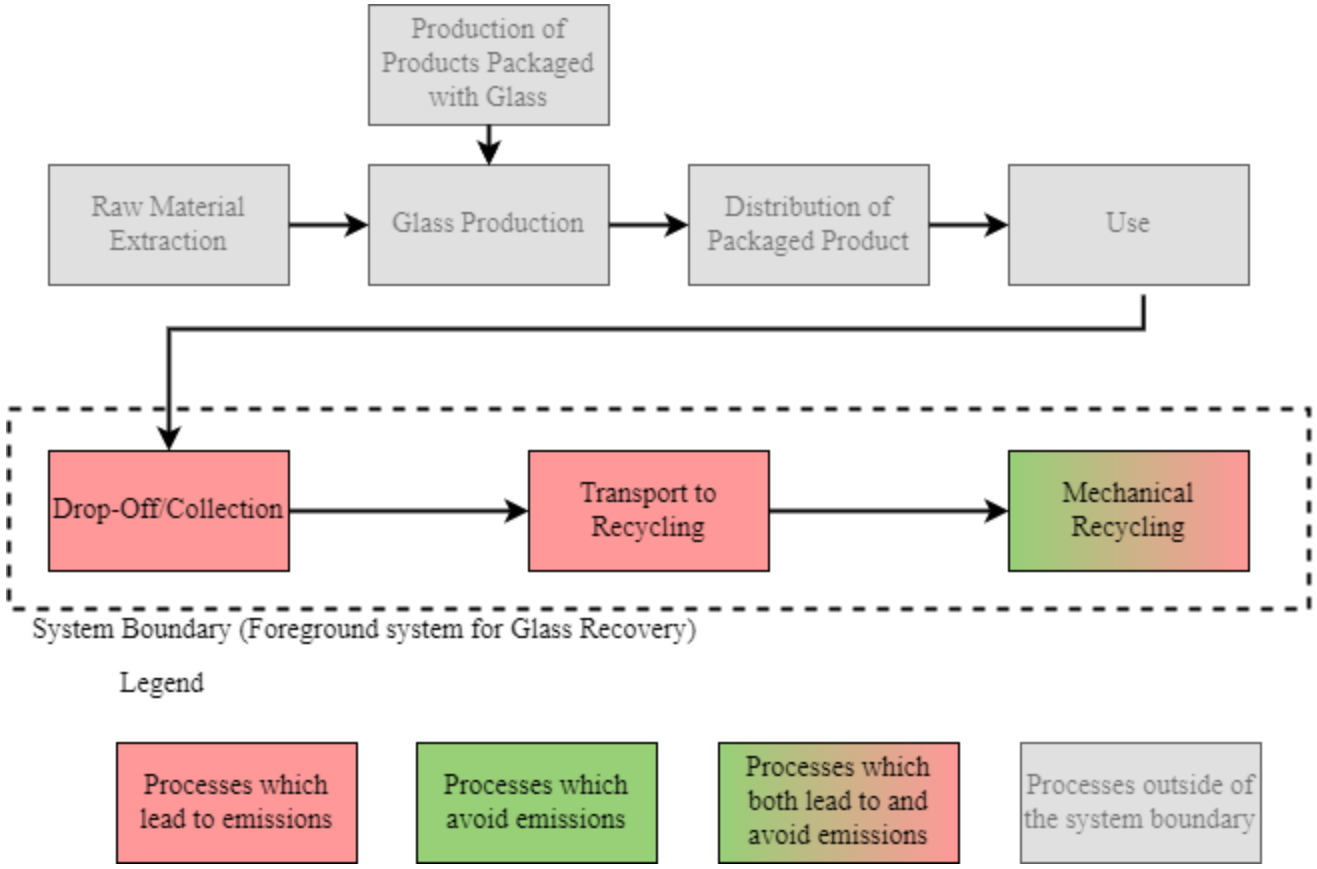
- Collection
  - Marginal vs Additional Drop-Off vs On Route Collection
  - Distinguish between Metro and Rest of State for all scenarios
  - Distinguish between lower and higher site density for drop-off scenarios
  - Distinguish between glass only and dual-compartment (glass + comingled) trucks for on-route scenarios
- End Markets for Mechanical Recycling or dispoisitions
  - Local Bottle Plant (Owens Brockway, Portland, OR*)
  - Distant Bottle Plant (Owens Brockway, Tracy, CA)
  - Fiberglass (Owens Corning, Santa Clara, CA)
  - Ground Glass Pozzolan (Hypothetical Plant in Vancouver, WA)
  - Mechanical Recycling to Aggregate (Oregon Generic)
  - Landfilling

Glass Scenarios Evaluated

Scenario	Collection*	Drop-Off Site Density	Region	Source Type	Disposition	End Markets
S1	On Route (Combined)	n/a	Metro	Residential	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S2	On Route (Combined)	n/a	Rest of State	Residential	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S3	On Route (Dedicated)	n/a	Metro	Residential	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S4	On Route (Dedicated)	n/a	Rest of State	Residential	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S5	On Route (Dedicated)	n/a	Metro	Commercial	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S6	On Route (Dedicated)	n/a	Rest of State	Commercial	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S7	Drop-Off (Additional)	Low	Metro	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S8	Drop-Off (Marginal)	Low	Metro	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S9	Drop-Off (Additional)	Low	Rest of State	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S10	Drop-Off (Marginal)	Low	Rest of State	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S11	Drop-Off (Additional)	High	Metro	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S12	Drop-Off (Marginal)	High	Metro	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S13	Drop-Off (Additional)	High	Rest of State	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S14	Drop-Off (Marginal)	High	Rest of State	Unspecified	Mechanical Recycling	Glass to Glass, Fiberglass, Pozzolan or Aggregate
S15	On Route	n/a	Rest of State	Residential	Landfill	n/a
S16	On Route	n/a	Metro	Residential	Landfill	n/a

*On-route (combined) = a single truck with two compartments, that picks-up both comingled recyclables and glass at the same time. On-Route (dedicated) = a glass only truck, no comingled recyclables. Drop-Off (Additional) = user behavior where an additional, dedicated trip, is taken to drop-off recyclables. Drop-Off (Marginal) = user behavior where recyclables are dropped-off as part of another trip (e.g. on the way to the grocery store).

Scope – System Boundary



Scope – System Boundary

- **Temporal Coverage** – 2016-2022
- **Geographical Coverage** – Oregon
- **Technological Coverage** – This study is intended to represent materials management options for container glass, the foreground system covers technology and processes related to transportation of glass to central locations or collection depots, transport to end markets, and mechanical recycling. Credits are based on substitution for three different materials – container glass, fiberglass, or ground glass pozzolan. The background system includes electricity, thermal energy, and energy carriers (e.g. fuels).

Scope – Data Sources

- Primary Data Sources
  - On-Route Collection – Multiple Haulers provided Transportation Distances for on-route collection
- Secondary Data Sources
  - Truck Emissions – diesel combustion from USLCI (US DOE)
  - Truck Fuel Efficiency – US EPA Smartway
  - Passenger Vehicle Emissions – GaBi Database
  - Mechanical Recycling – GaBi Database
  - Fuels (Diesel or Gasoline) – GaBi Database
  - Production Emissions for Displaced Materials (Primary glass production, fiberglass, and Portland Cement) – GaBi Database

Scope – Selected Impact Categories and Indicators

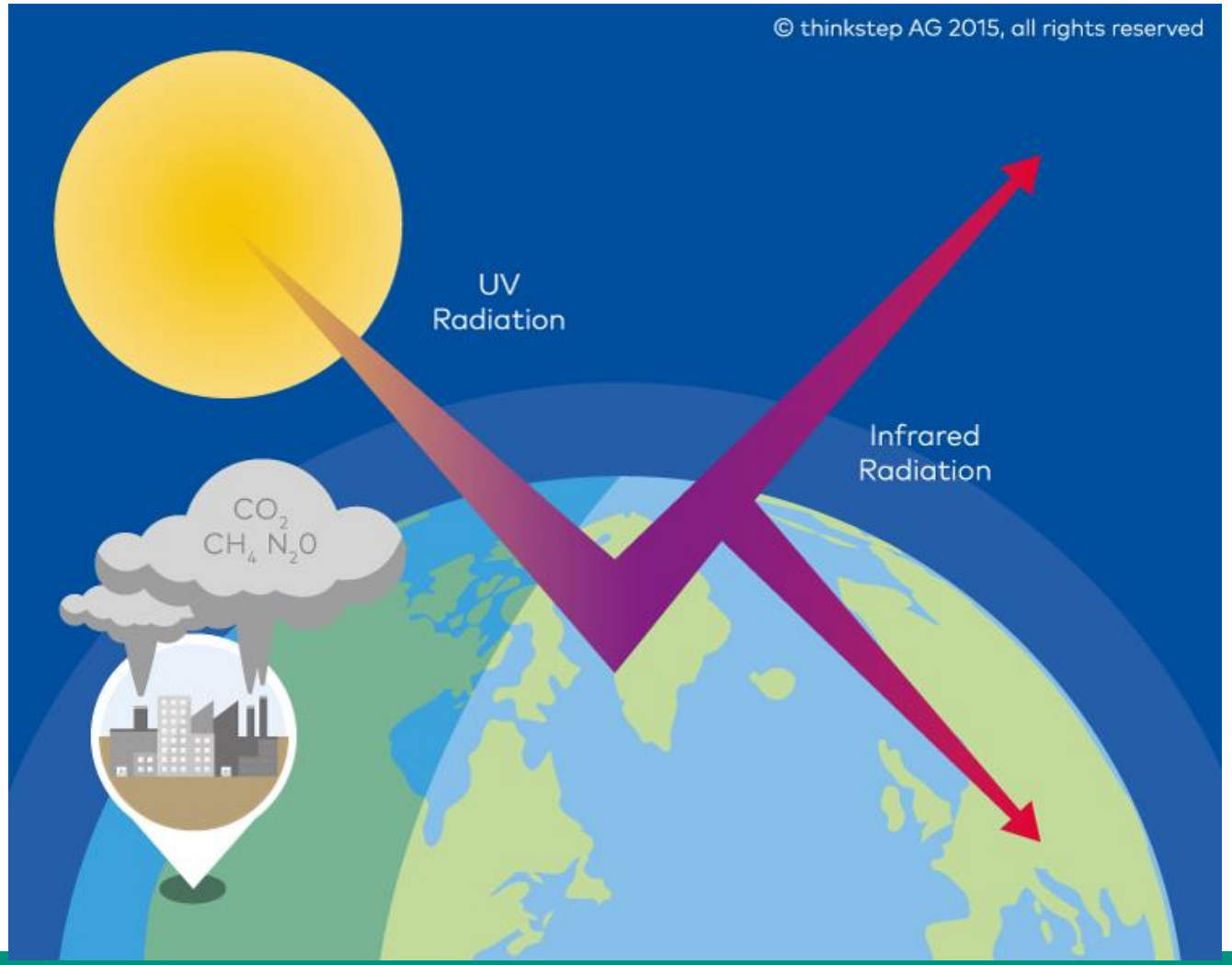
TRACI 2.1 LCIA Categories

- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Ecotoxicity (ETP)
- Global Warming Potential (GWP100)
- Particulate Matter (PM2.5) Potential
- Human Toxicity Potential (HTP) – Cancer
- Human Toxicity Potential (HTP) – NonCancer
- Ozone Depletion Potential (ODP)
- Smog Formation Potential (SFP)

Environmental Indicators

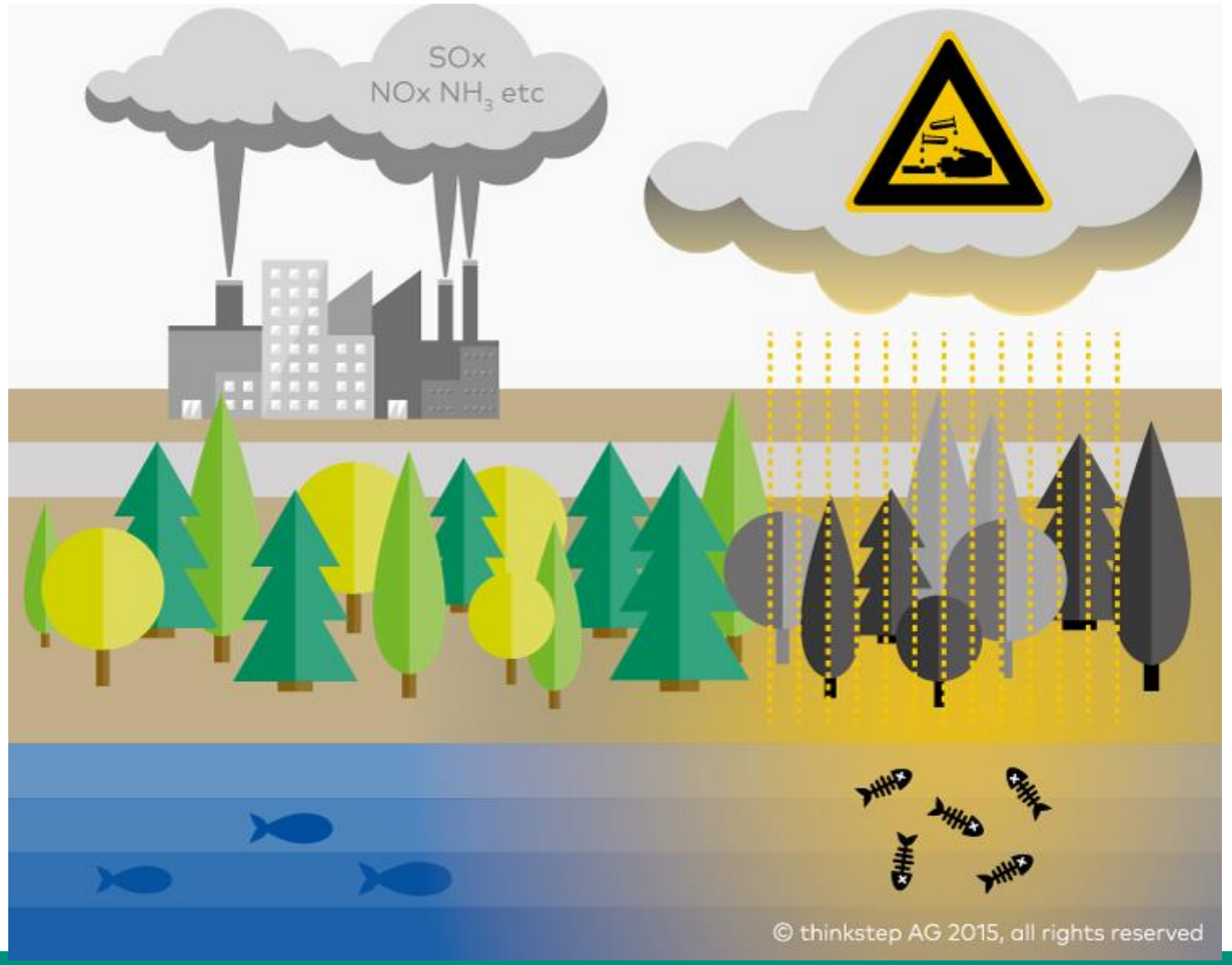
- Fossil Resource use
- Water Consumption
- Primary Energy Demand

Global Warming Potential



Source: thinkstep, used with permission

Acidification Potential



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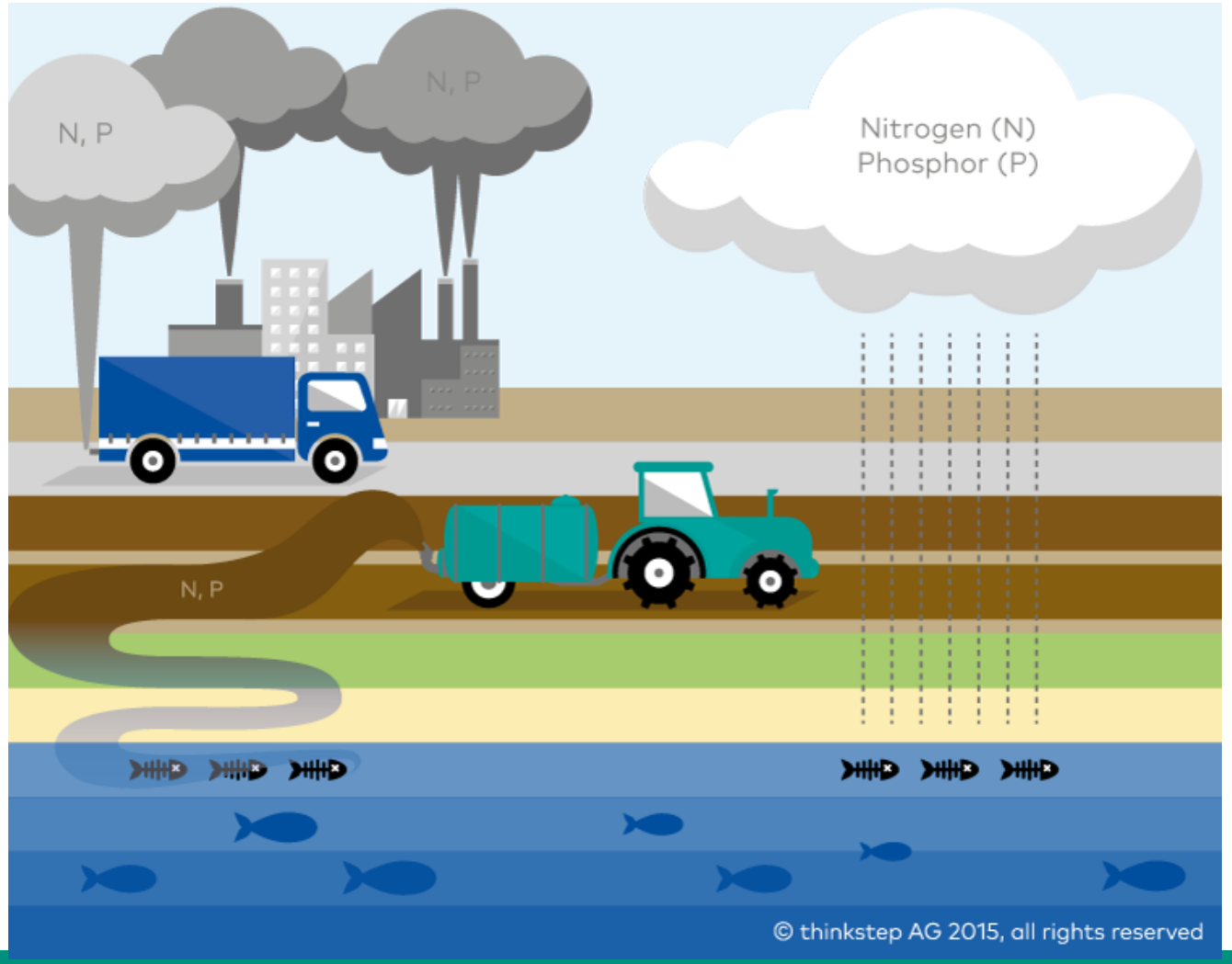
Eutrophication Potential

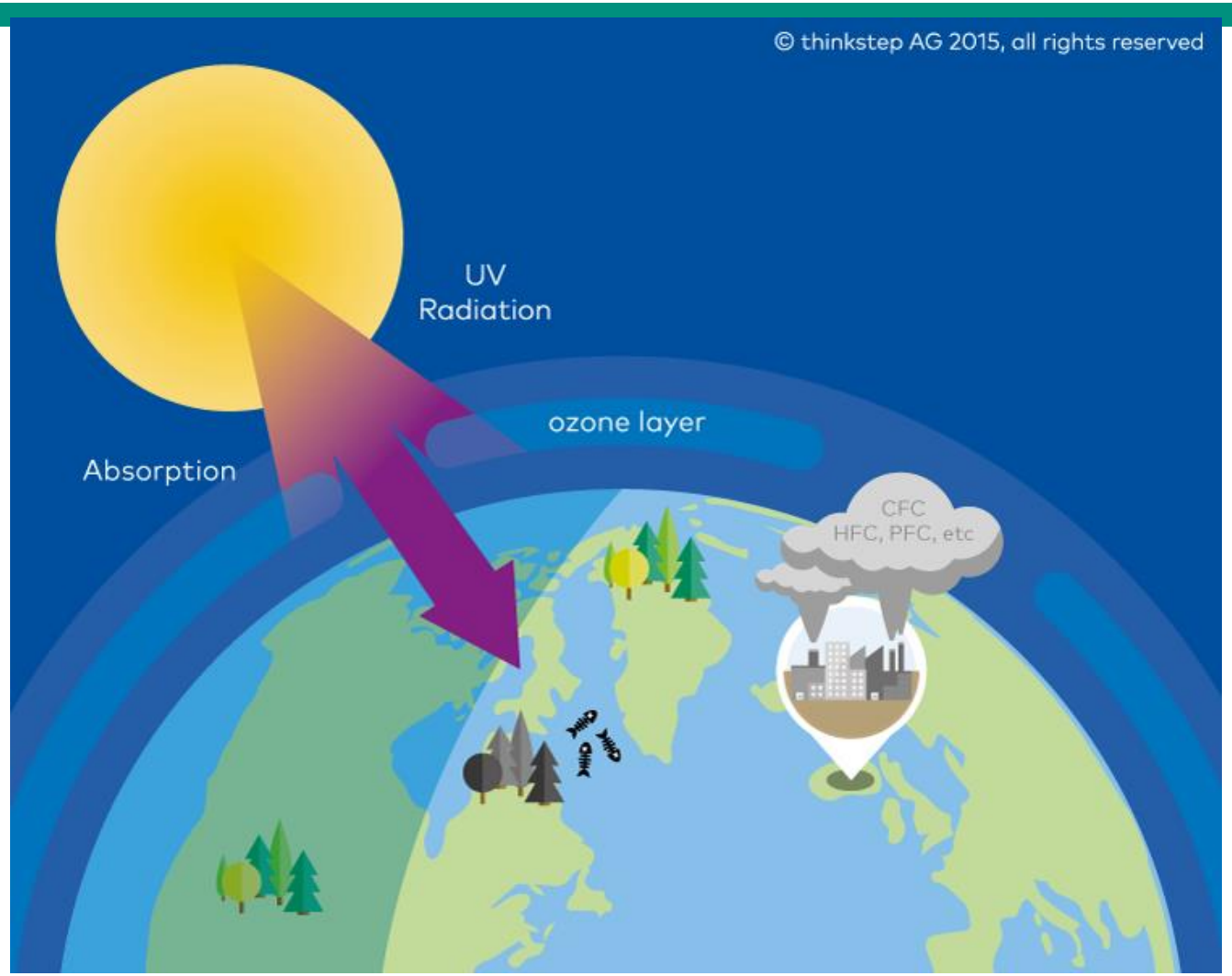


Source: thinkstep, used with permission

Smog Formation Potential

Source: thinkstep, used with permission

Ozone Depletion Potential



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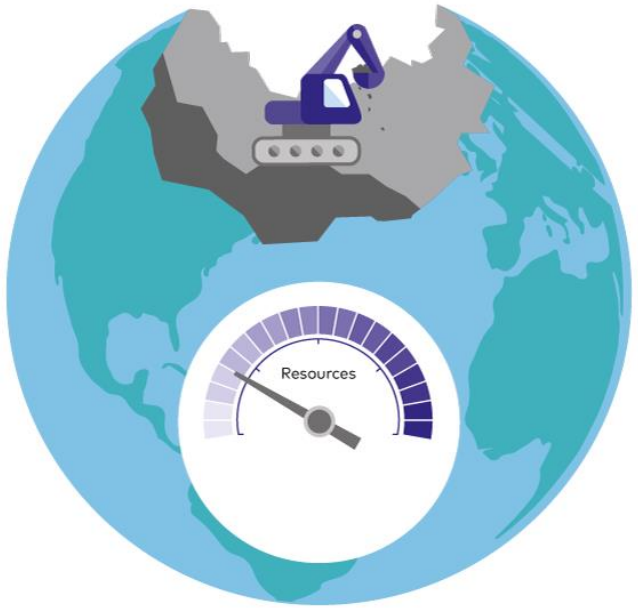
Primary Energy Demand



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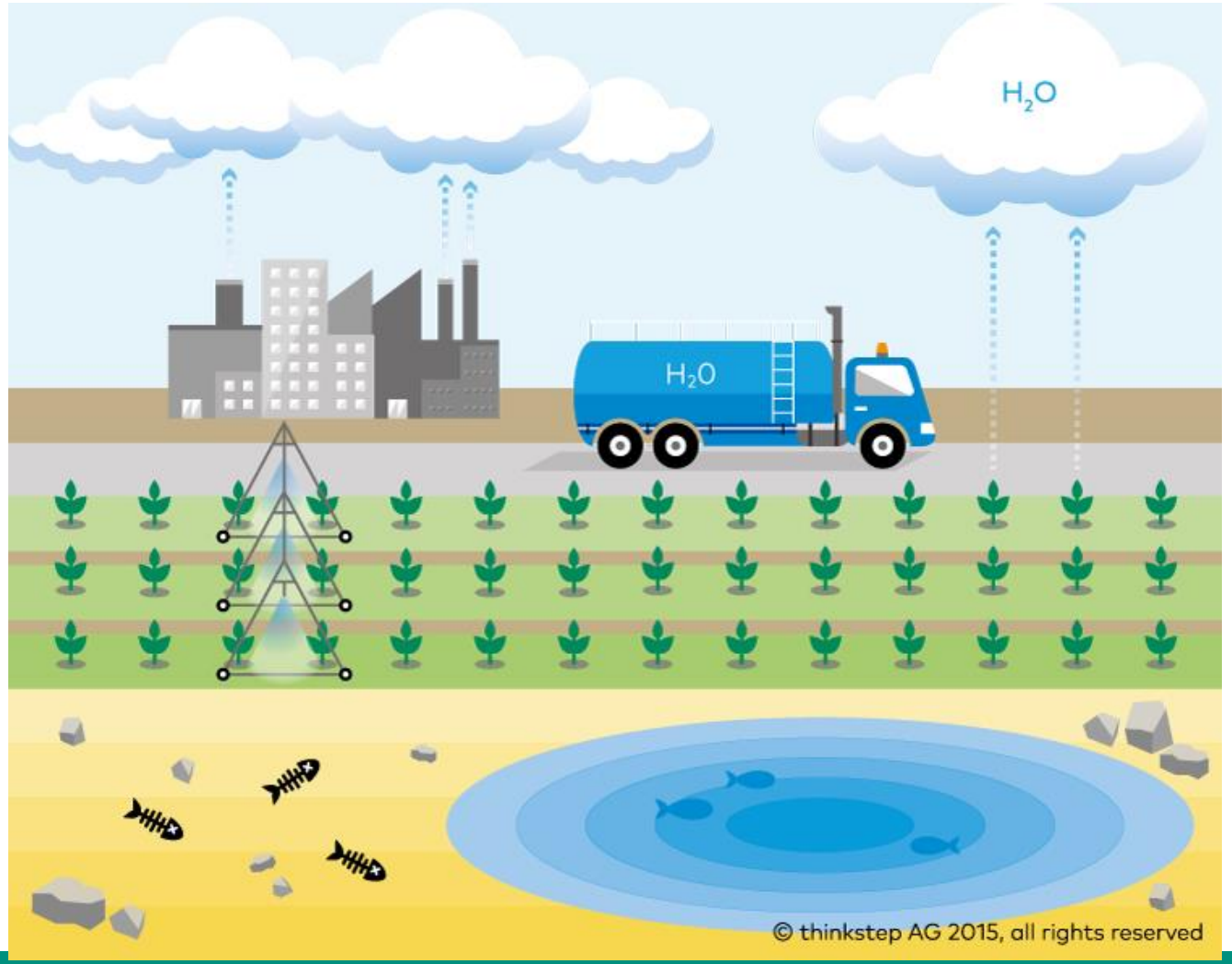
Source: thinkstep, used with permission and iStockphoto.com/DrAfter123

Freshwater Consumption



Source: thinkstep, used with permission

Revisions based on TWG Feedback

1. For transport to end market changed mode of transportation from class 8 truck to diesel-powered rail for M2 (glass to glass – distant end market) and M3 (glass to fiberglass)
2. Added 2 landfill scenarios (S15 and S16), one of which represents a local landfill and one a distant landfill
3. Added an additional end market (M5) to represent a scenario where the glass is recycled into aggregate
4. For the local glass to glass end market (M1) adjusted the transport to recycling distances to reflect a shift from Kalama plant to PDX plant for Owens Brockway

Preliminary Results

Life Cycle Impact Assessment (LCIA) and Indicators

Glass Scenarios Evaluated

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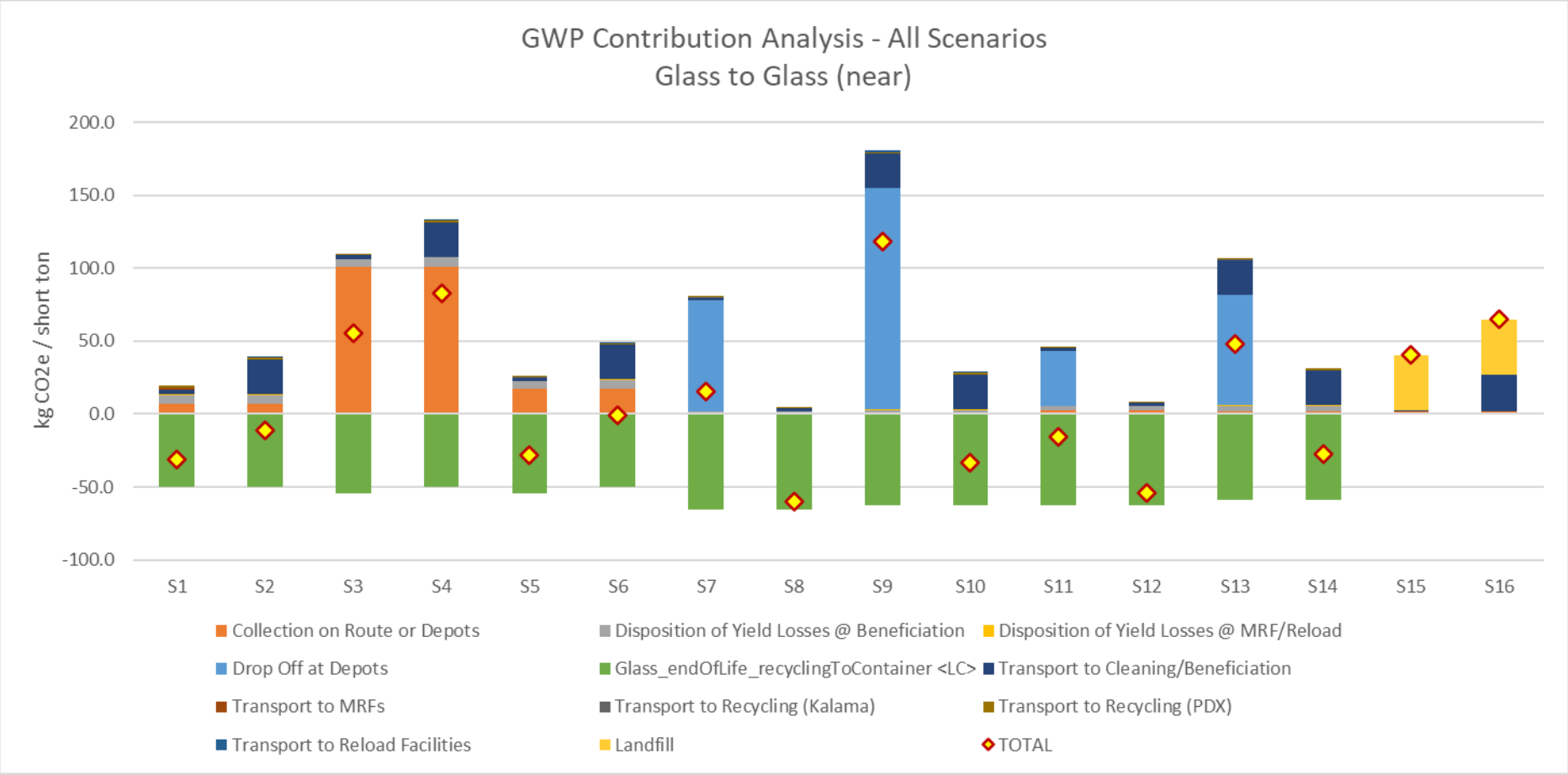
“Glass to Glass (Near)” Results

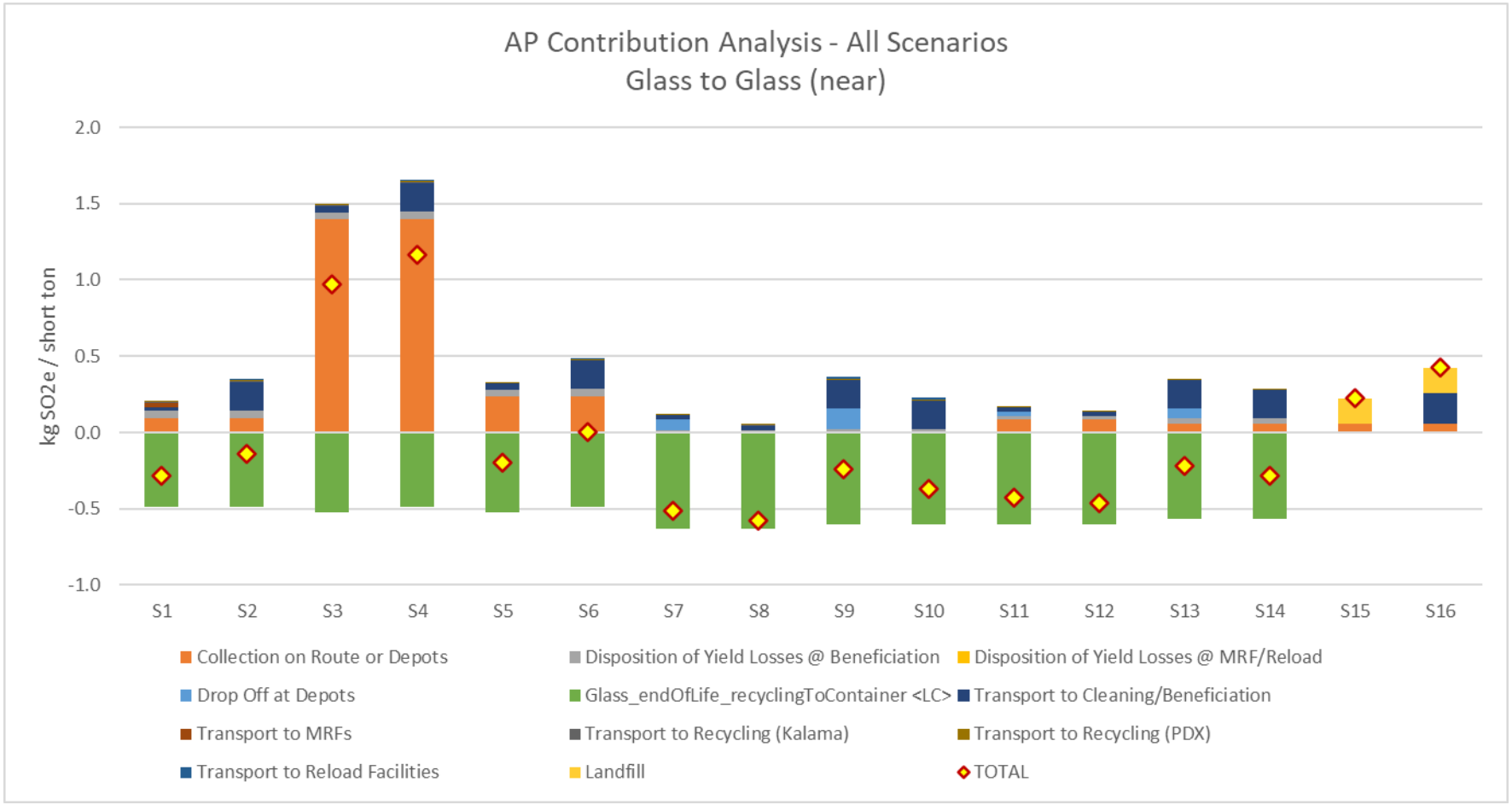
Owens Brockway

Portland, OR

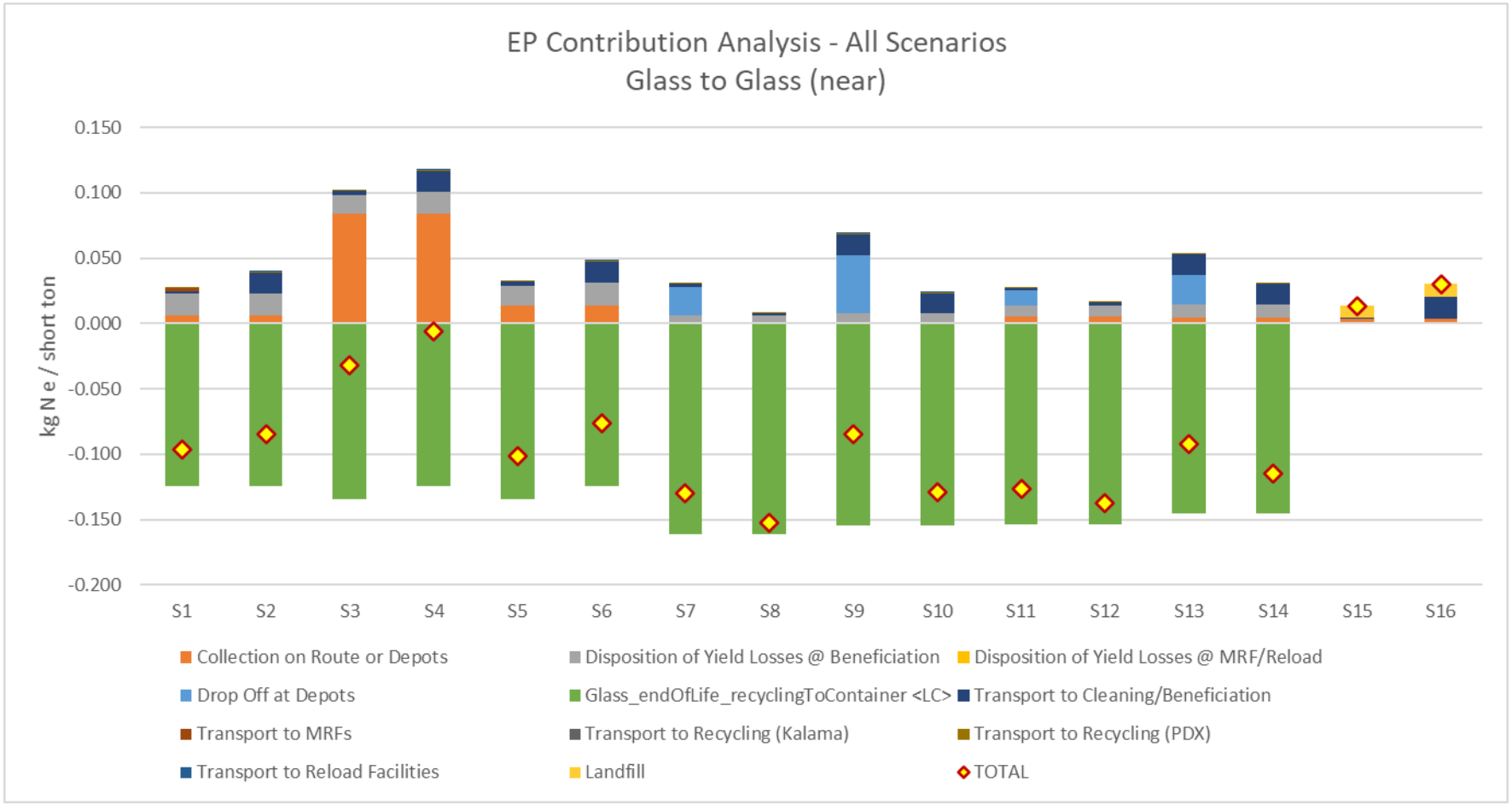
LCIA Results – Global Warming Potential (GWP)



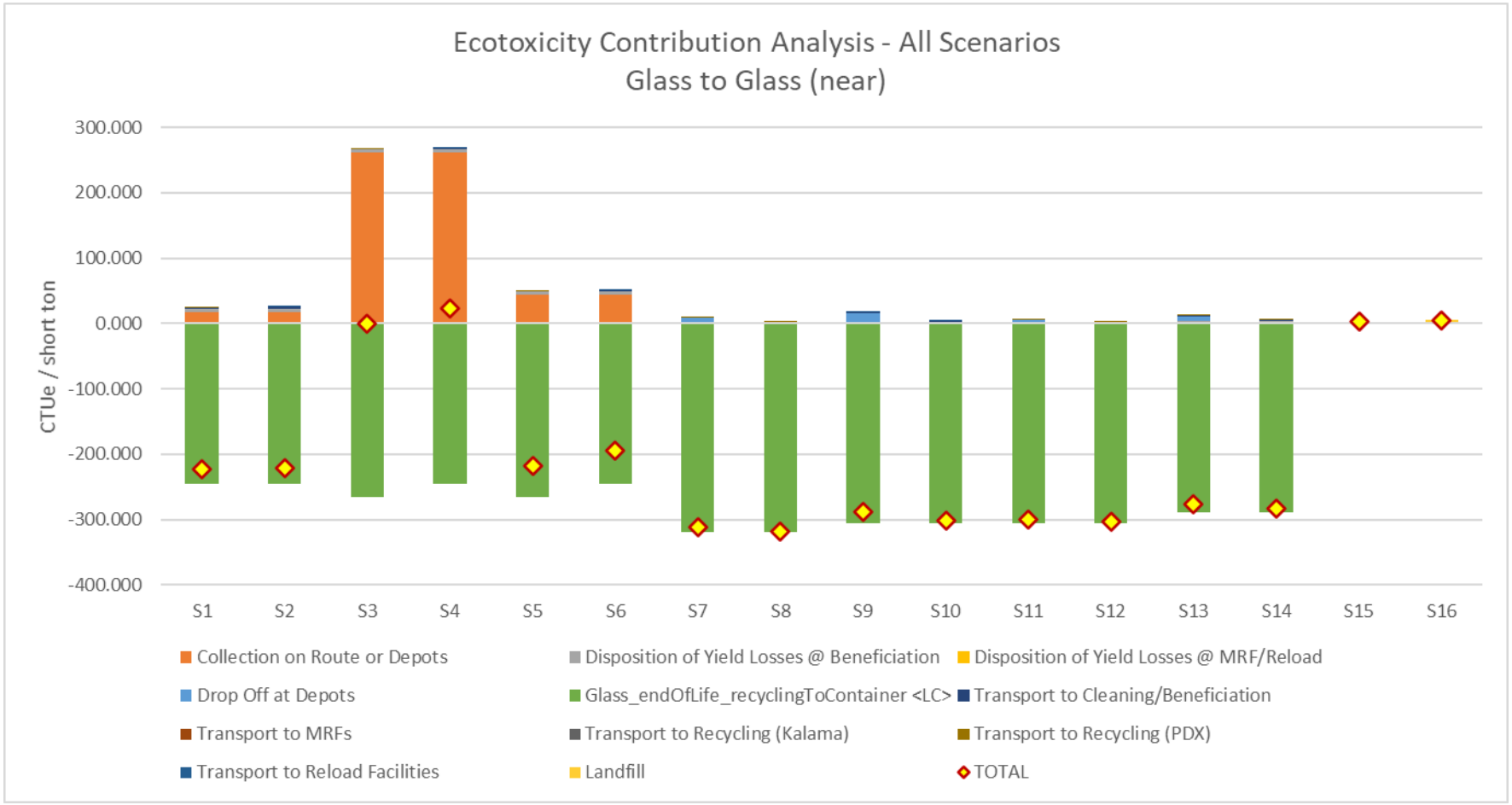
LCIA Results – Acidification Potential (AP)



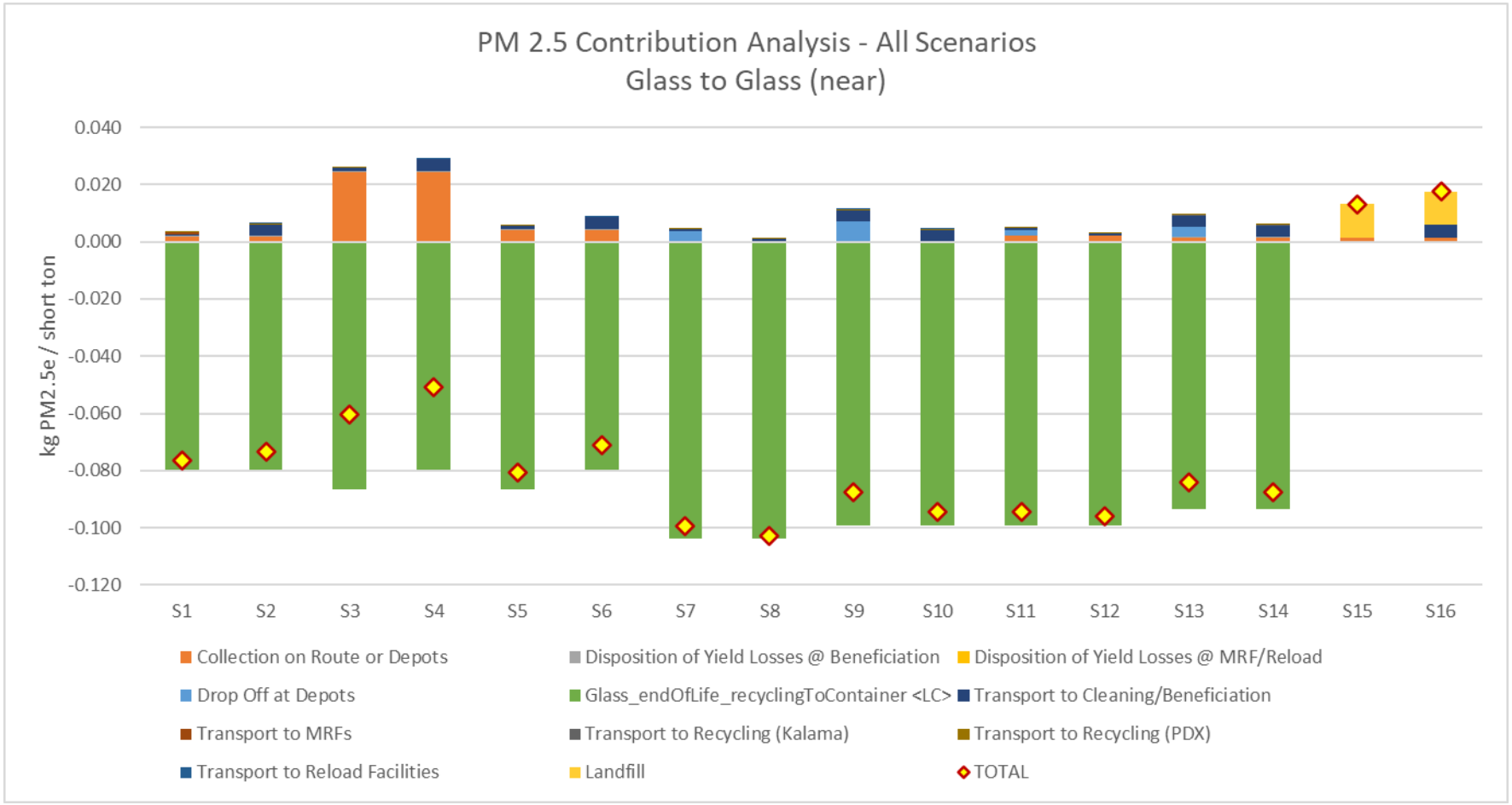
LCIA Results – Eutrophication Potential (EP)



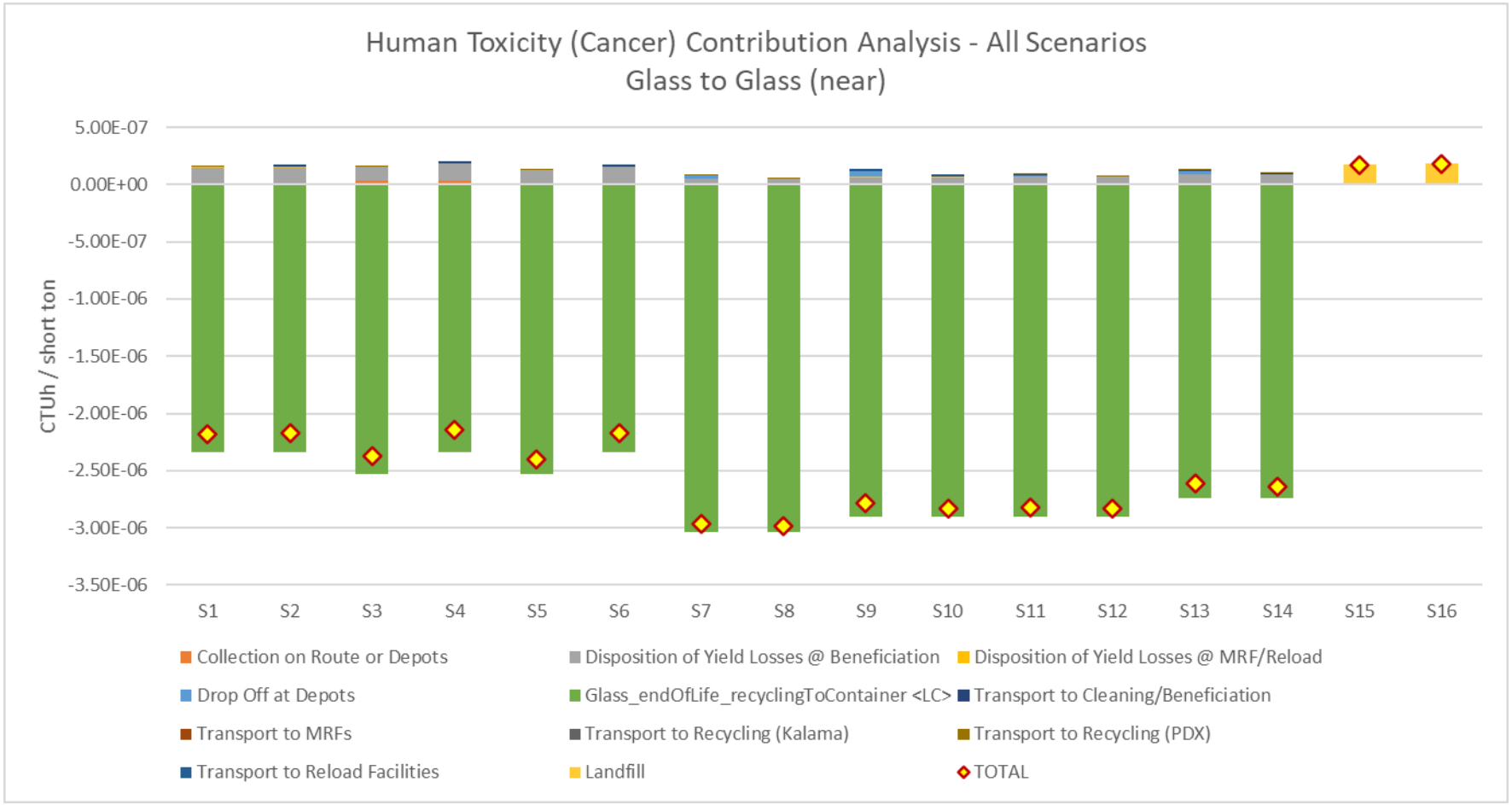
LCIA Results – Ecotoxicity Potential (ETP)



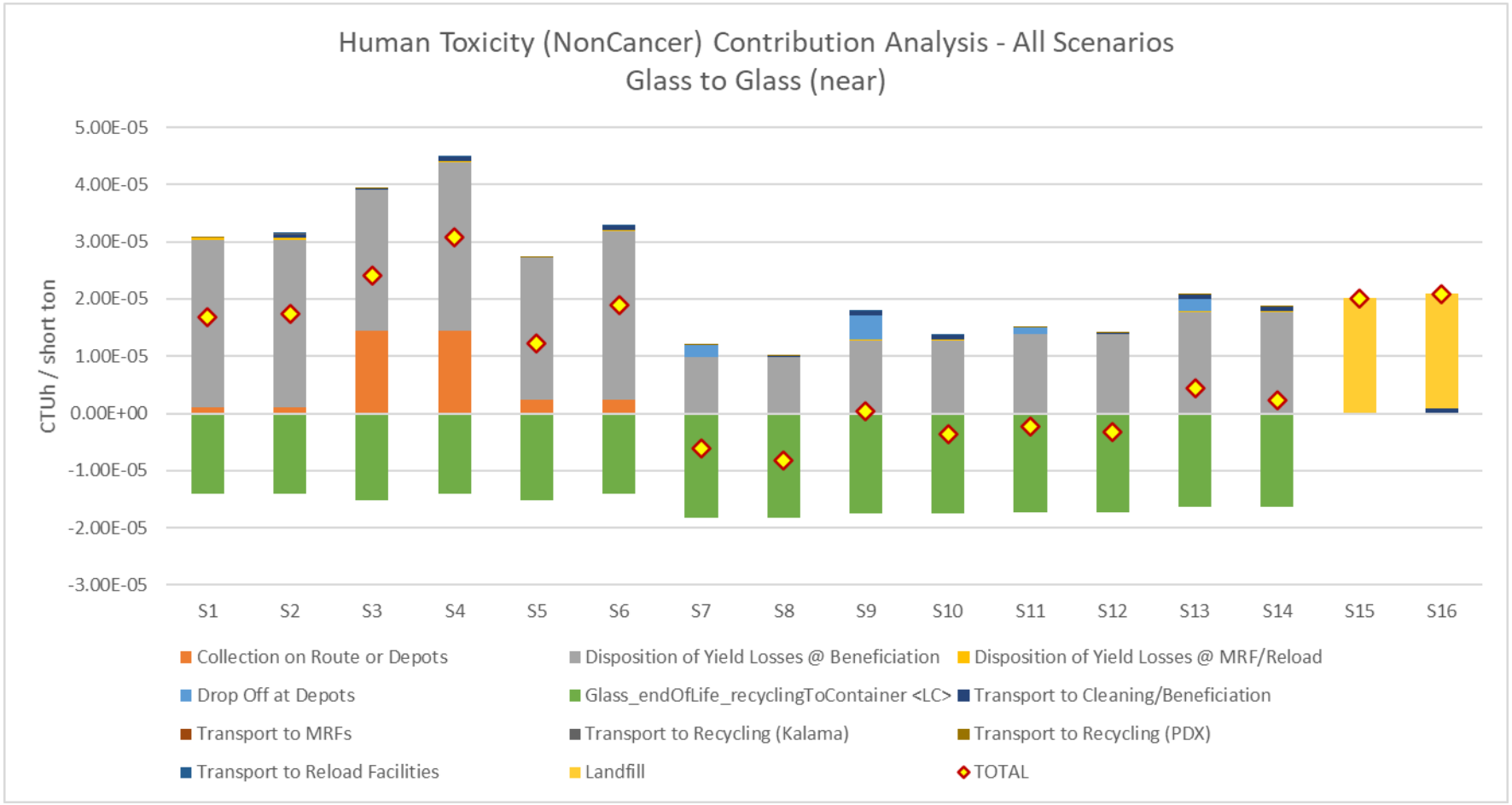
LCIA Results – Particulate Matter (PM 2.5)



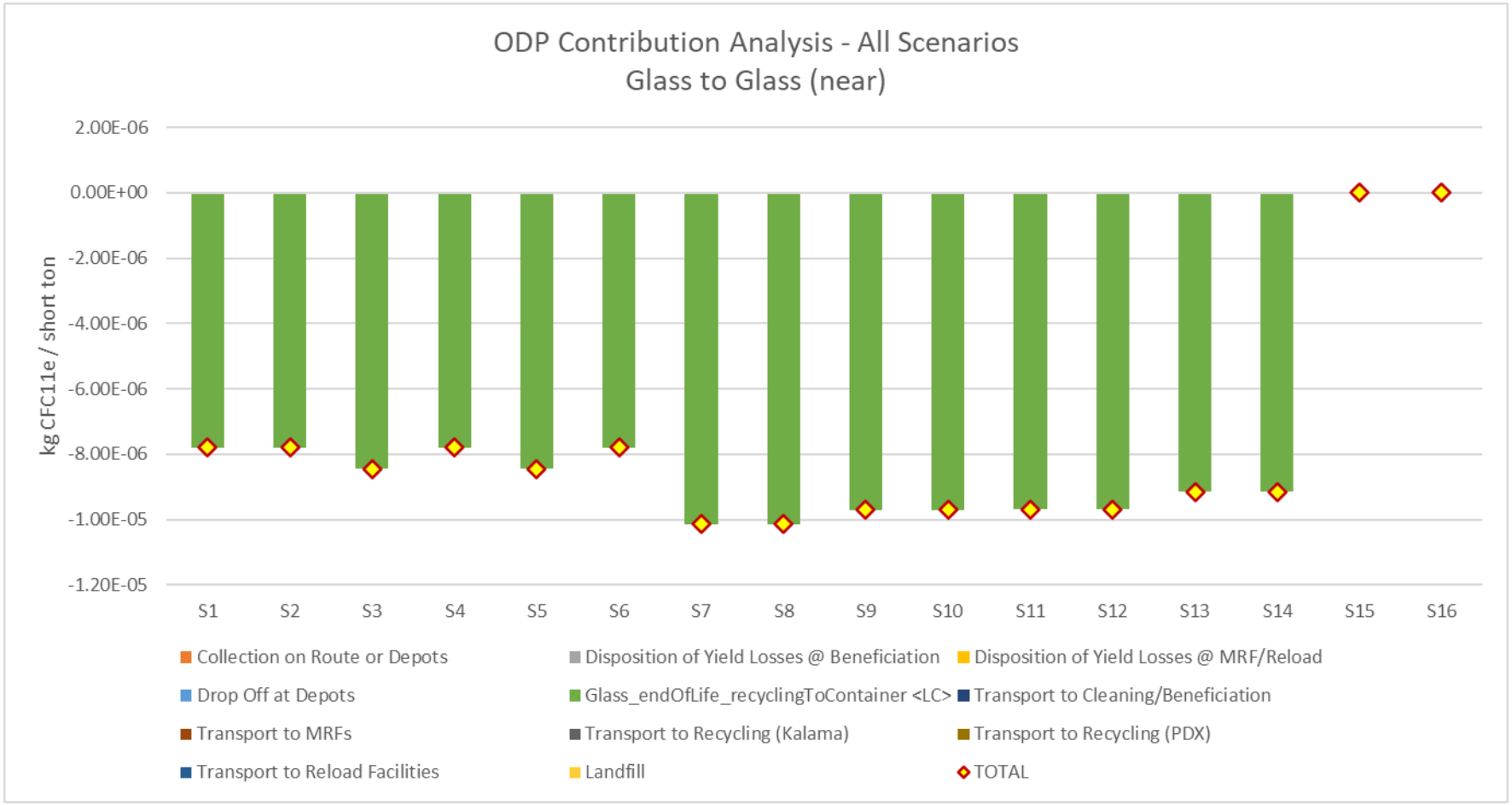
LCIA Results – Human Toxicity Potential (Cancer)



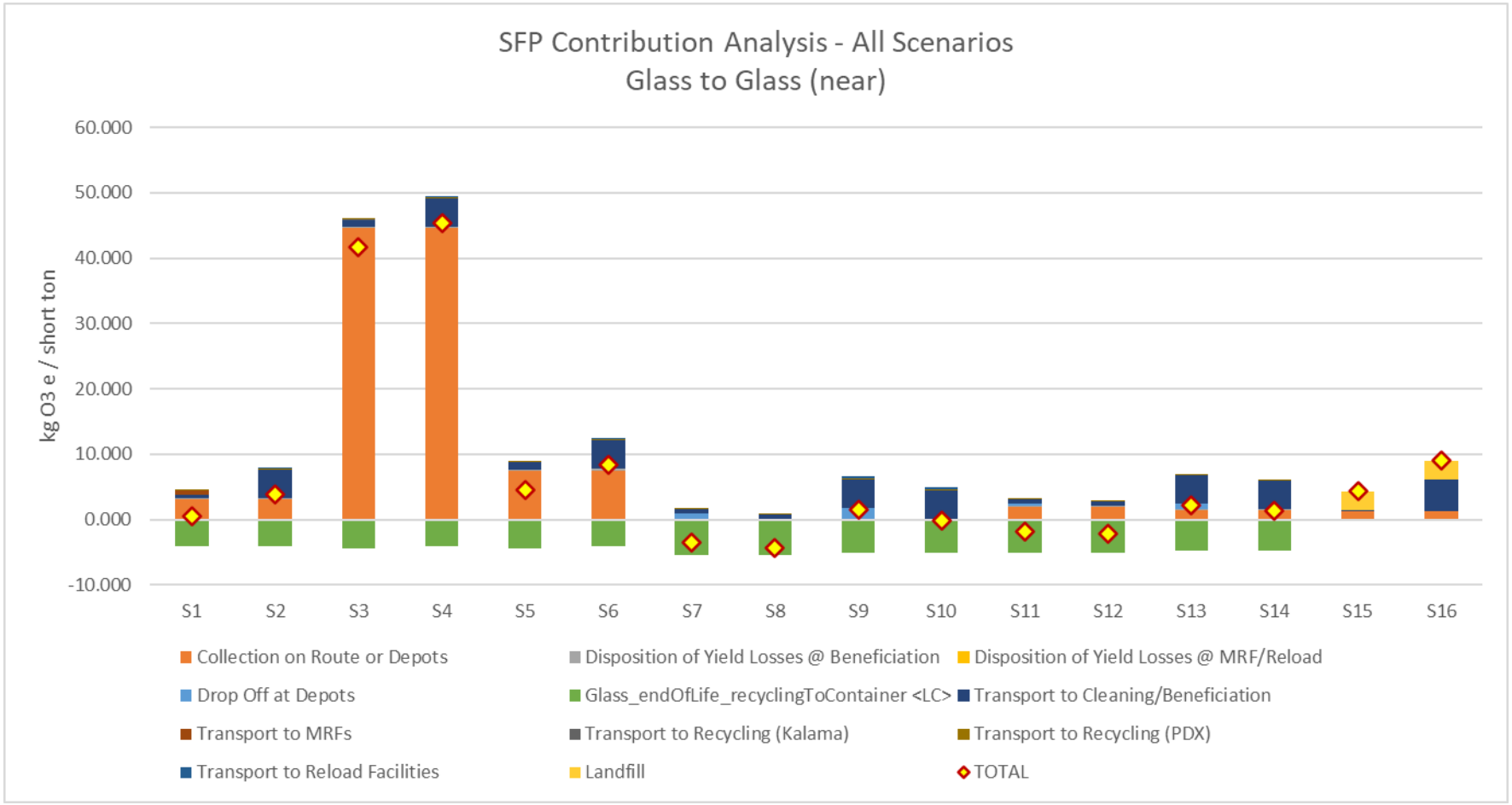
LCIA Results - Human Toxicity Potential (NonCancer)



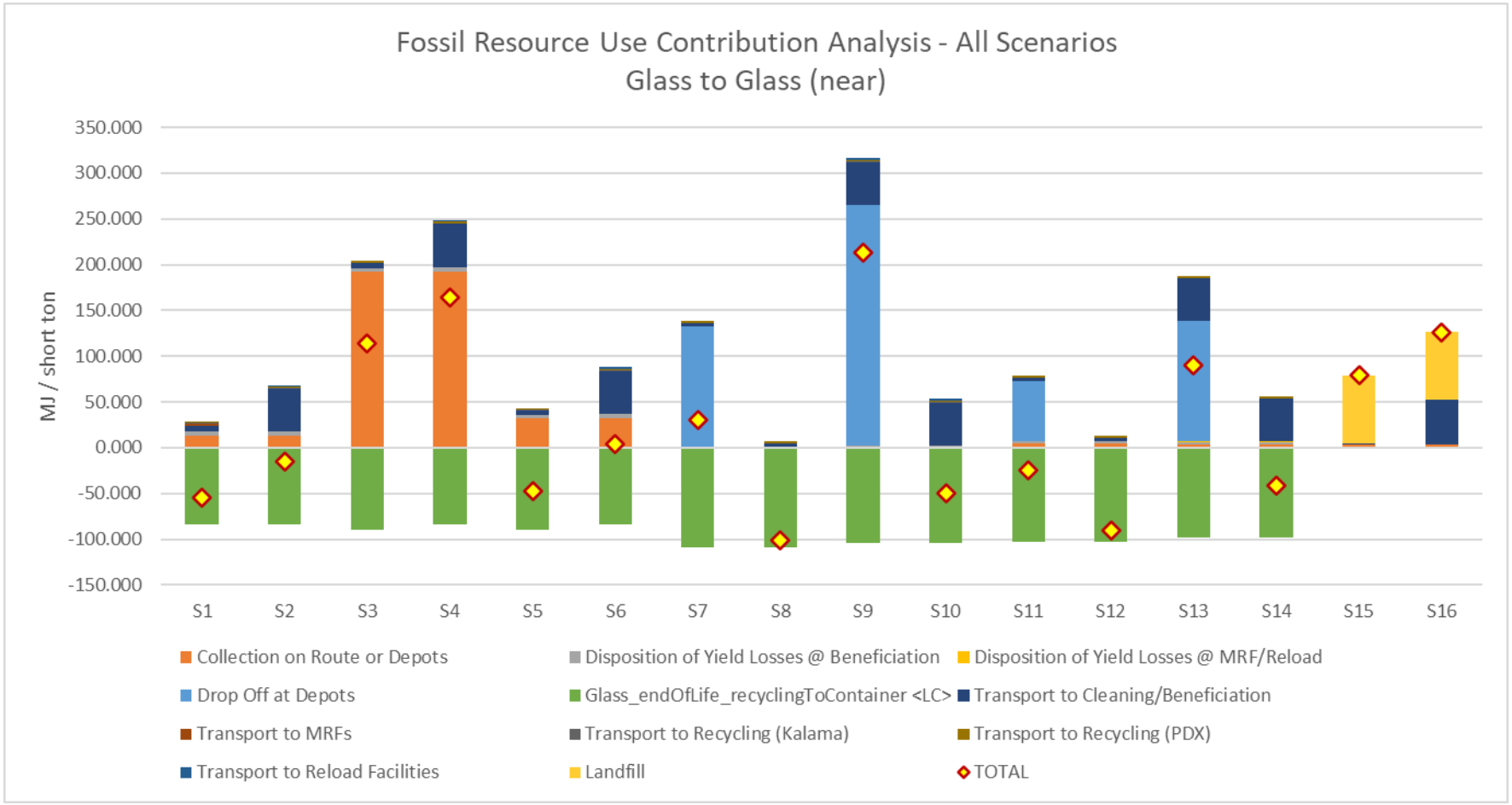
LCIA Results – Ozone Depletion Potential (ODP)



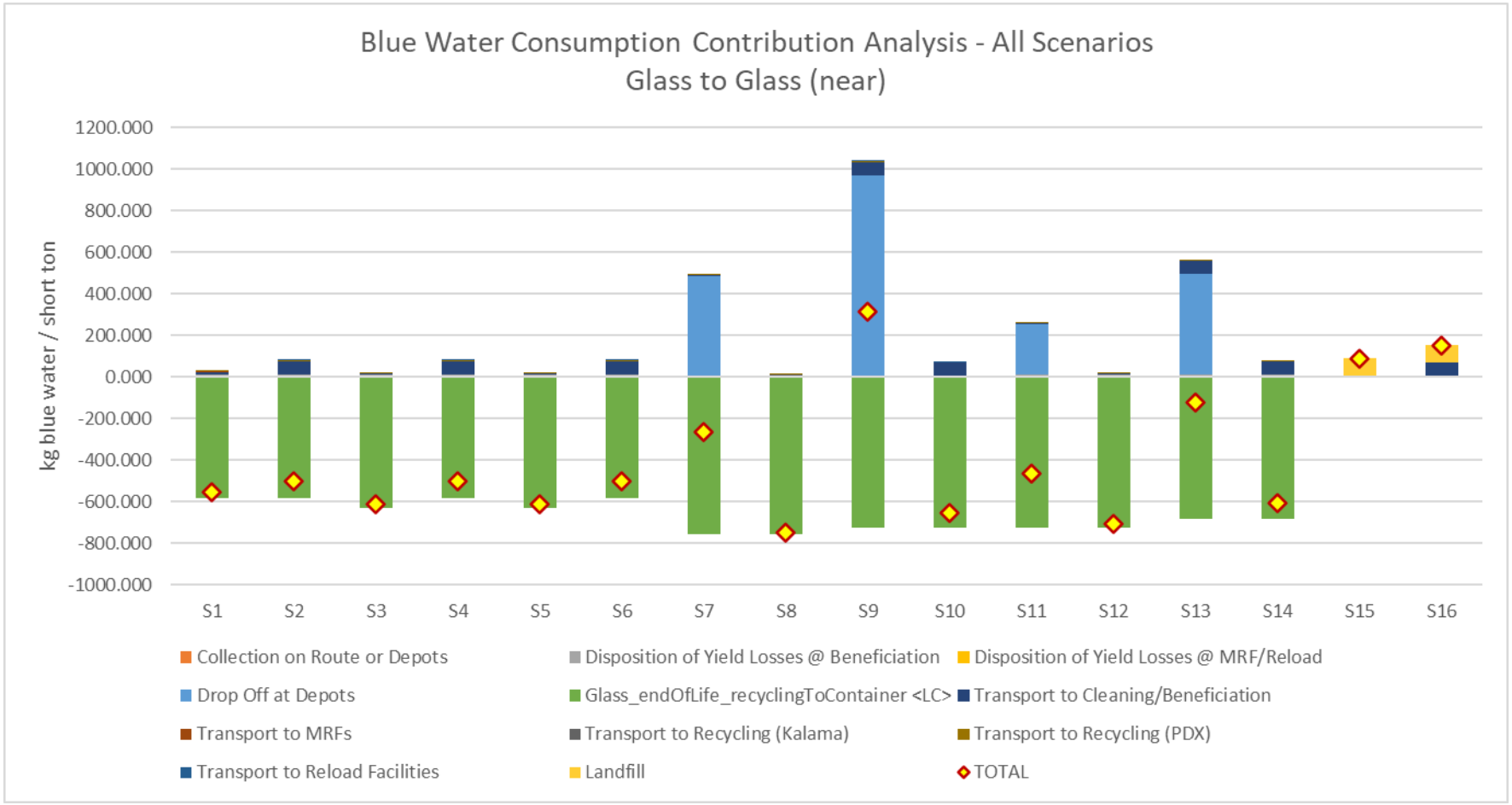
LCIA Results – Smog Formation Potential (SFP)



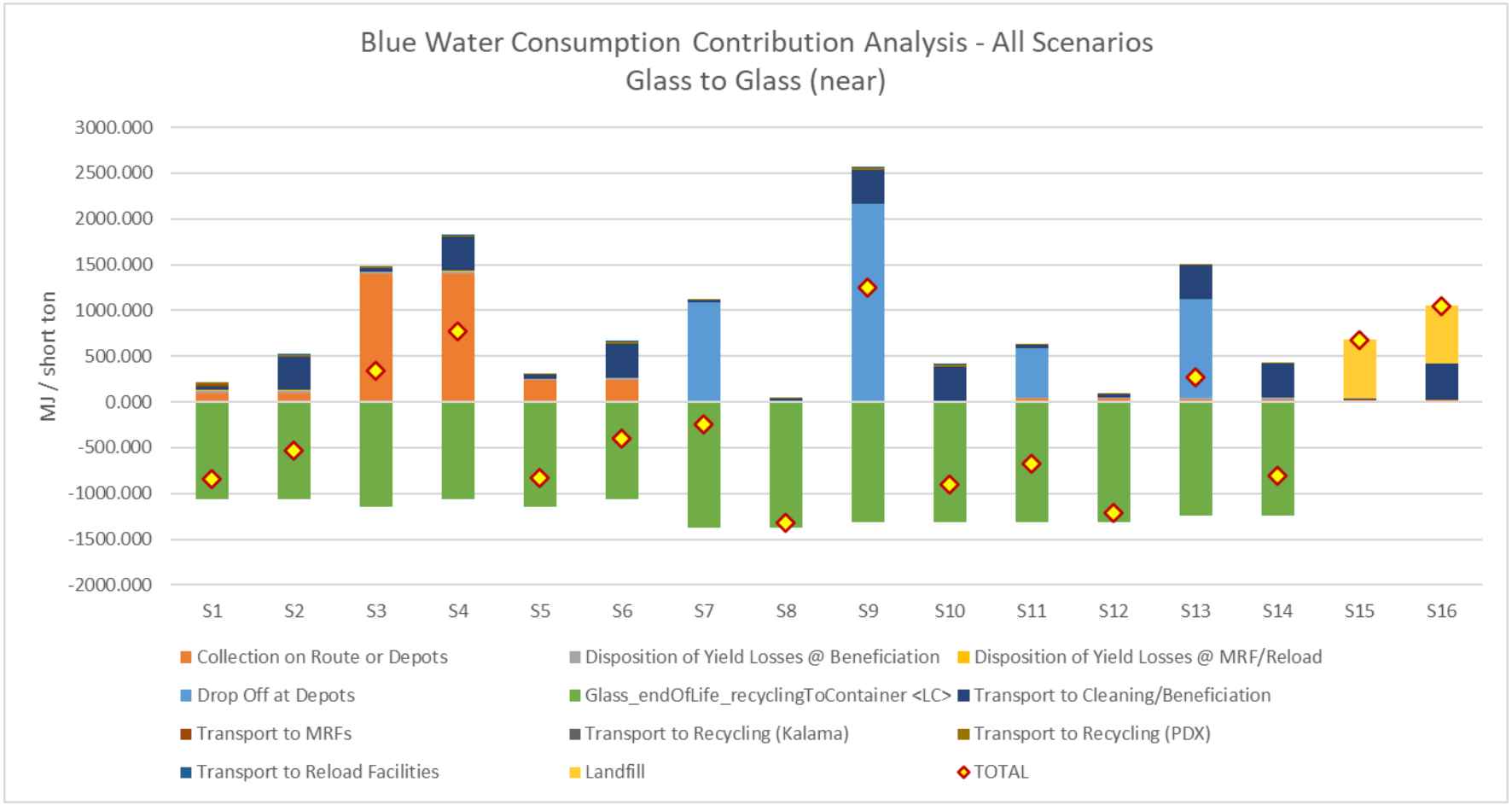
Indicator Results – Fossil Resource Use



Indicator Results – Bluewater Consumption



Indicator Results – Primary Energy Demand (PED)

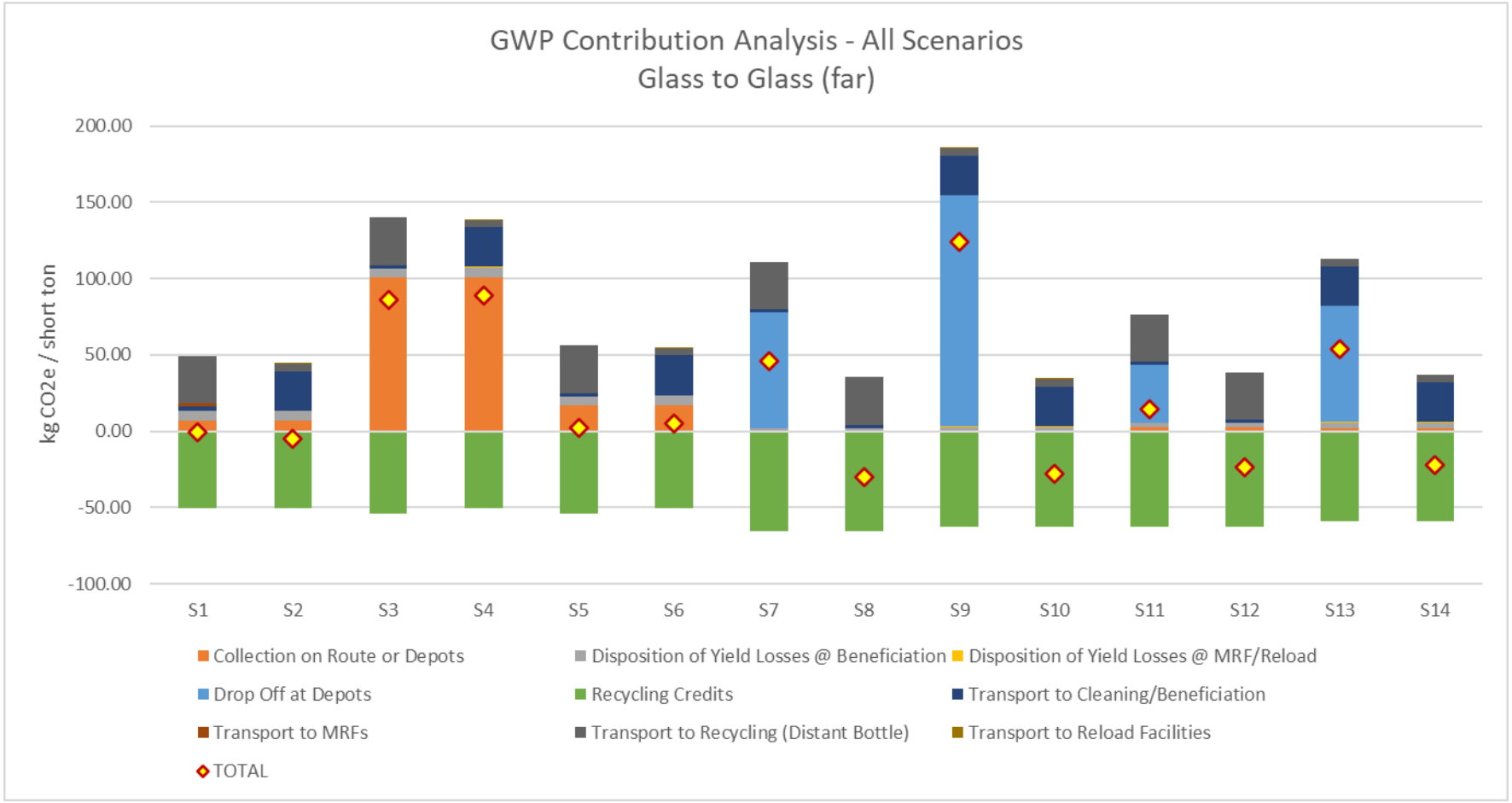


“Glass to Glass (Far)” Results

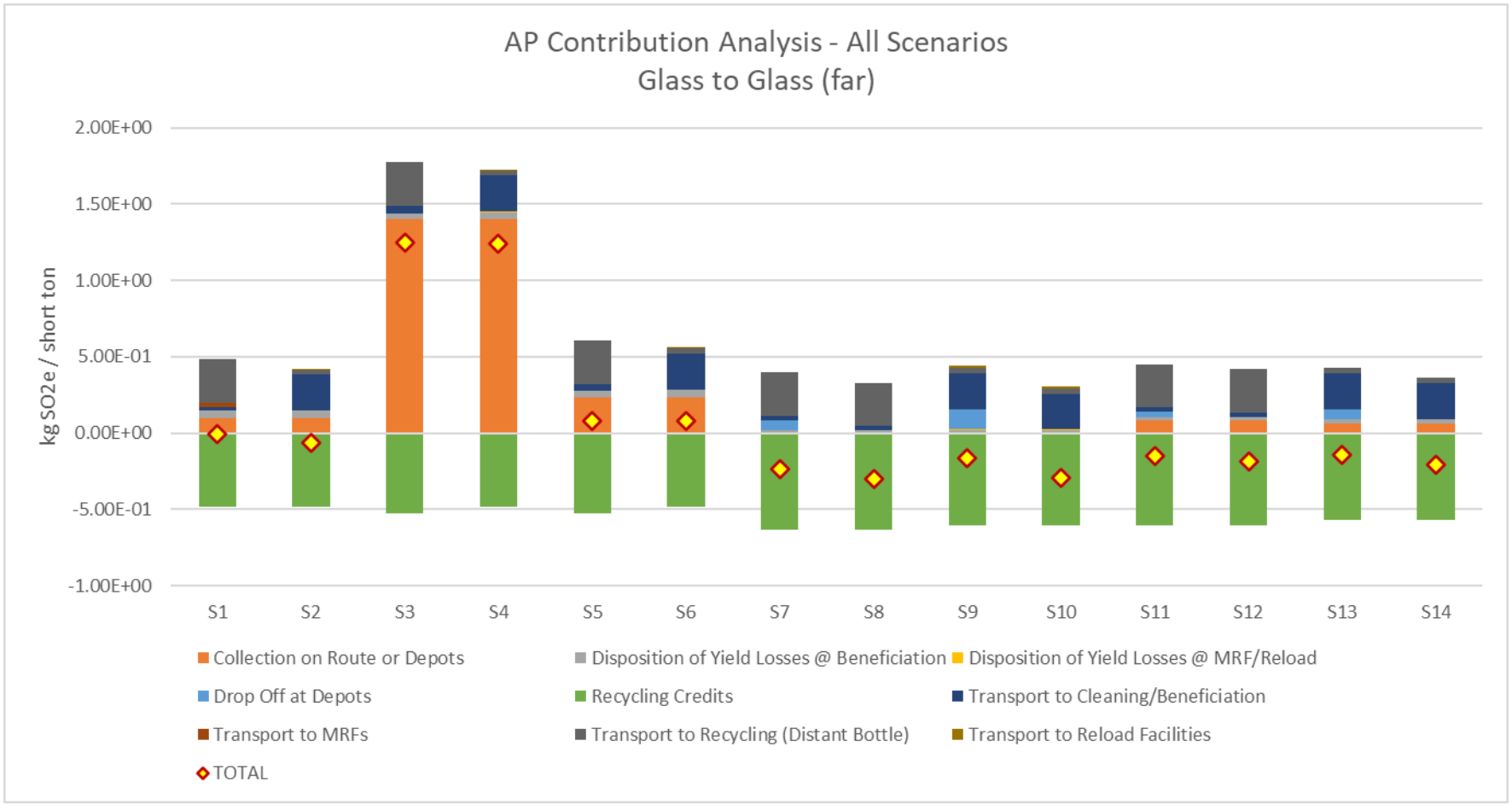
Owens Brockway

Tracy, CA

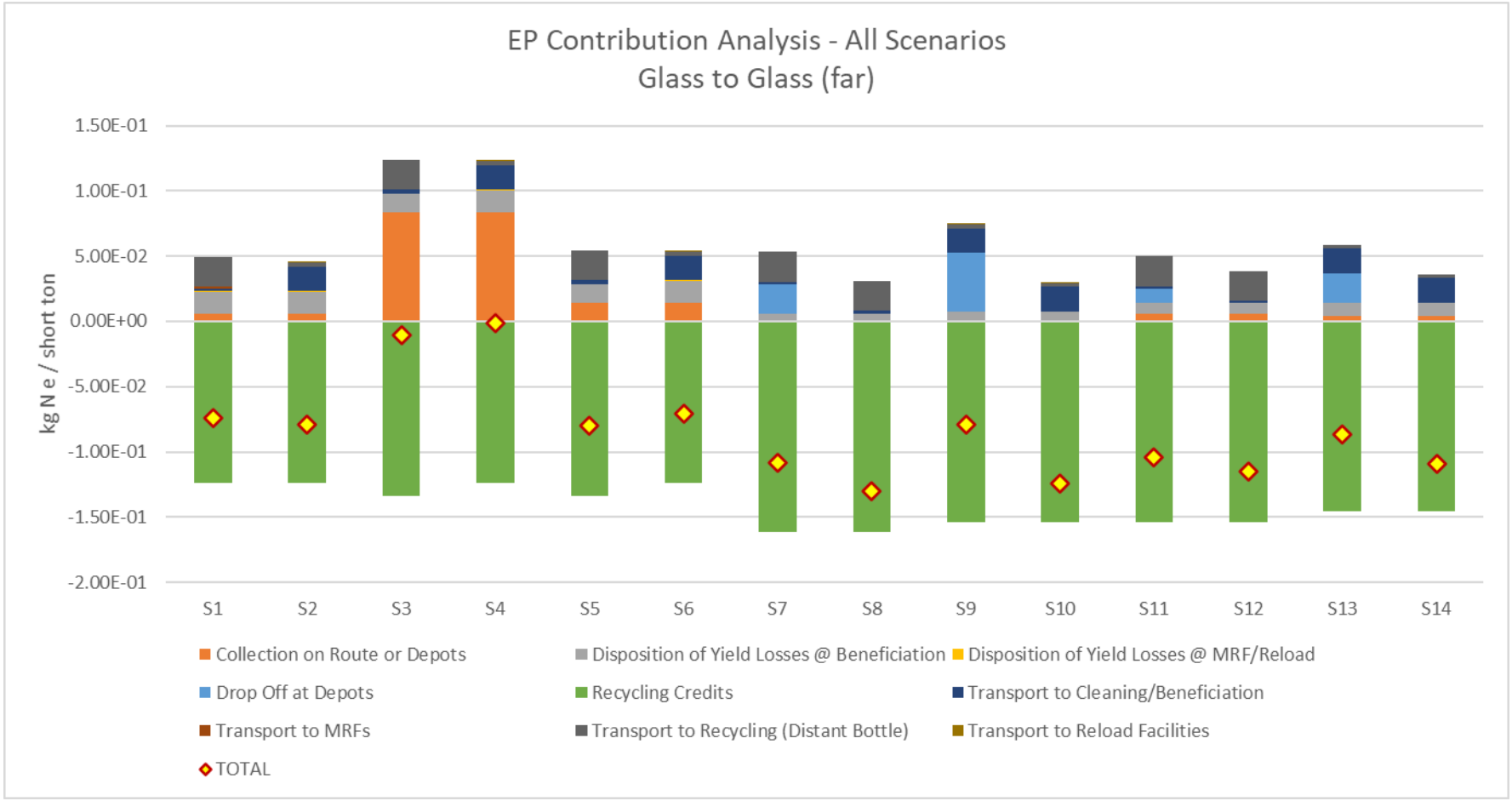
LCIA Results – Global Warming Potential (GWP)



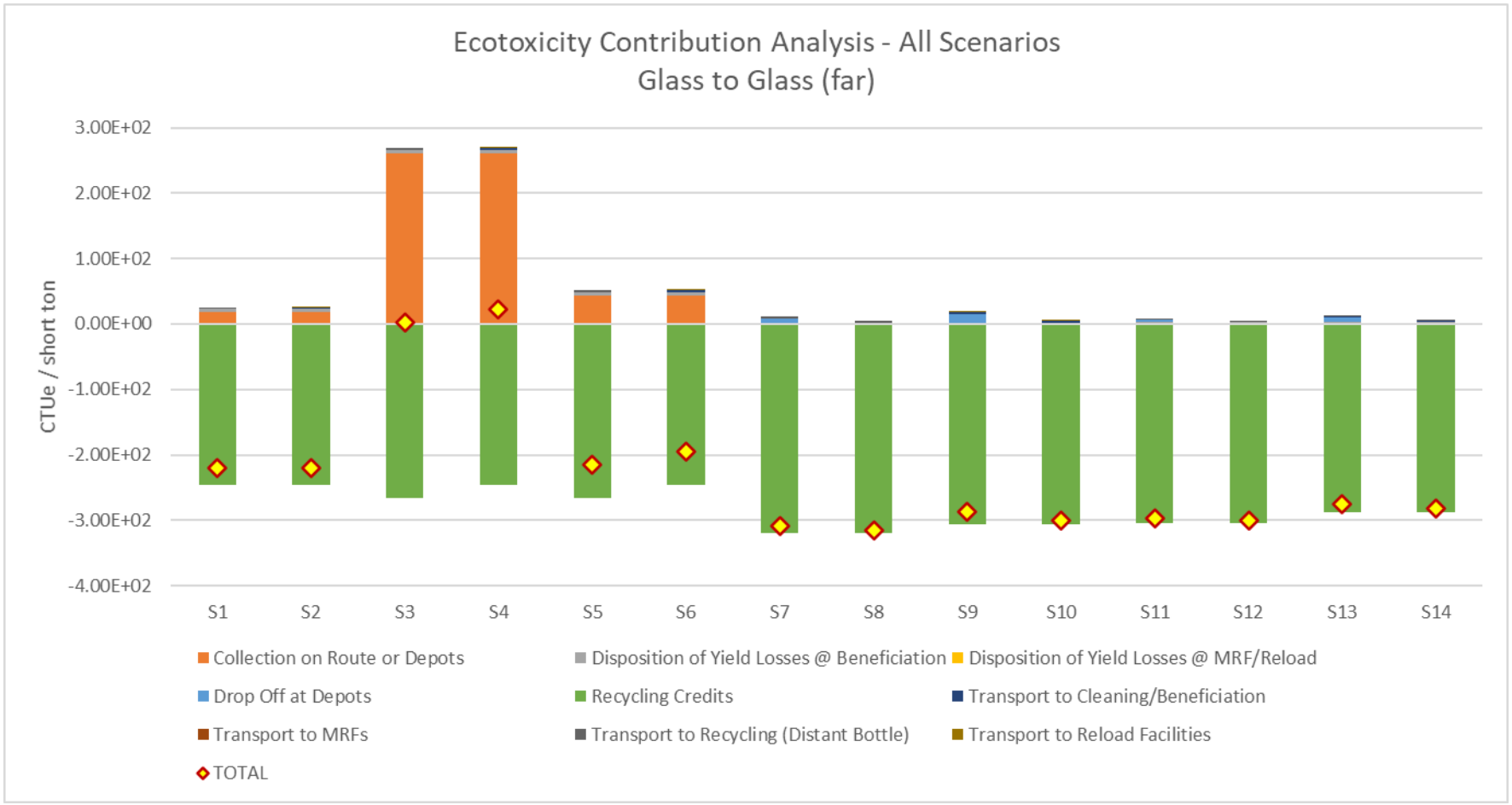
LCIA Results – Acidification Potential (AP)



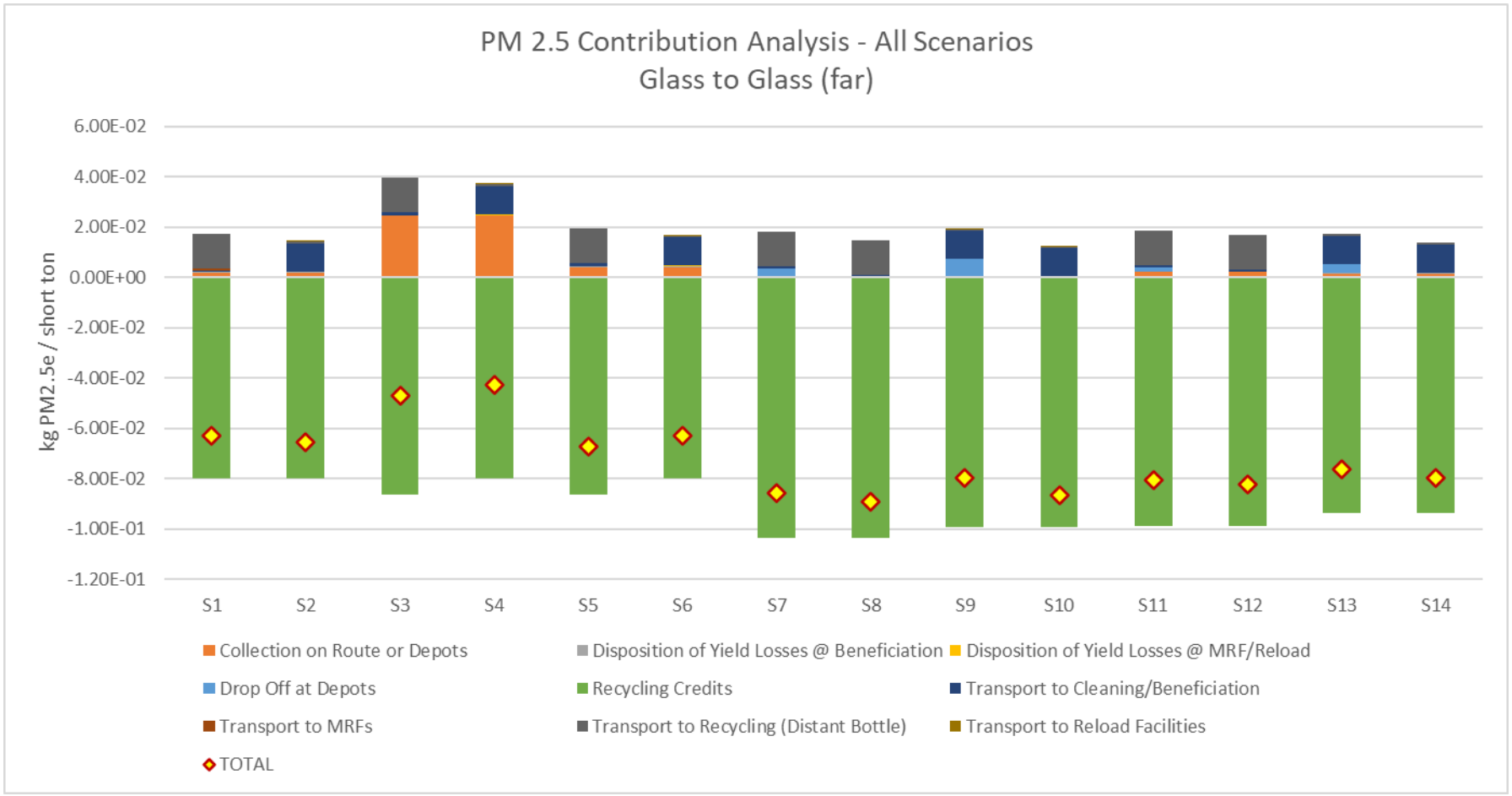
LCIA Results – Eutrophication Potential (EP)



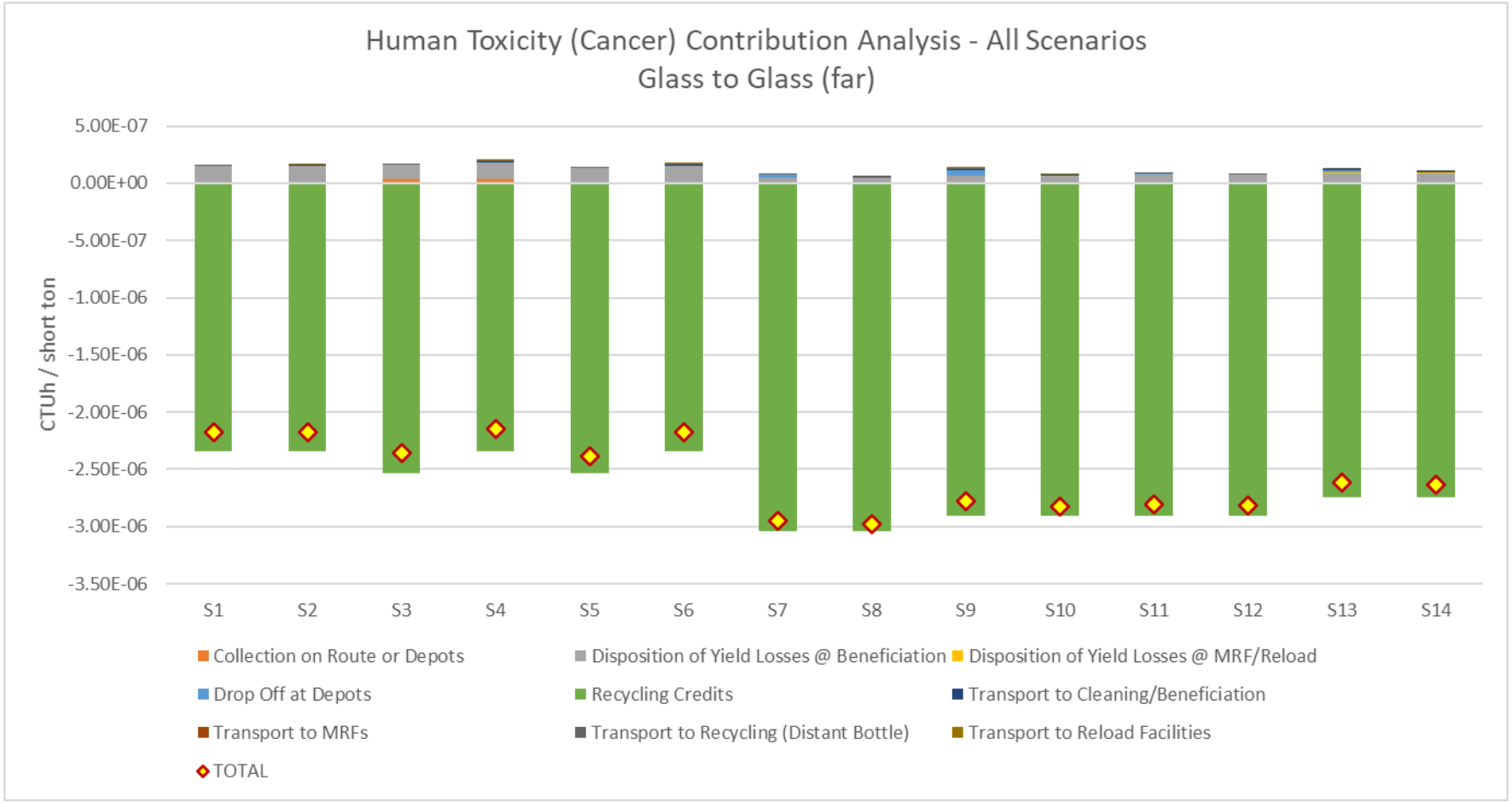
LCIA Results – Ecotoxicity Potential (ETP)



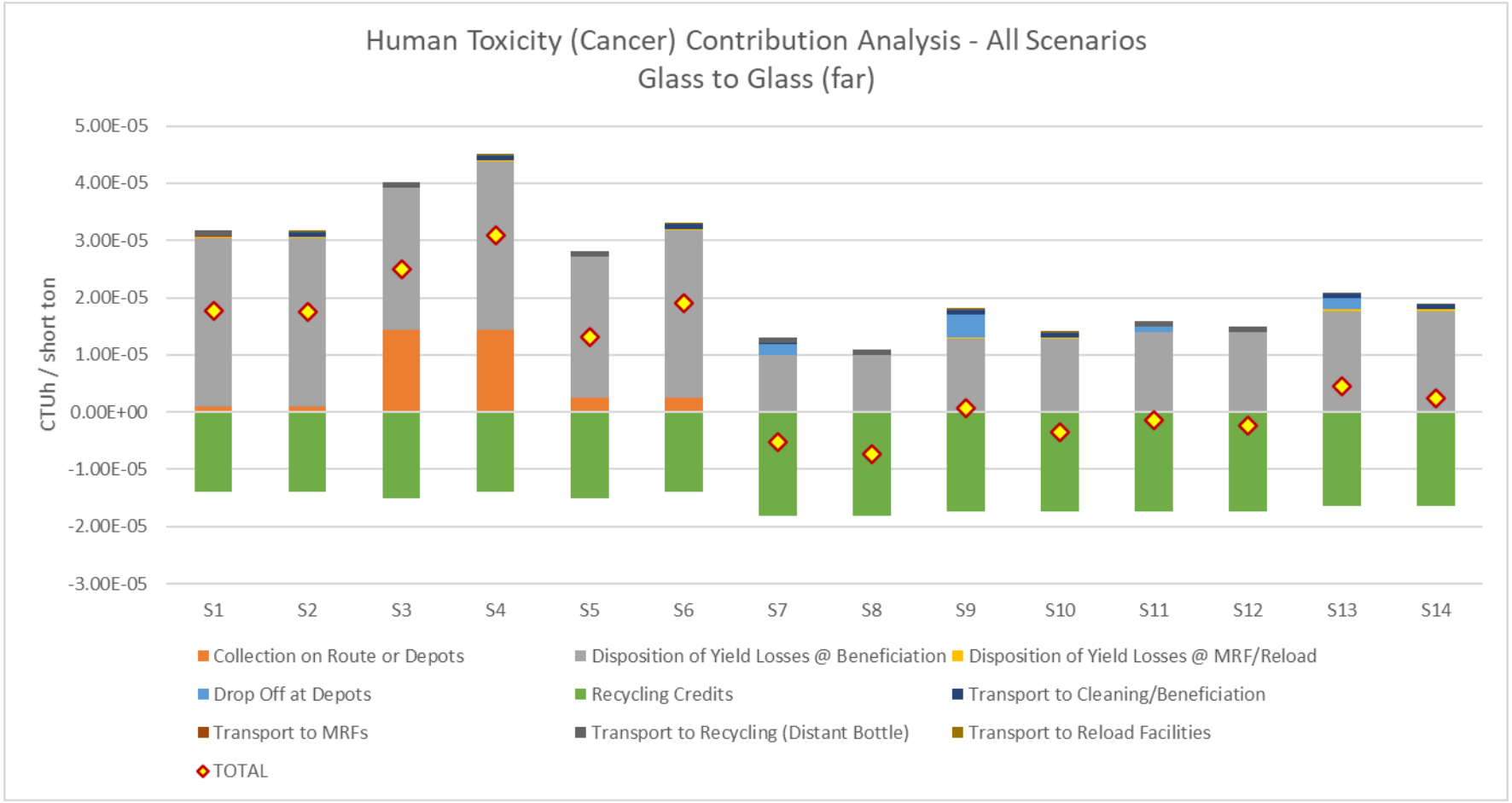
LCIA Results – Particulate Matter (PM 2.5)



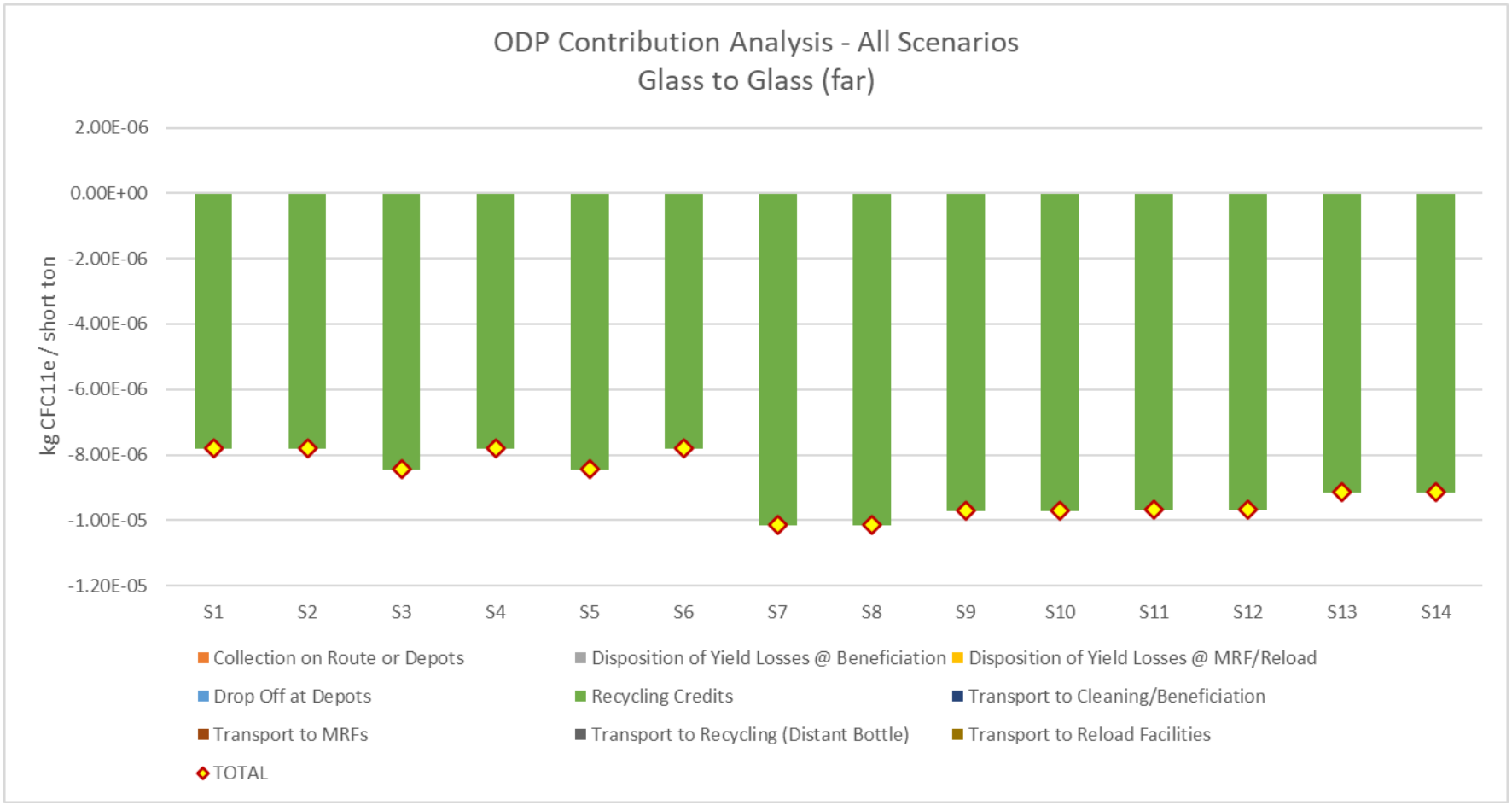
LCIA Results – Human Toxicity Potential (Cancer)



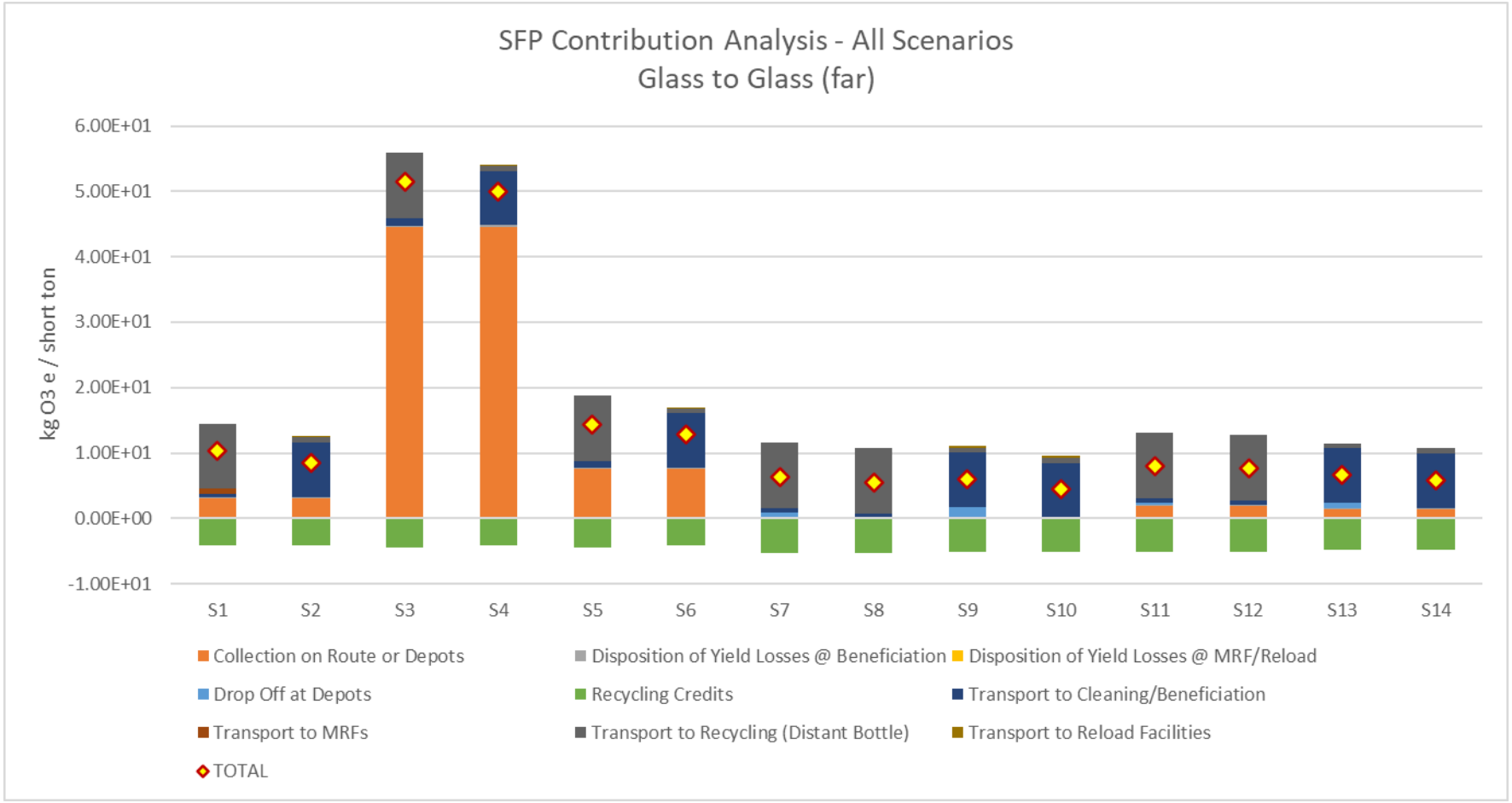
LCIA Results - Human Toxicity Potential (NonCancer)



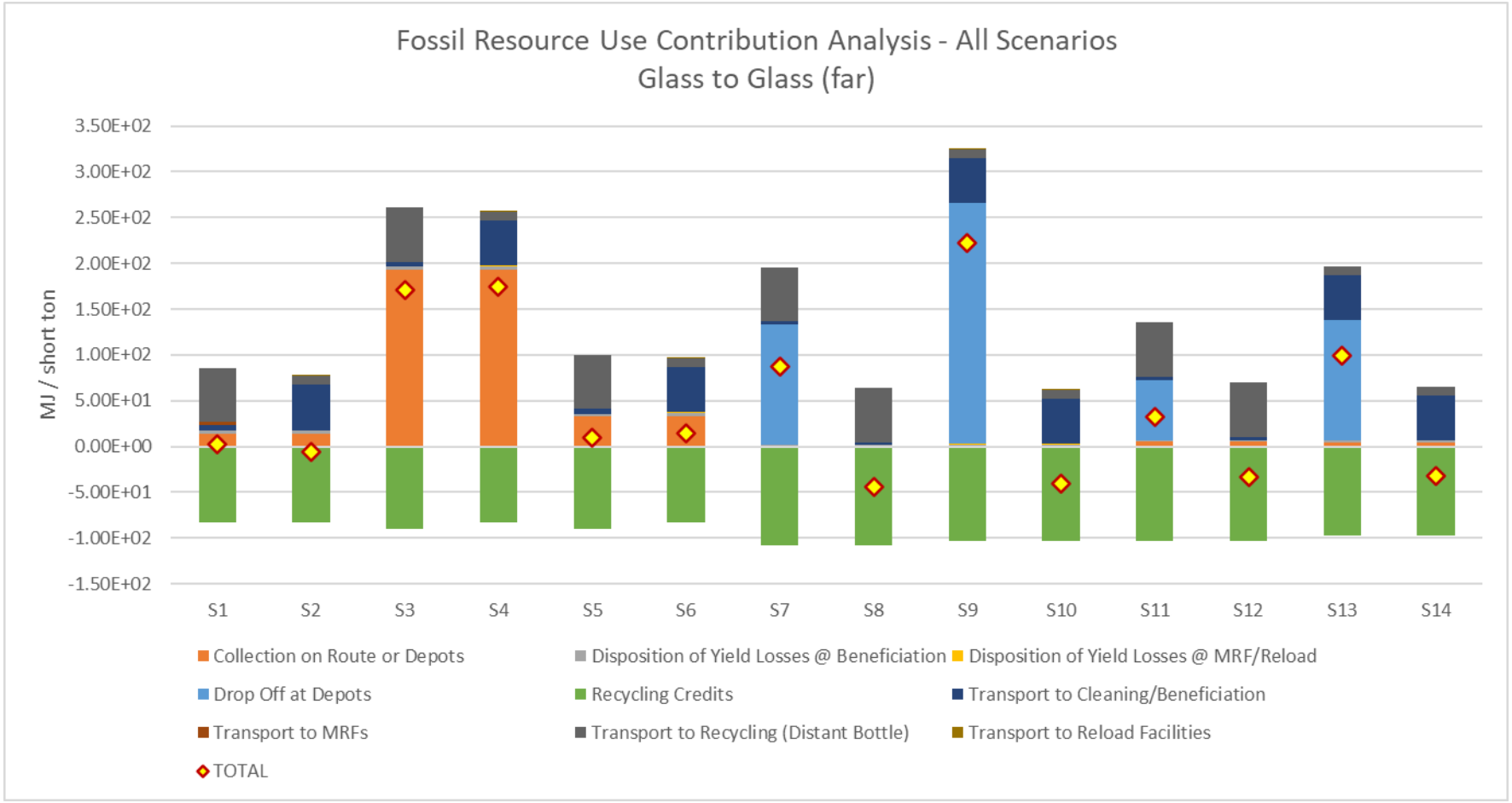
LCIA Results – Ozone Depletion Potential (ODP)



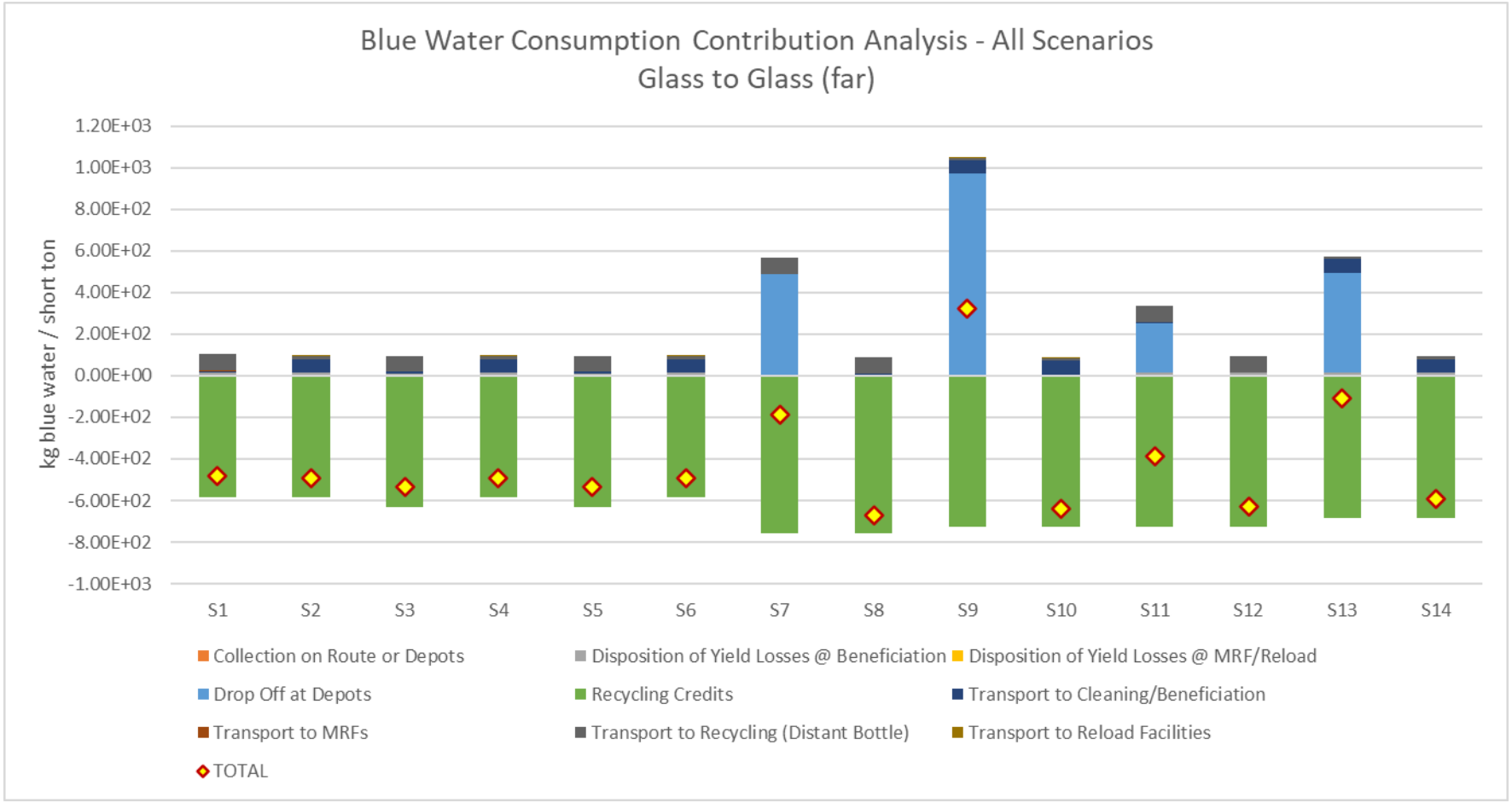
LCIA Results – Smog Formation Potential (SFP)



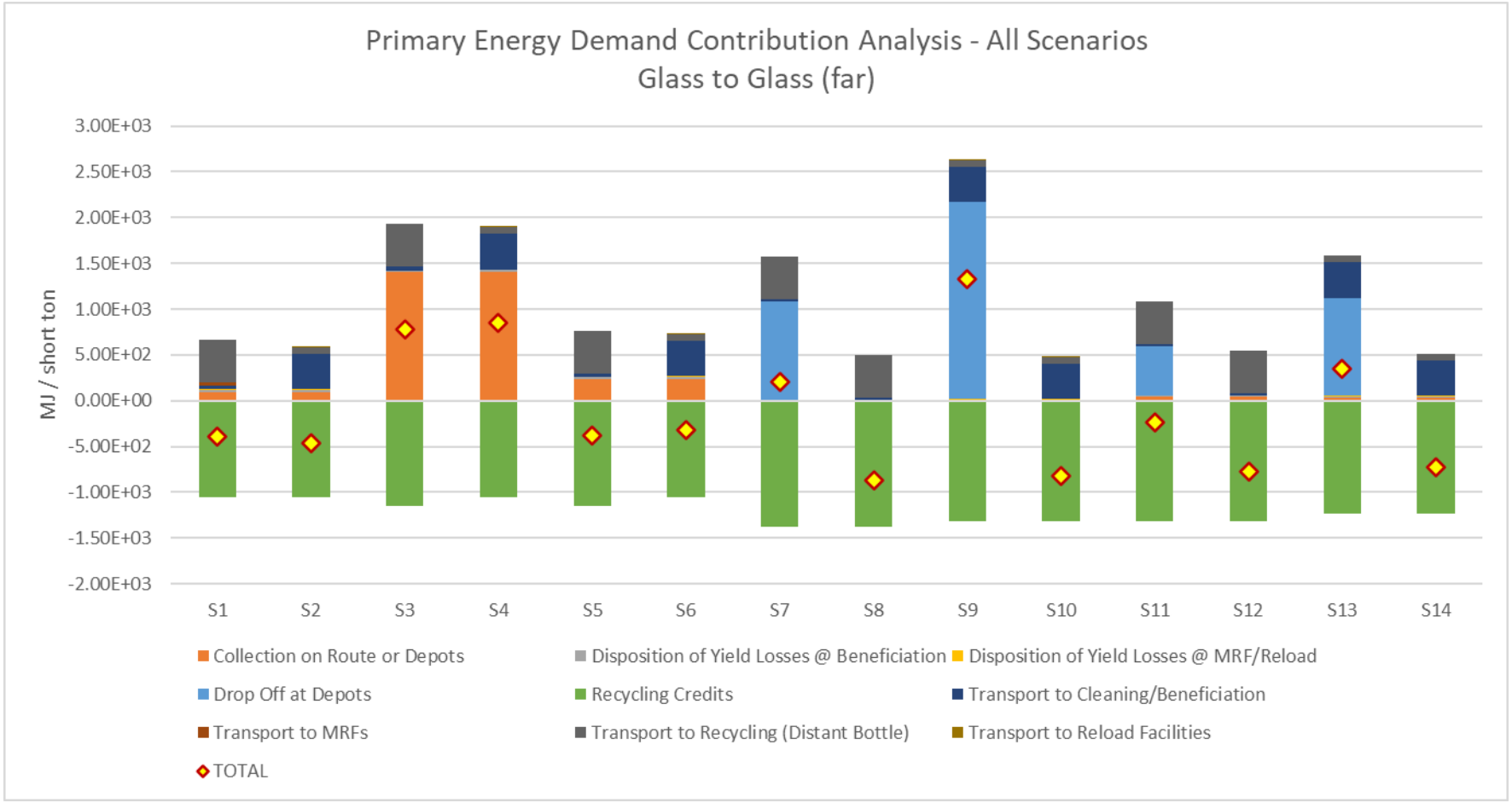
Indicator Results – Fossil Resource Use



Indicator Results – Bluewater Consumption



Indicator Results – Primary Energy Demand (PED)

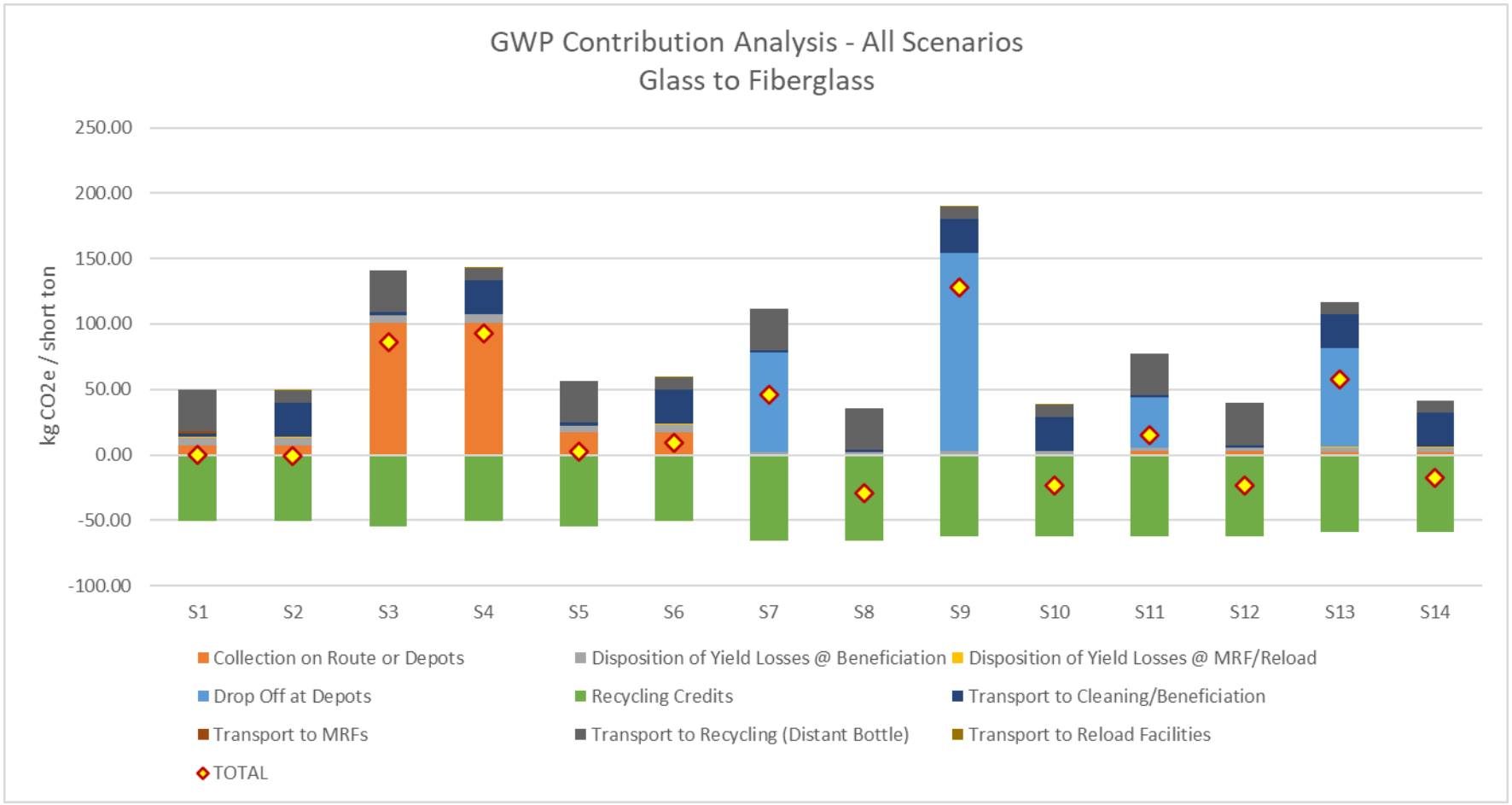


“Glass to Fiberglass” Results

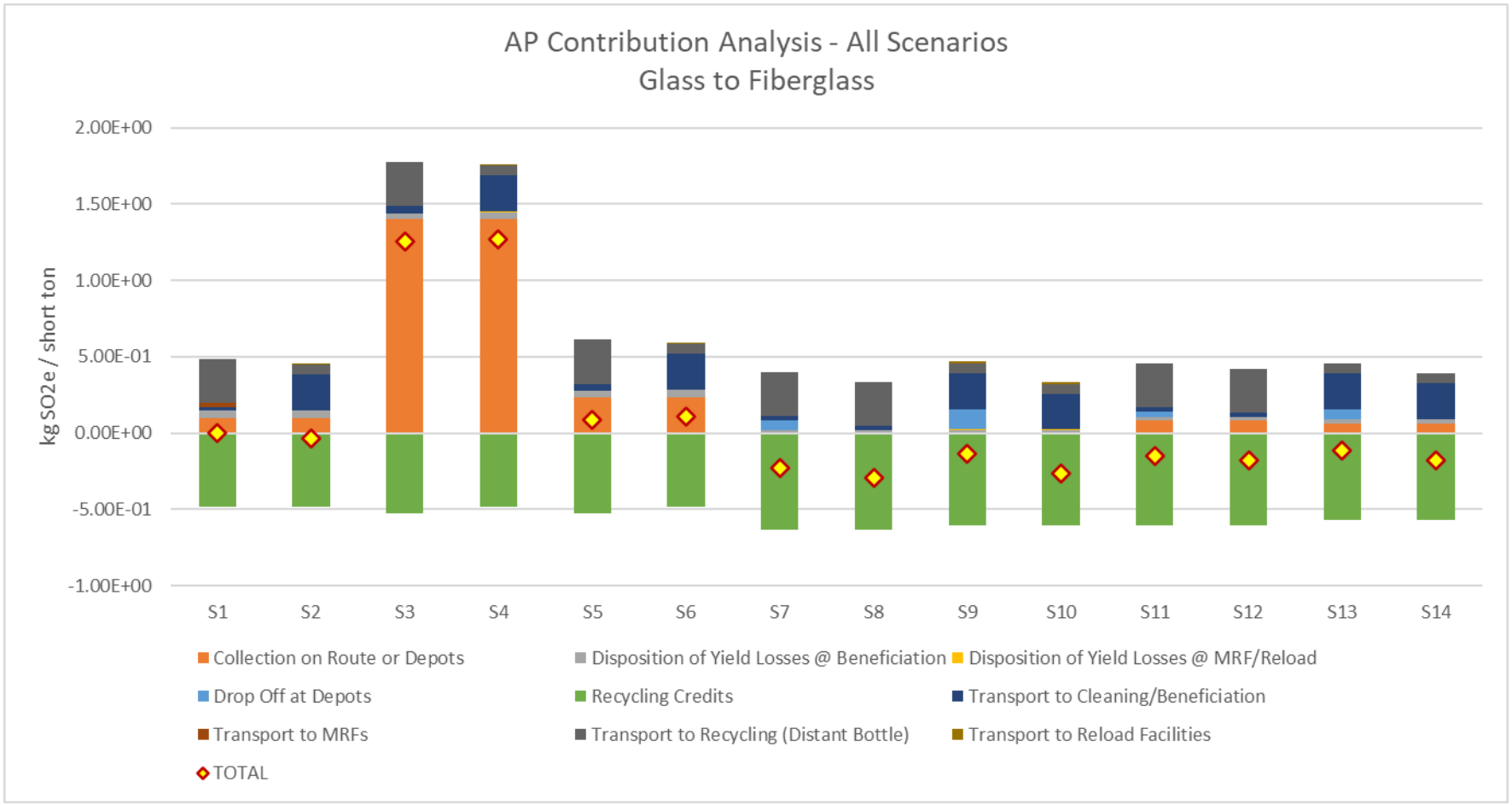
Owens Corning

Santa Clara, CA

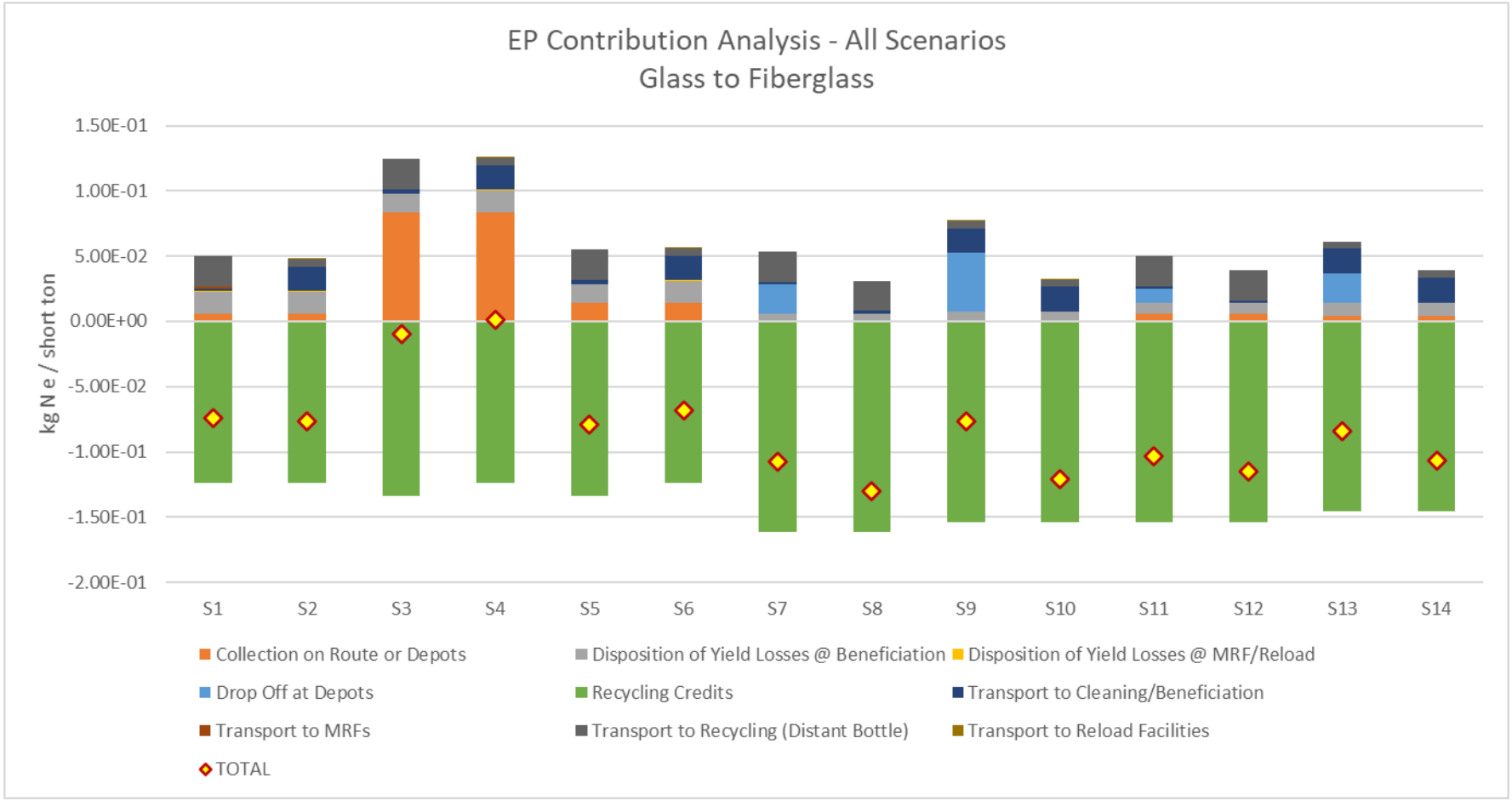
LCIA Results – Global Warming Potential (GWP)



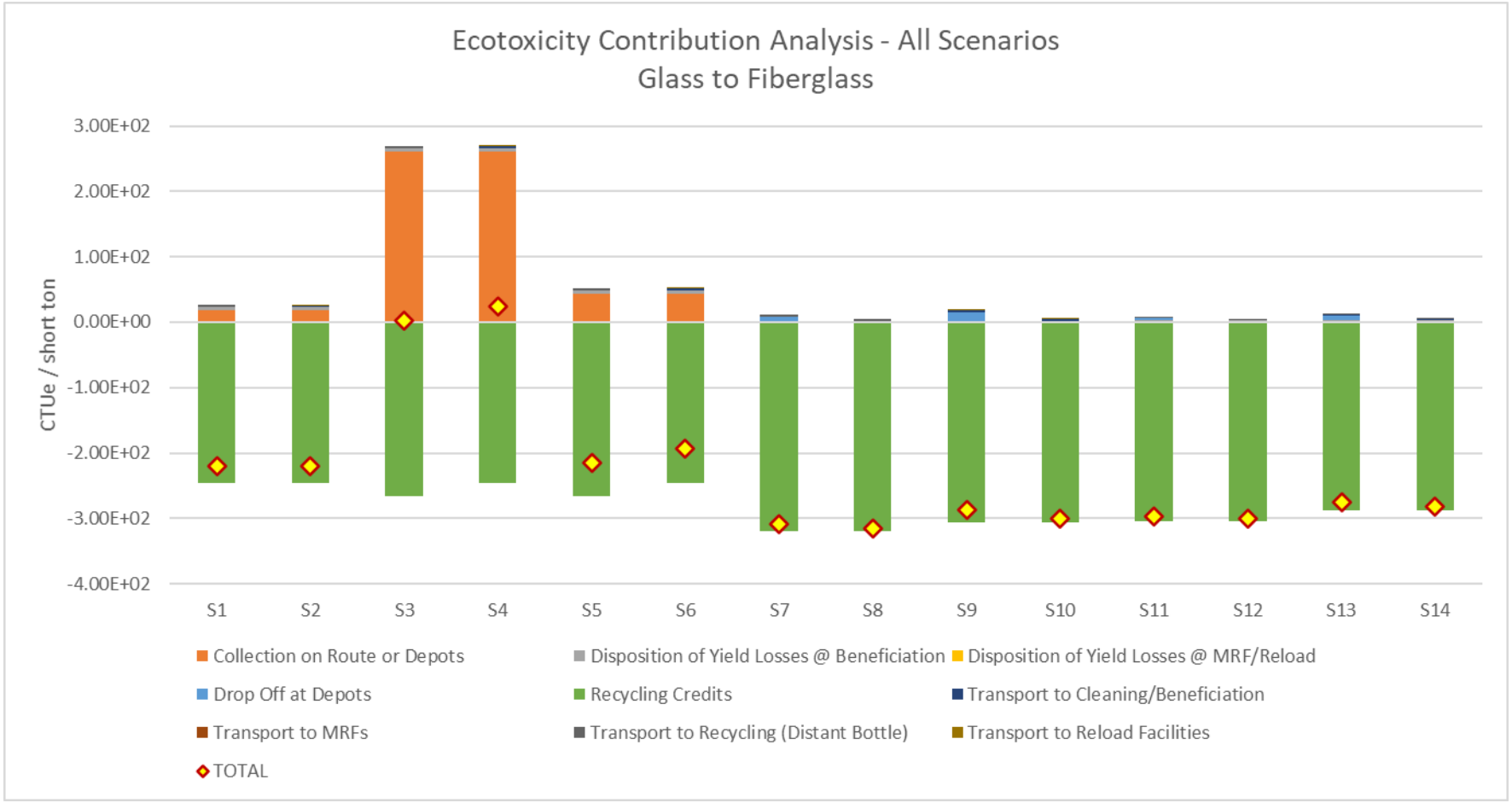
LCIA Results – Acidification Potential (AP)



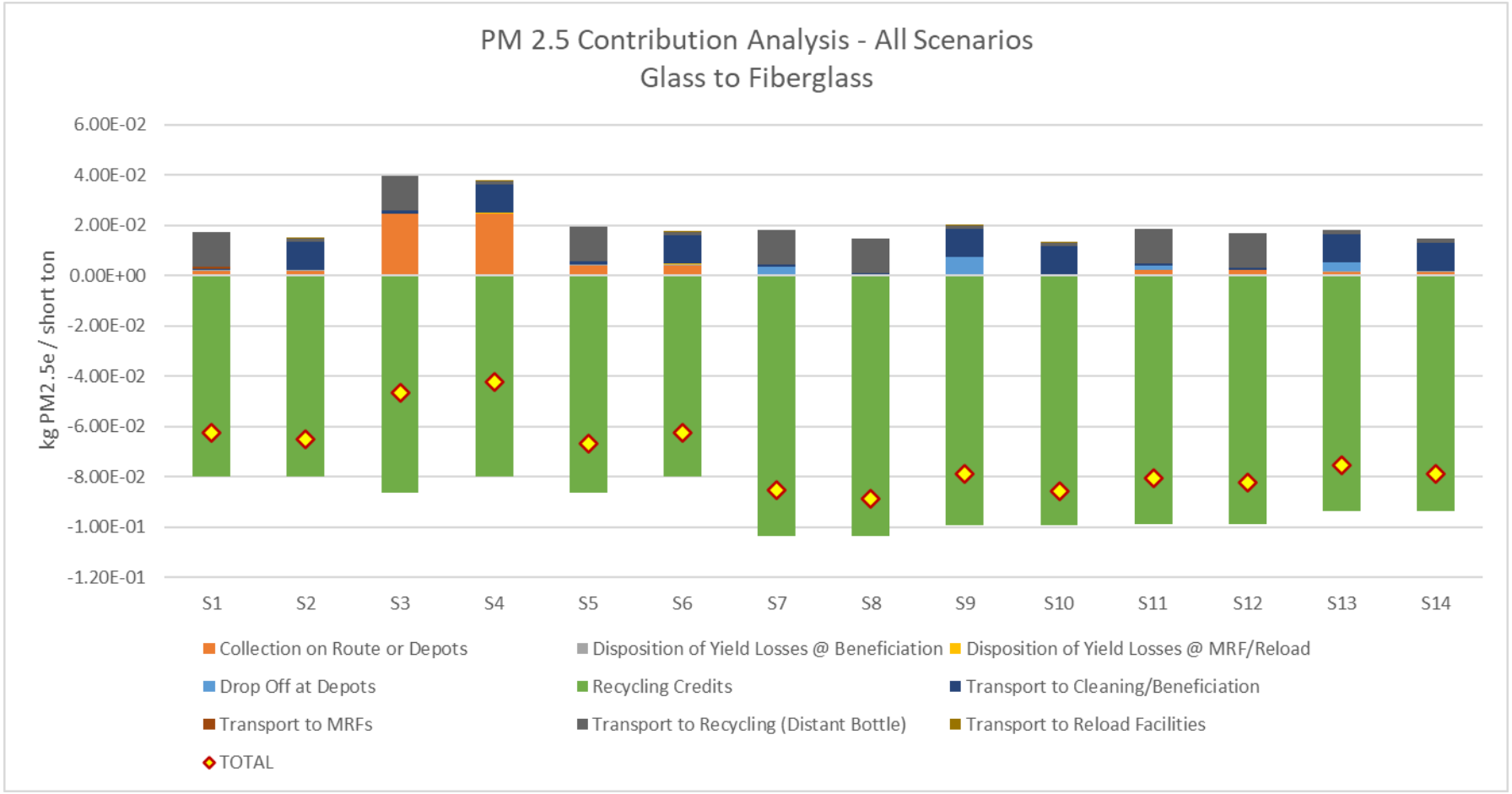
LCIA Results – Eutrophication Potential (EP)



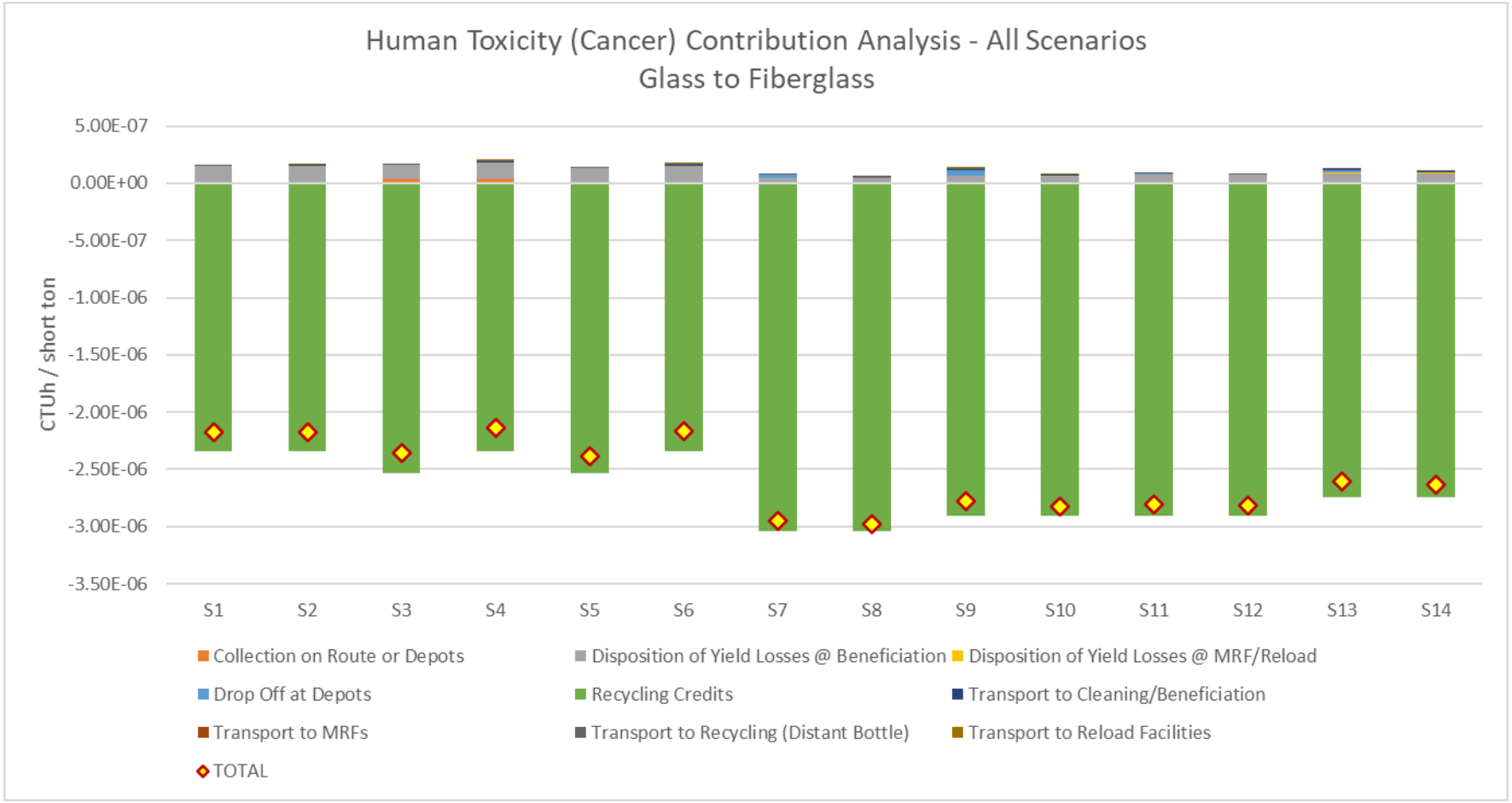
LCIA Results – Ecotoxicity Potential (ETP)



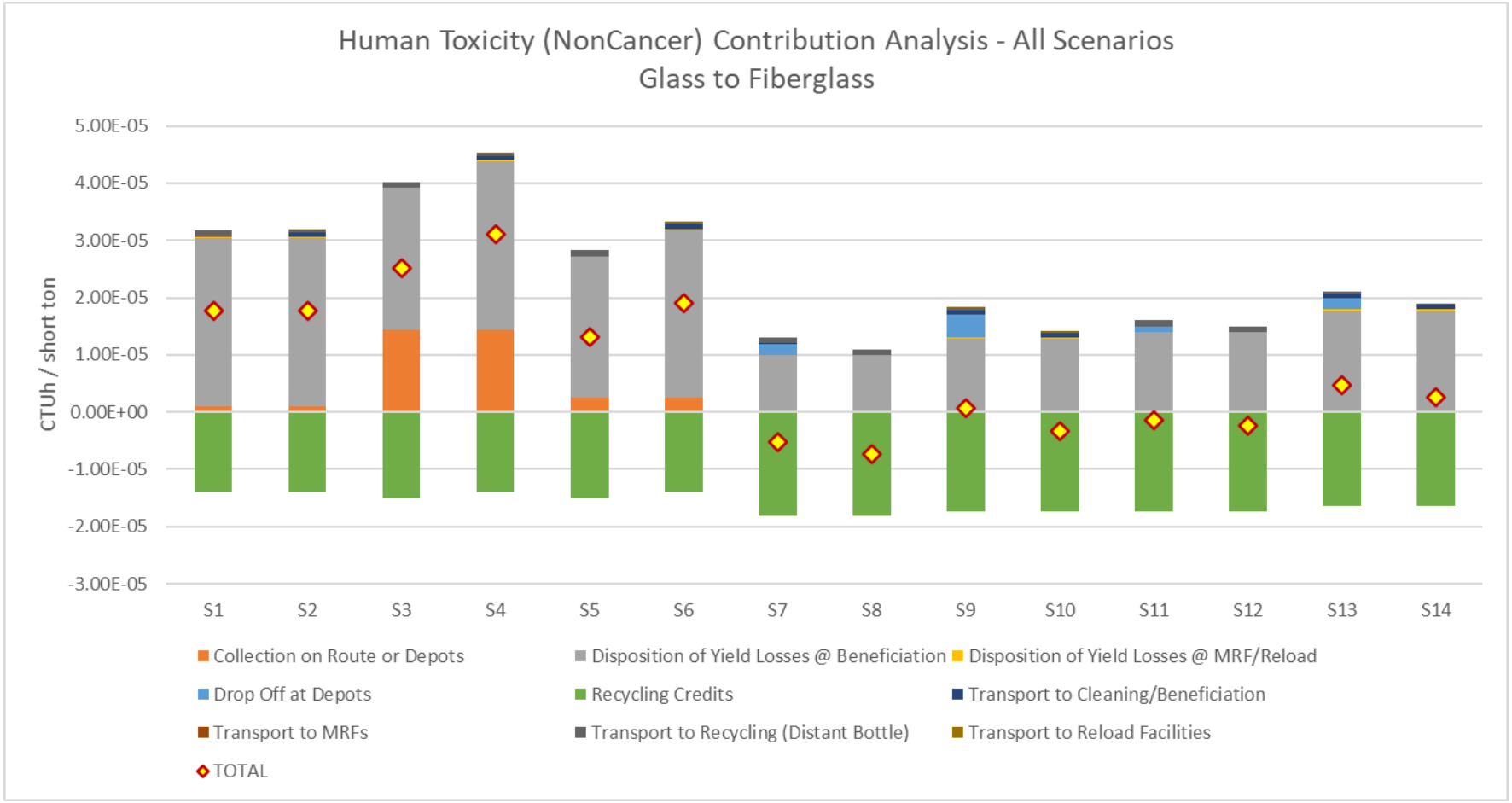
LCIA Results – Particulate Matter (PM 2.5)



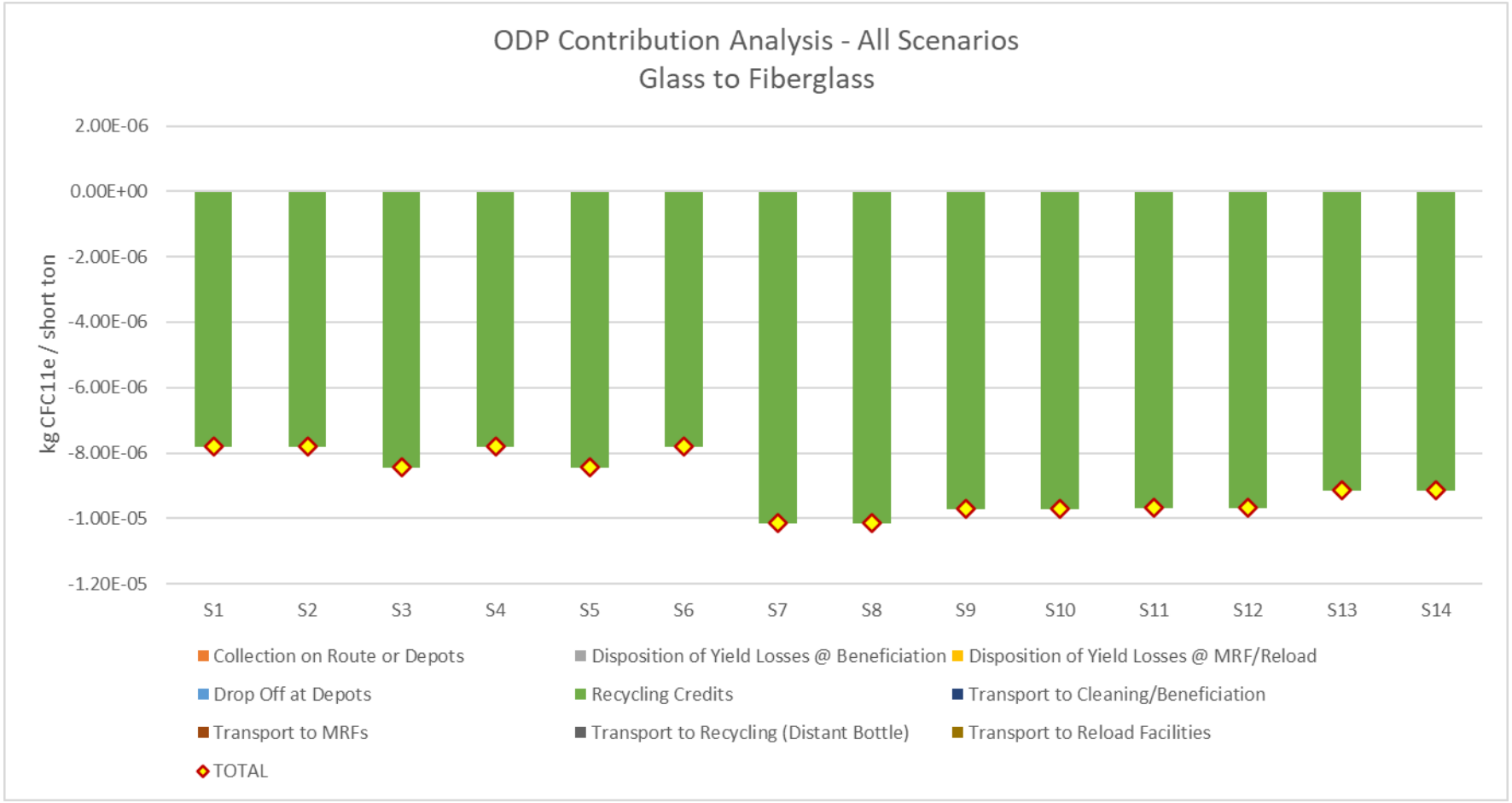
LCIA Results – Human Toxicity Potential (Cancer)



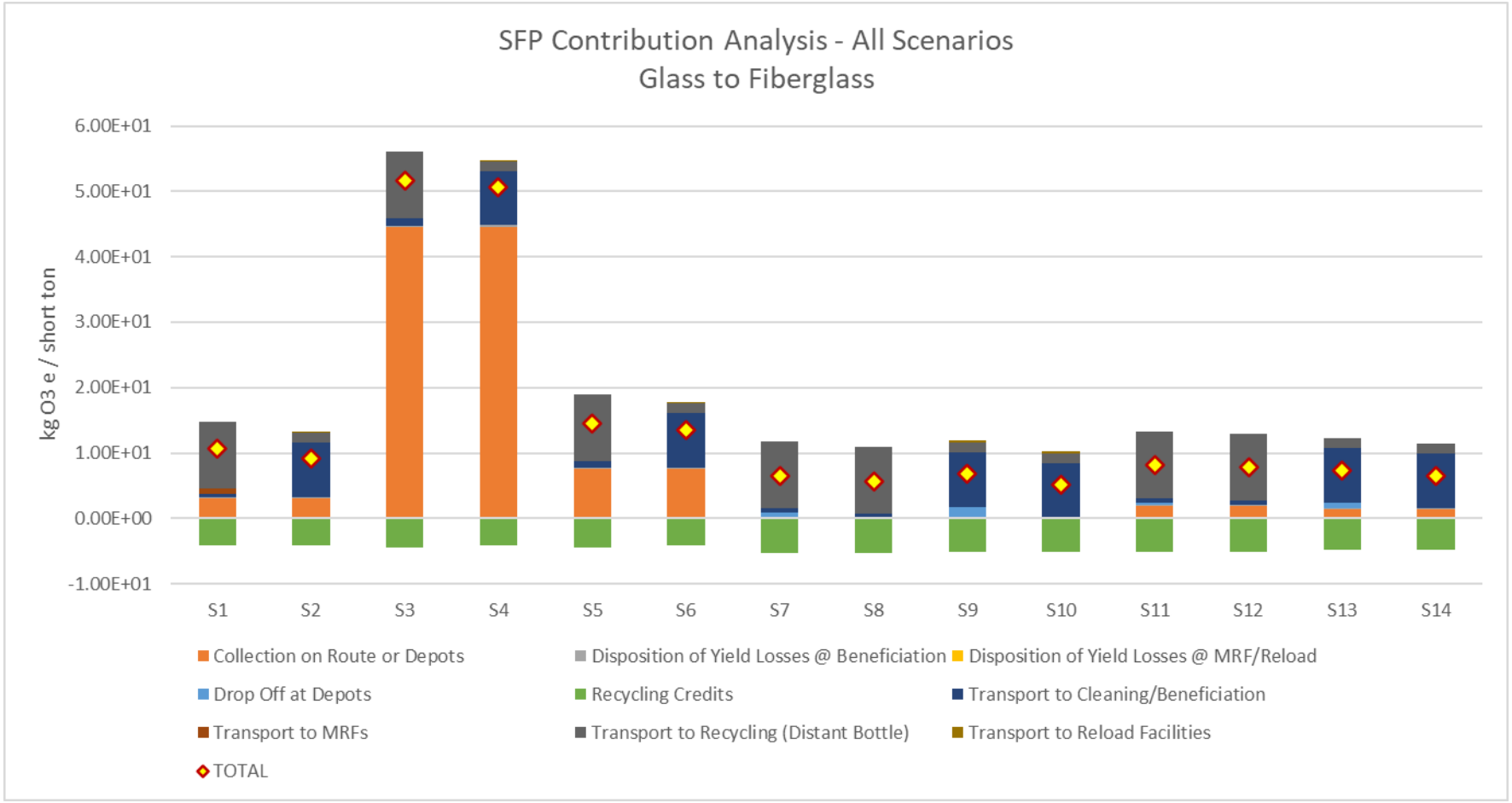
LCIA Results - Human Toxicity Potential (NonCancer)



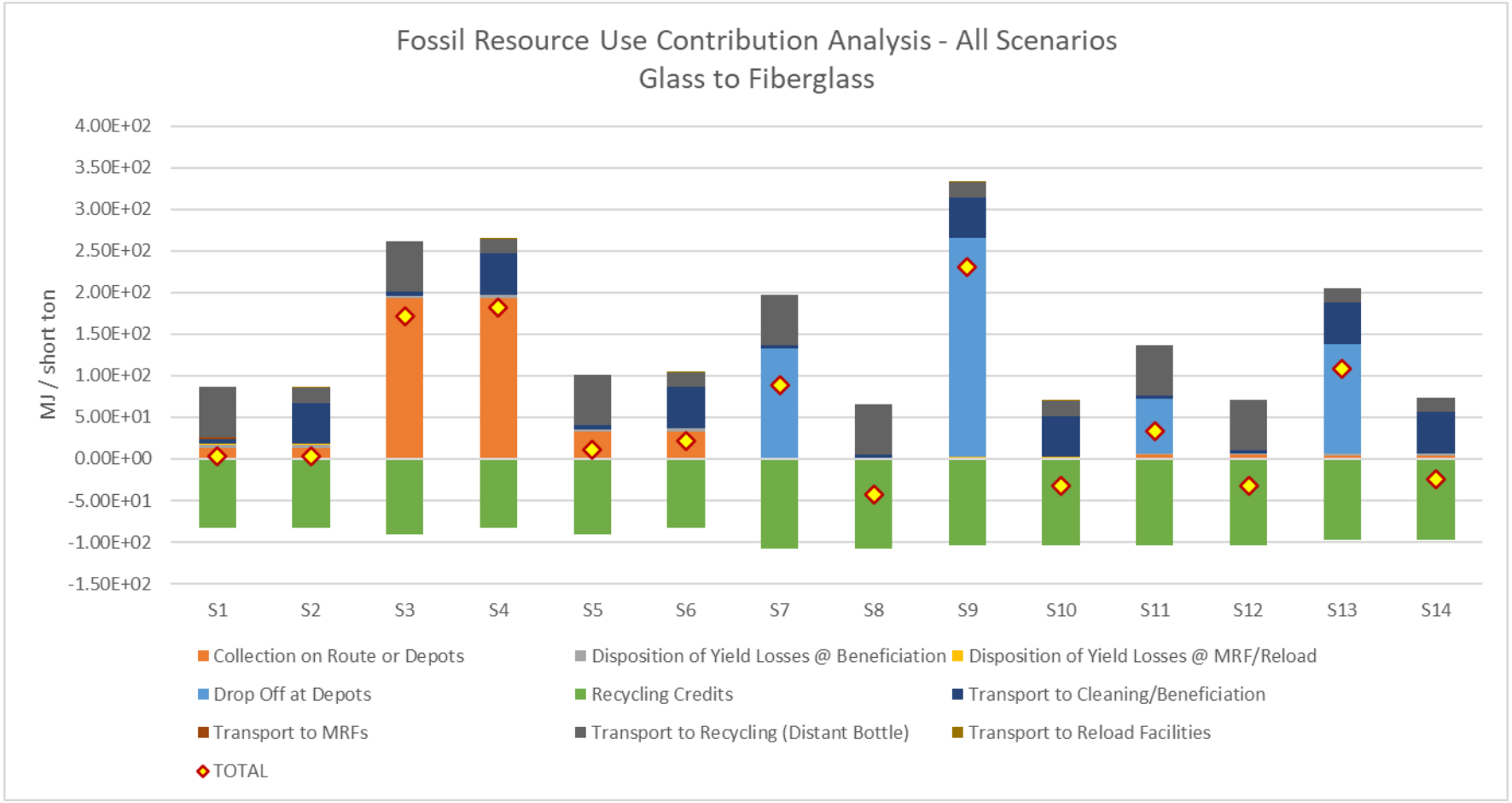
LCIA Results – Ozone Depletion Potential (ODP)



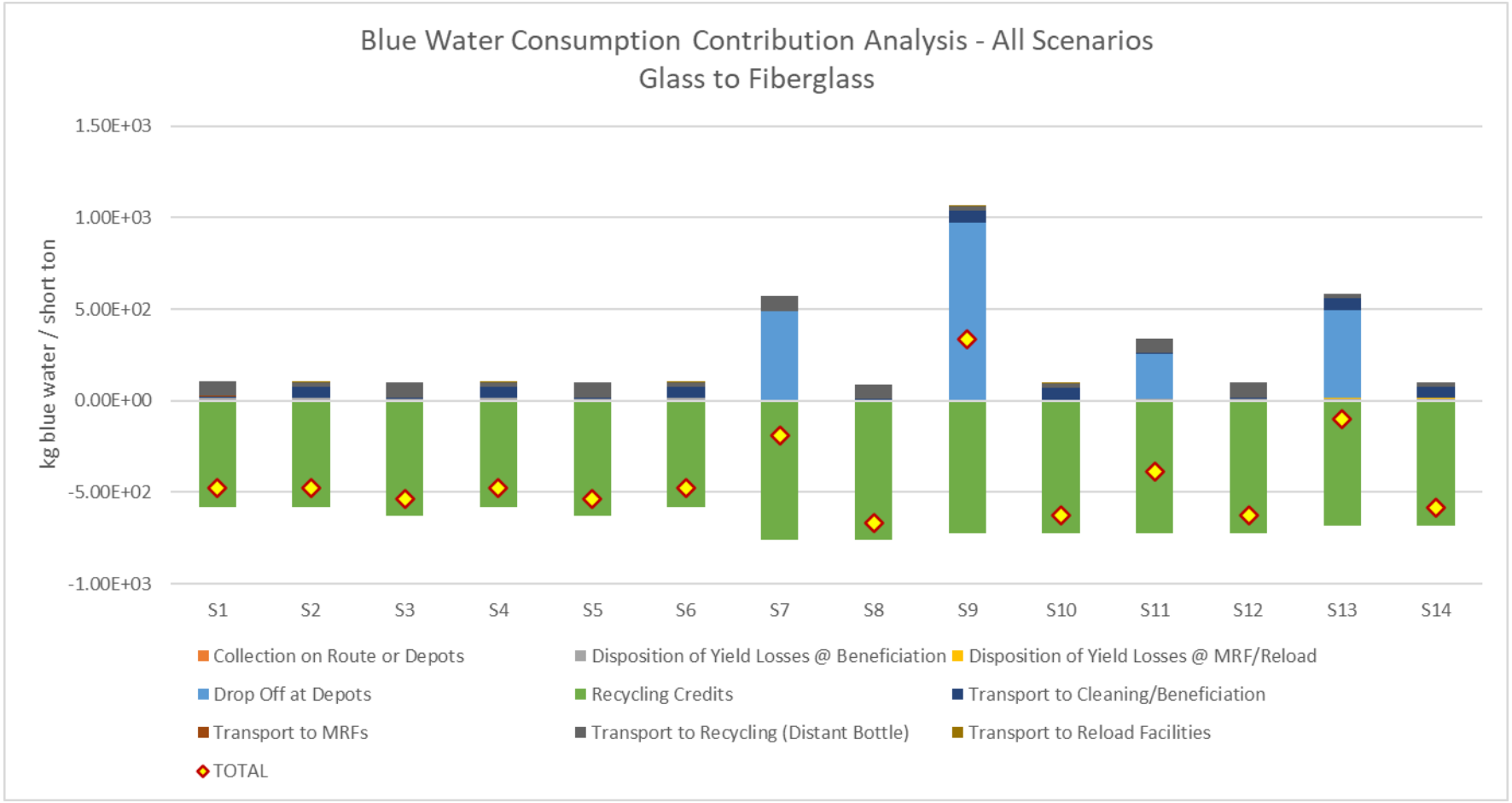
LCIA Results – Smog Formation Potential (SFP)



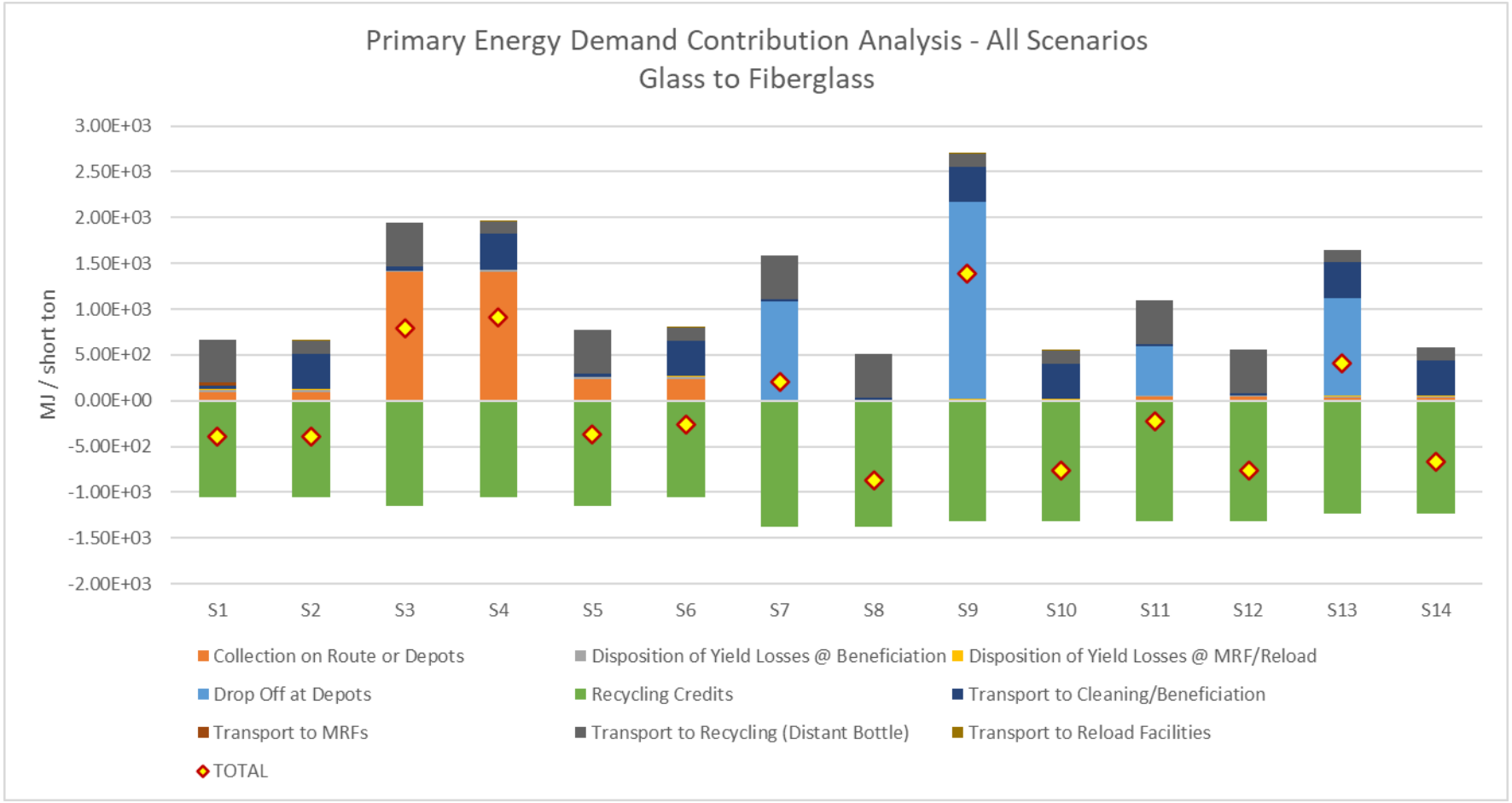
Indicator Results – Fossil Resource Use



Indicator Results – Bluewater Consumption



Indicator Results – Primary Energy Demand (PED)

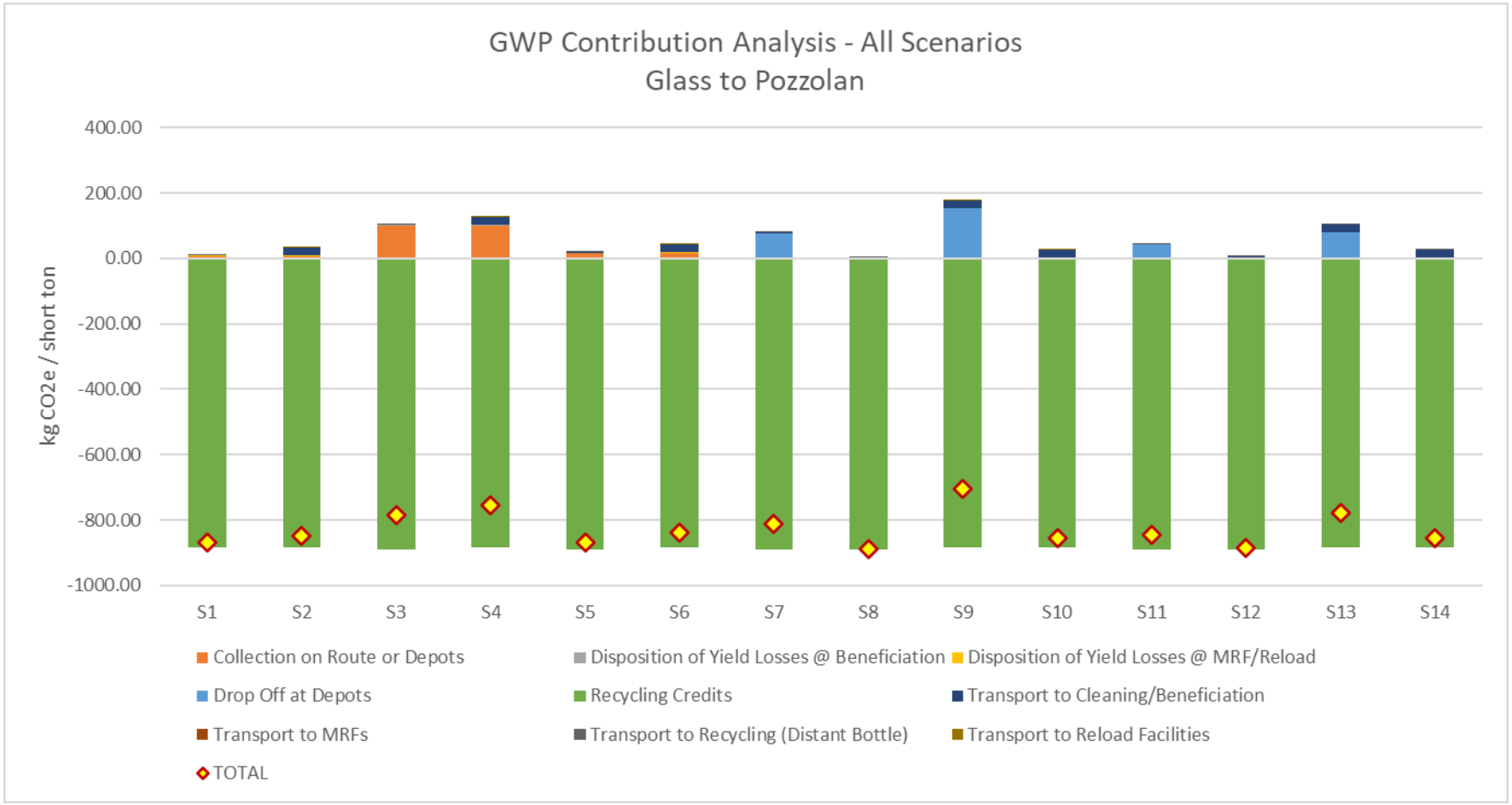


“Glass to Pozzolan” Results

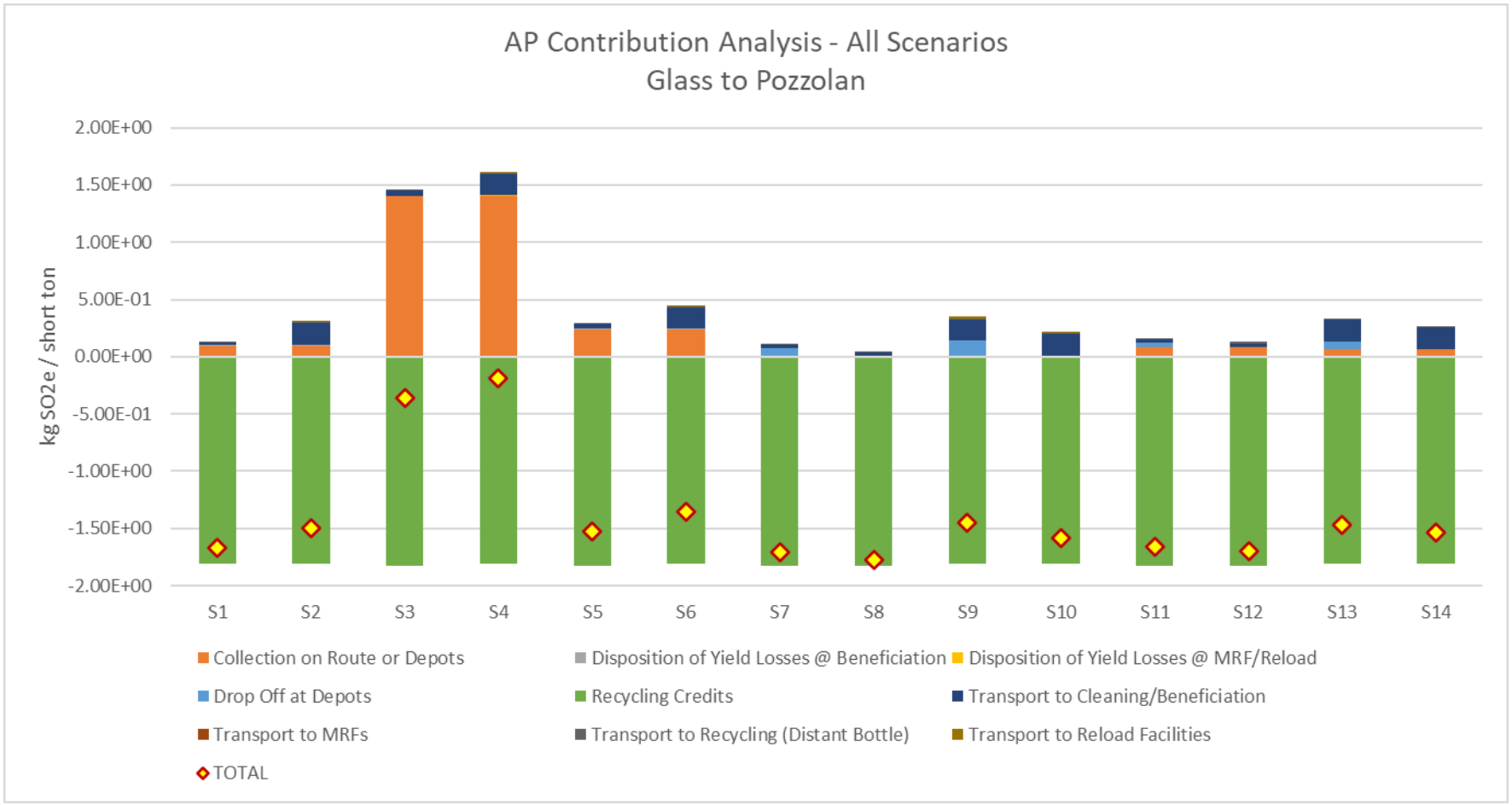
Hypothetical Plant

Vancouver, WA

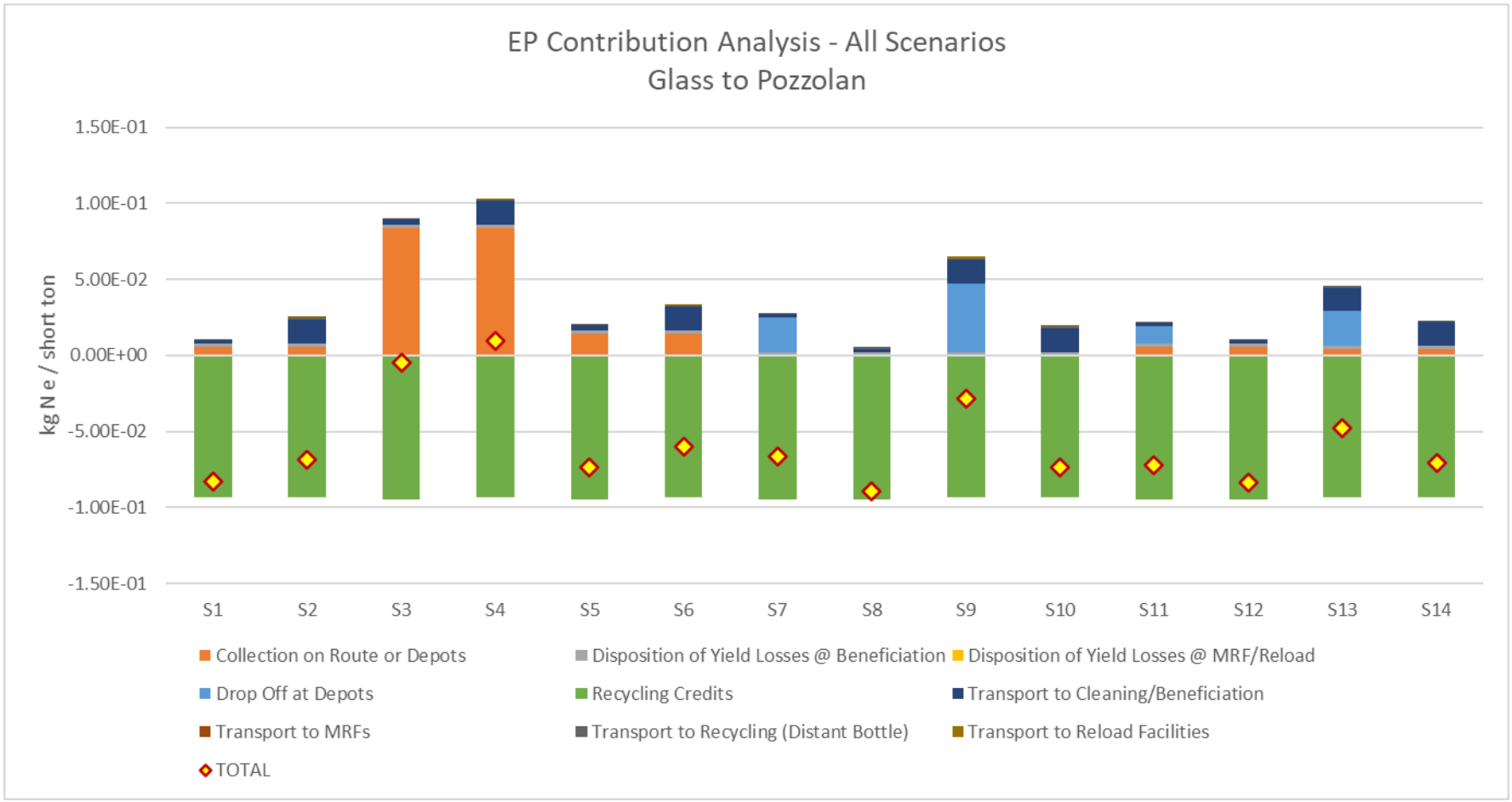
LCIA Results – Global Warming Potential (GWP)



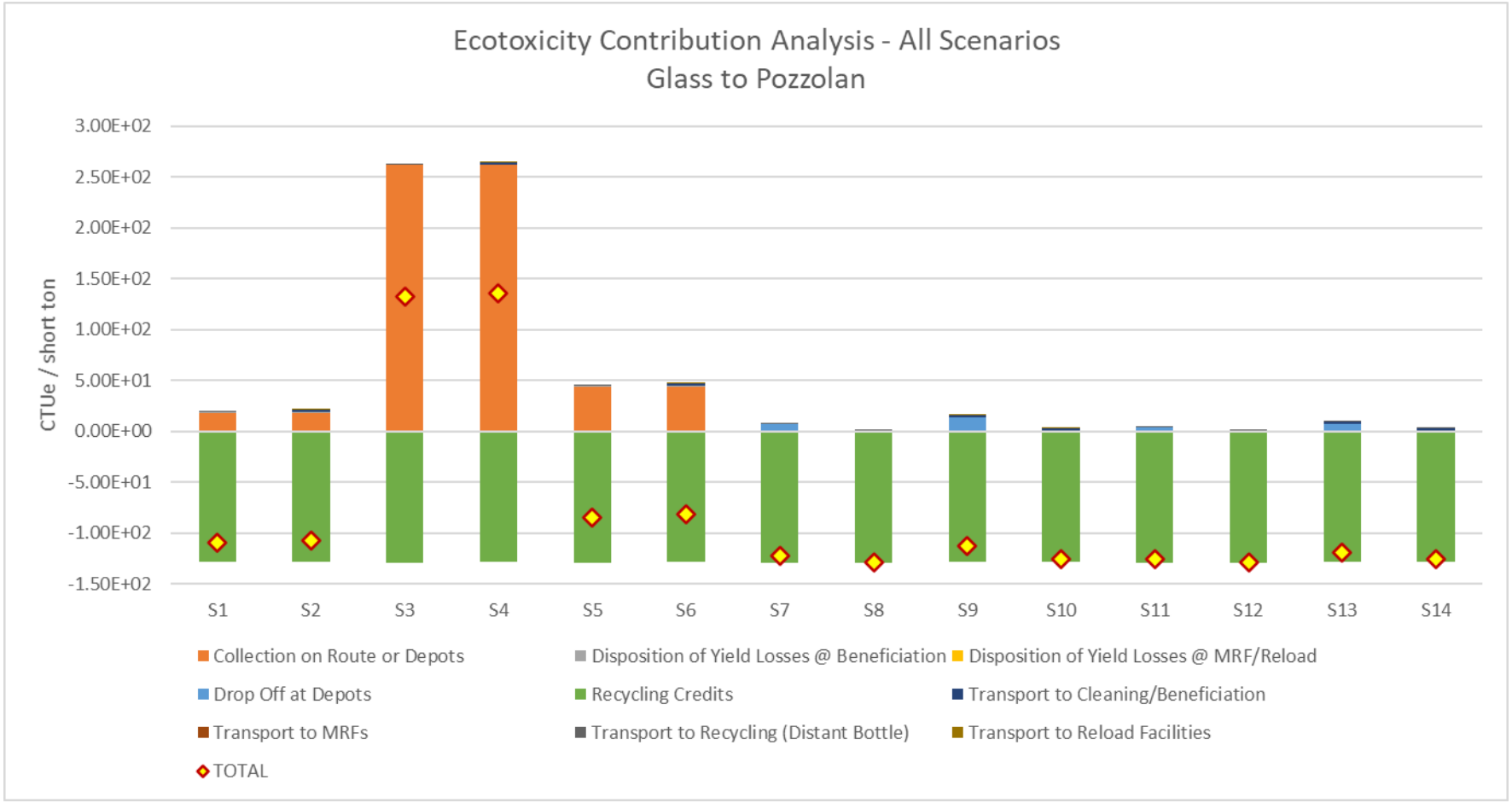
LCIA Results – Acidification Potential (AP)



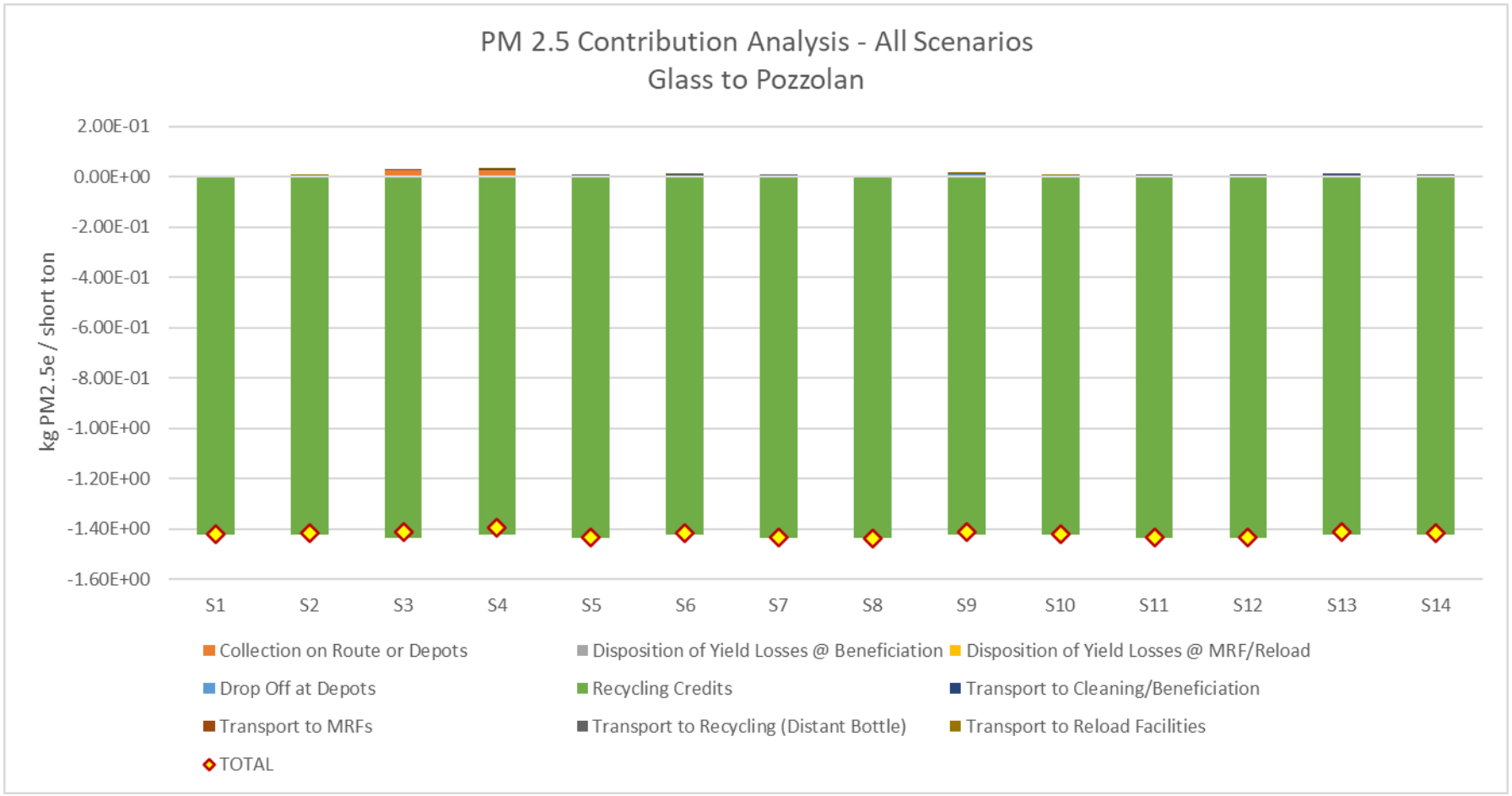
LCIA Results – Eutrophication Potential (EP)



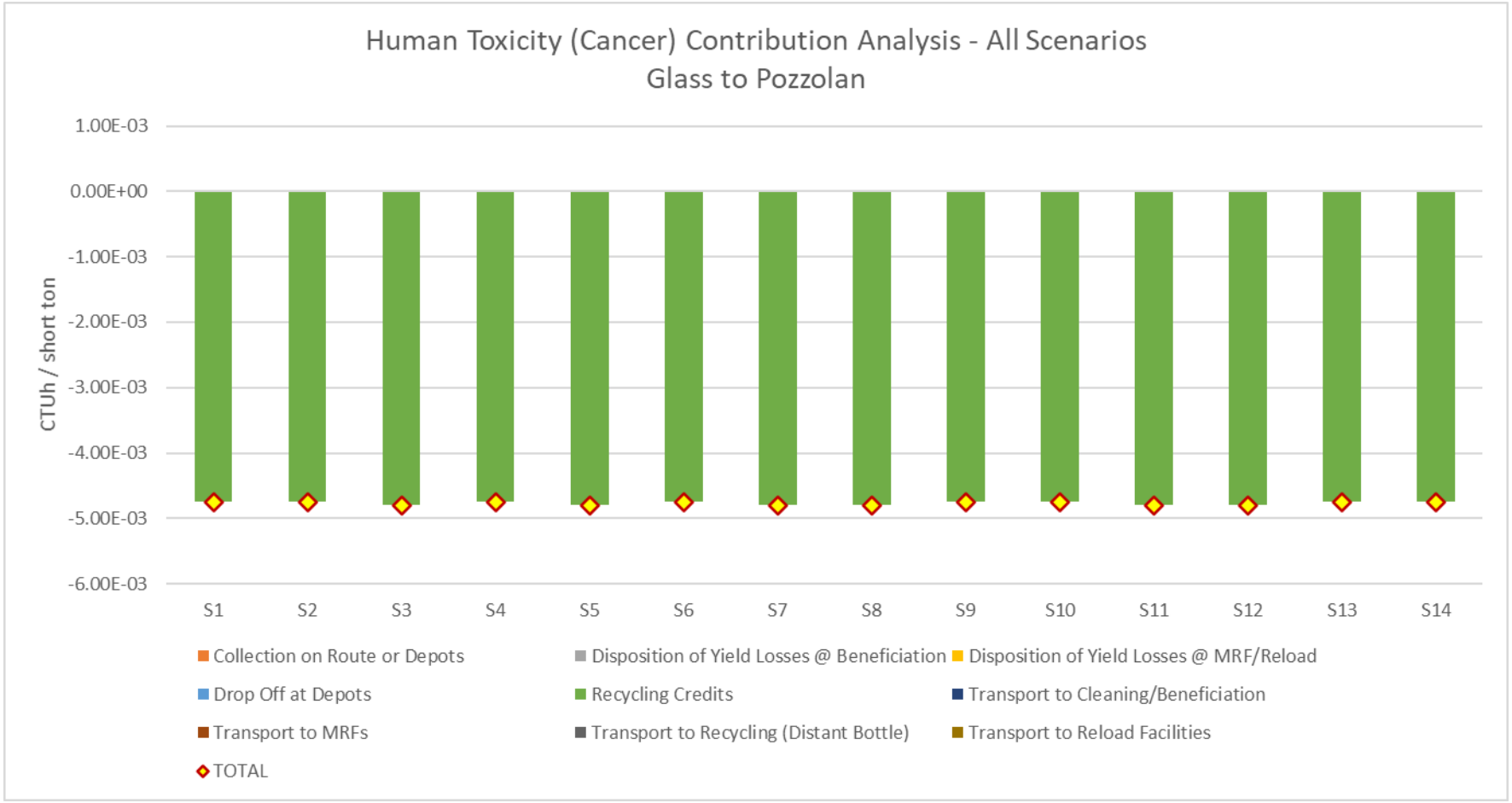
LCIA Results – Ecotoxicity Potential (ETP)



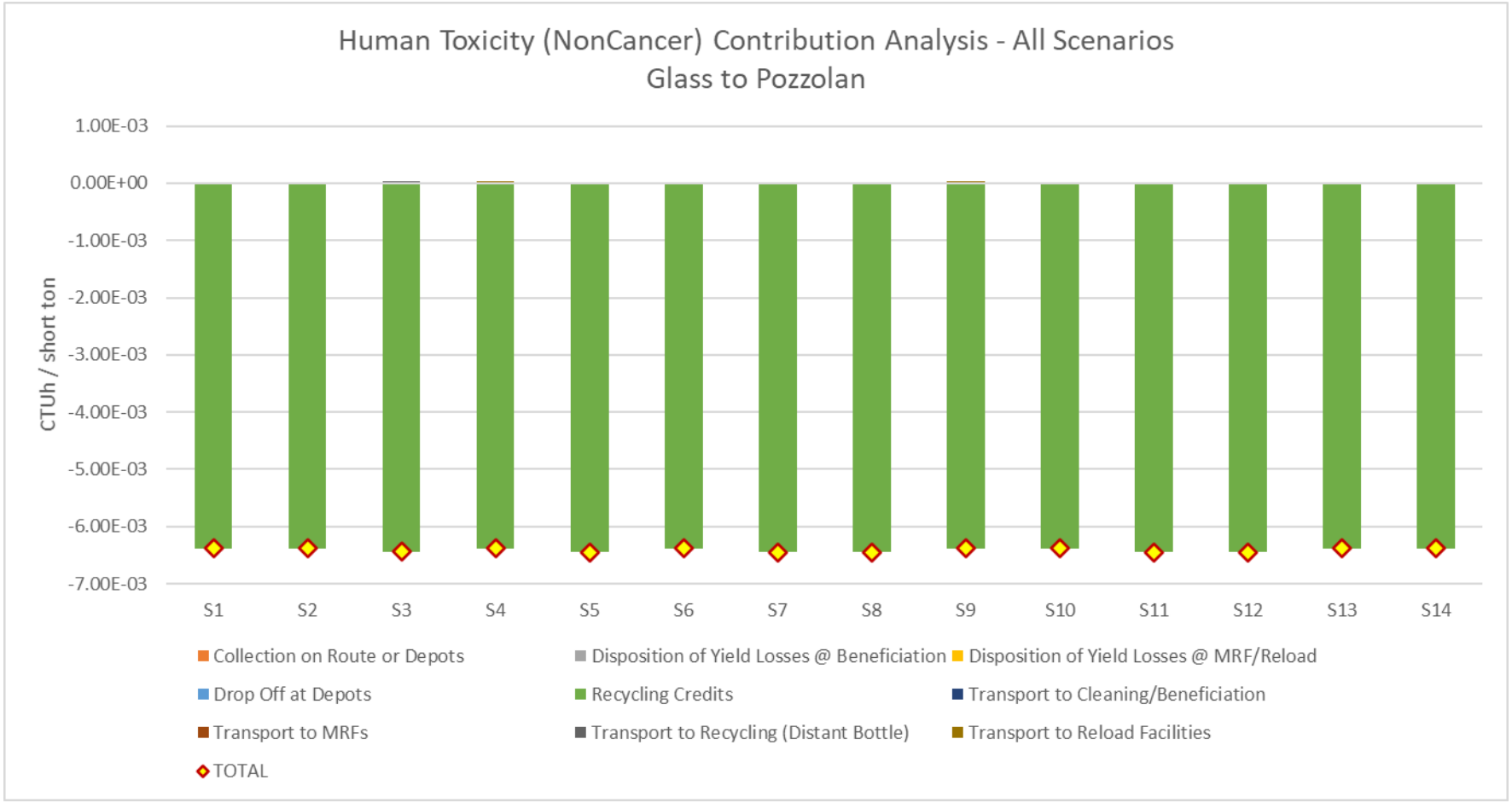
LCIA Results – Particulate Matter (PM 2.5)



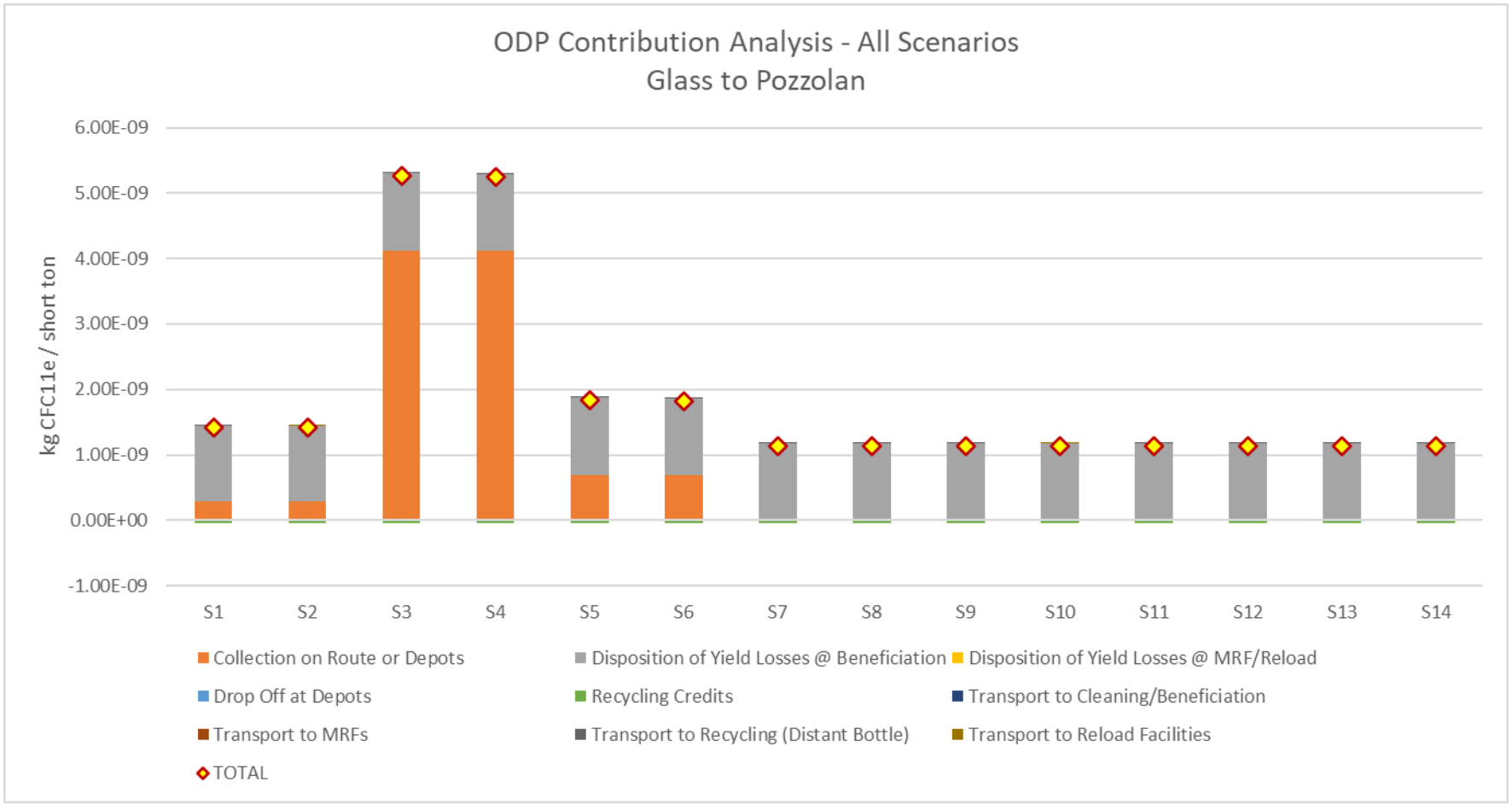
LCIA Results – Human Toxicity Potential (Cancer)



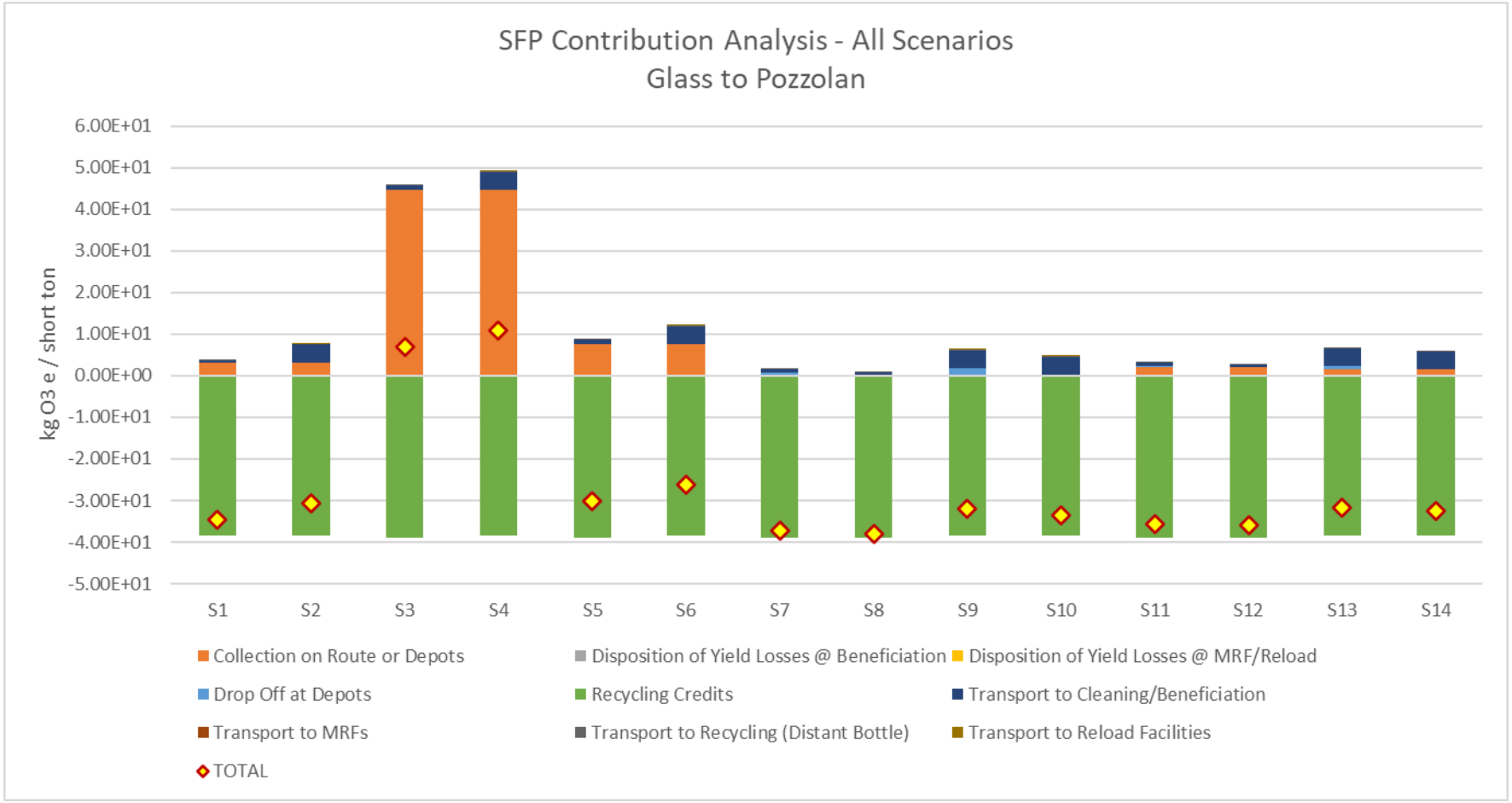
LCIA Results - Human Toxicity Potential (NonCancer)



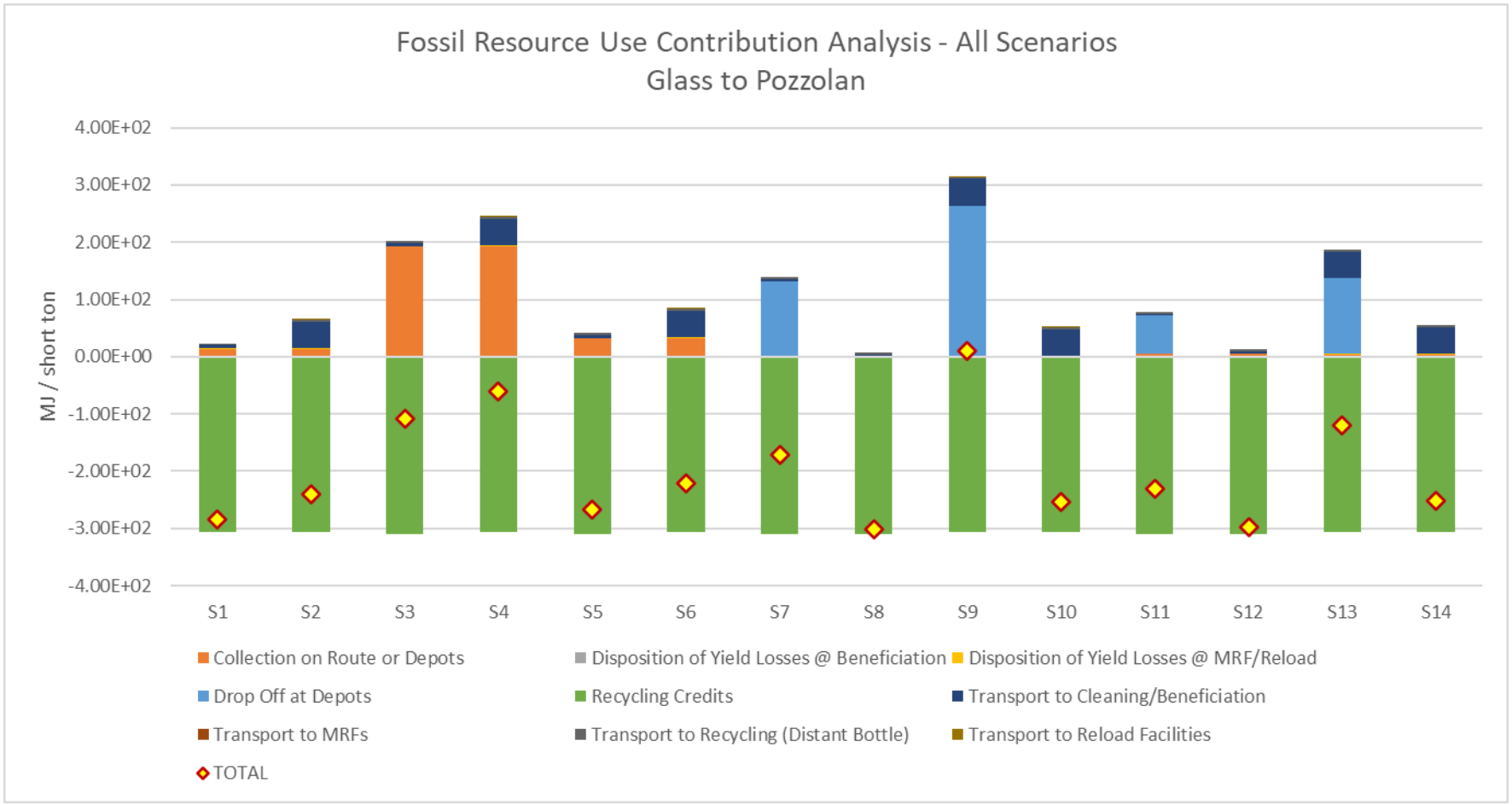
LCIA Results – Ozone Depletion Potential (ODP)



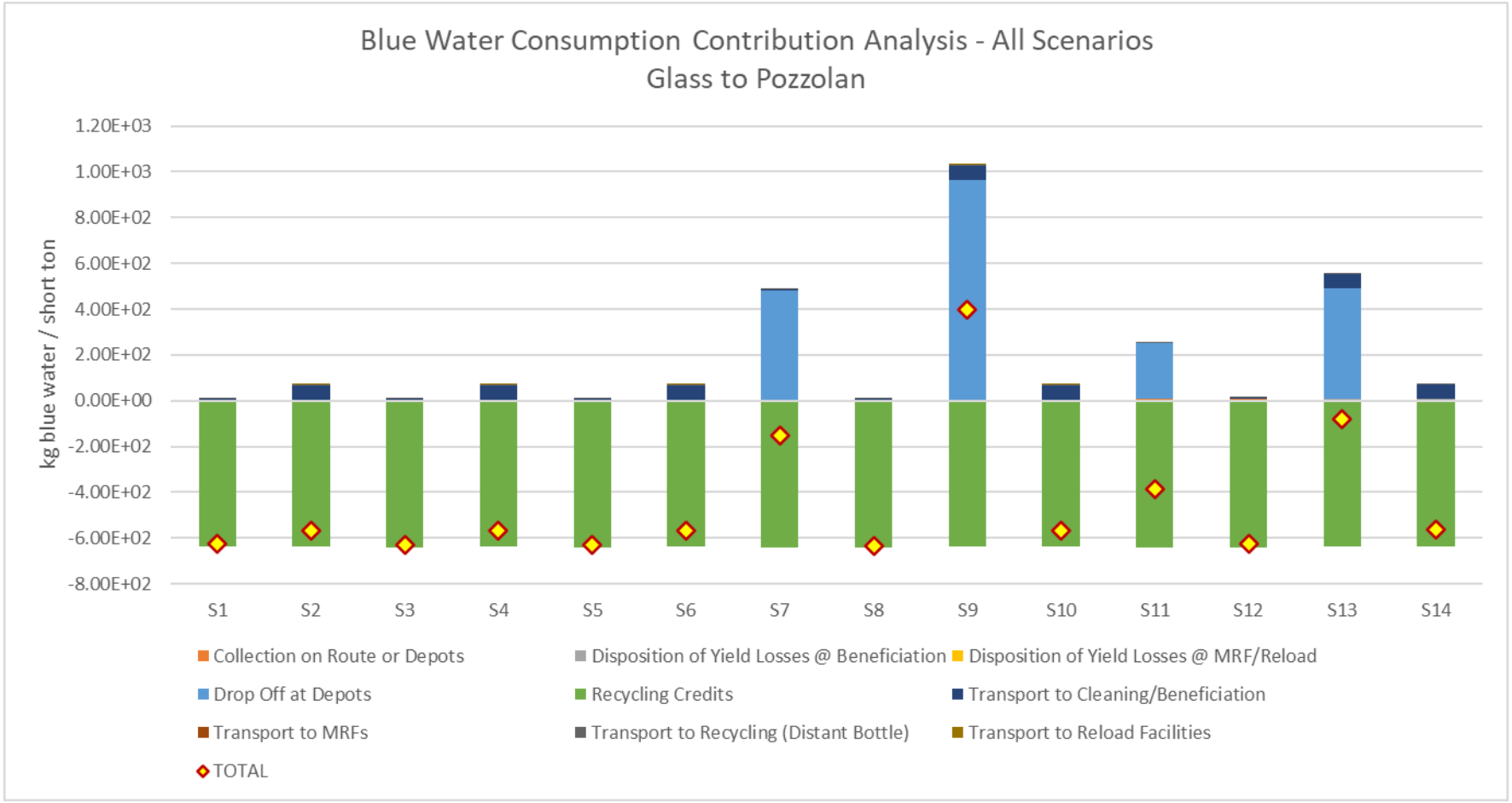
LCIA Results – Smog Formation Potential (SFP)



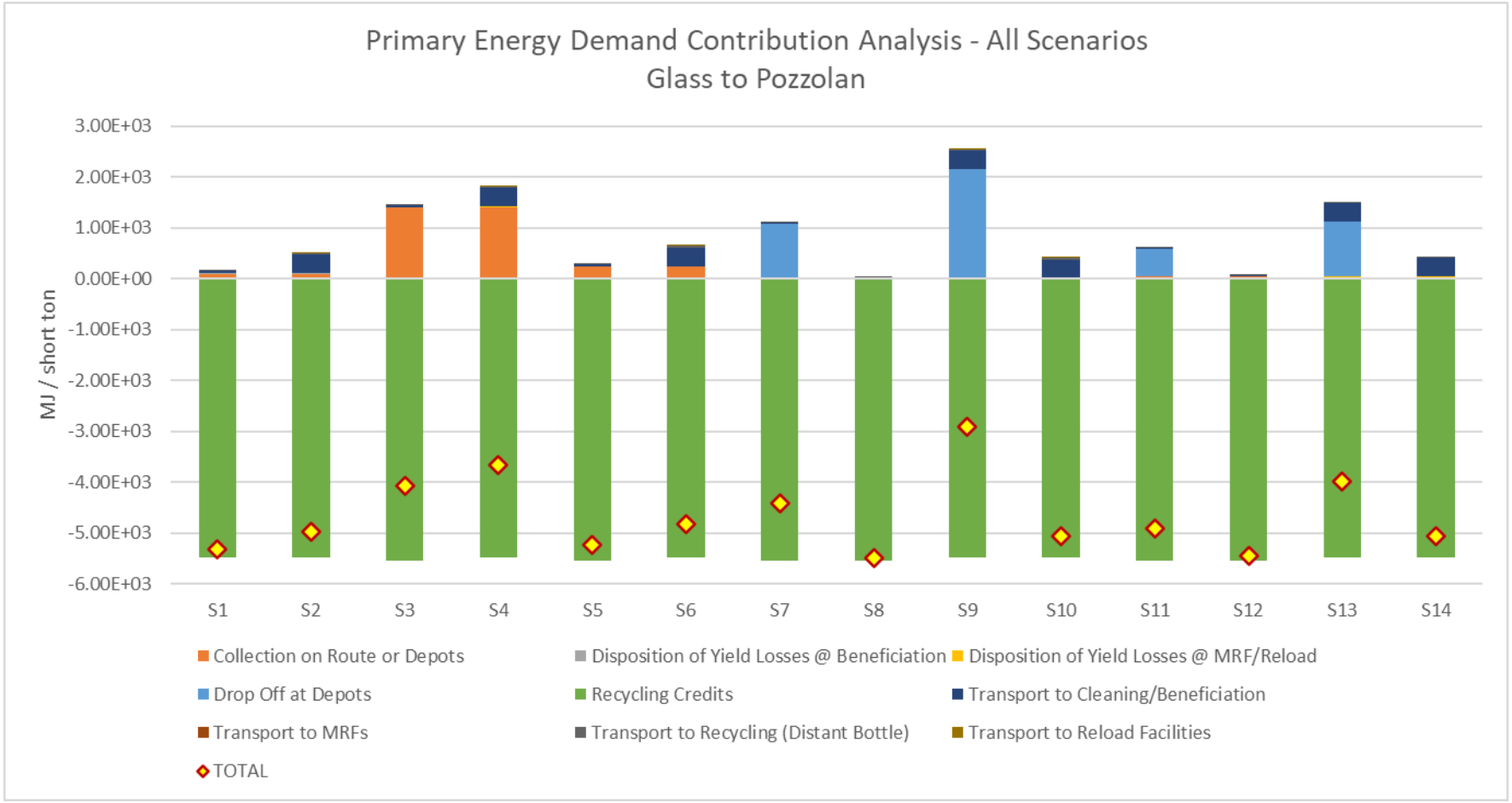
Indicator Results – Fossil Resource Use



Indicator Results – Bluewater Consumption



Indicator Results – Primary Energy Demand (PED)

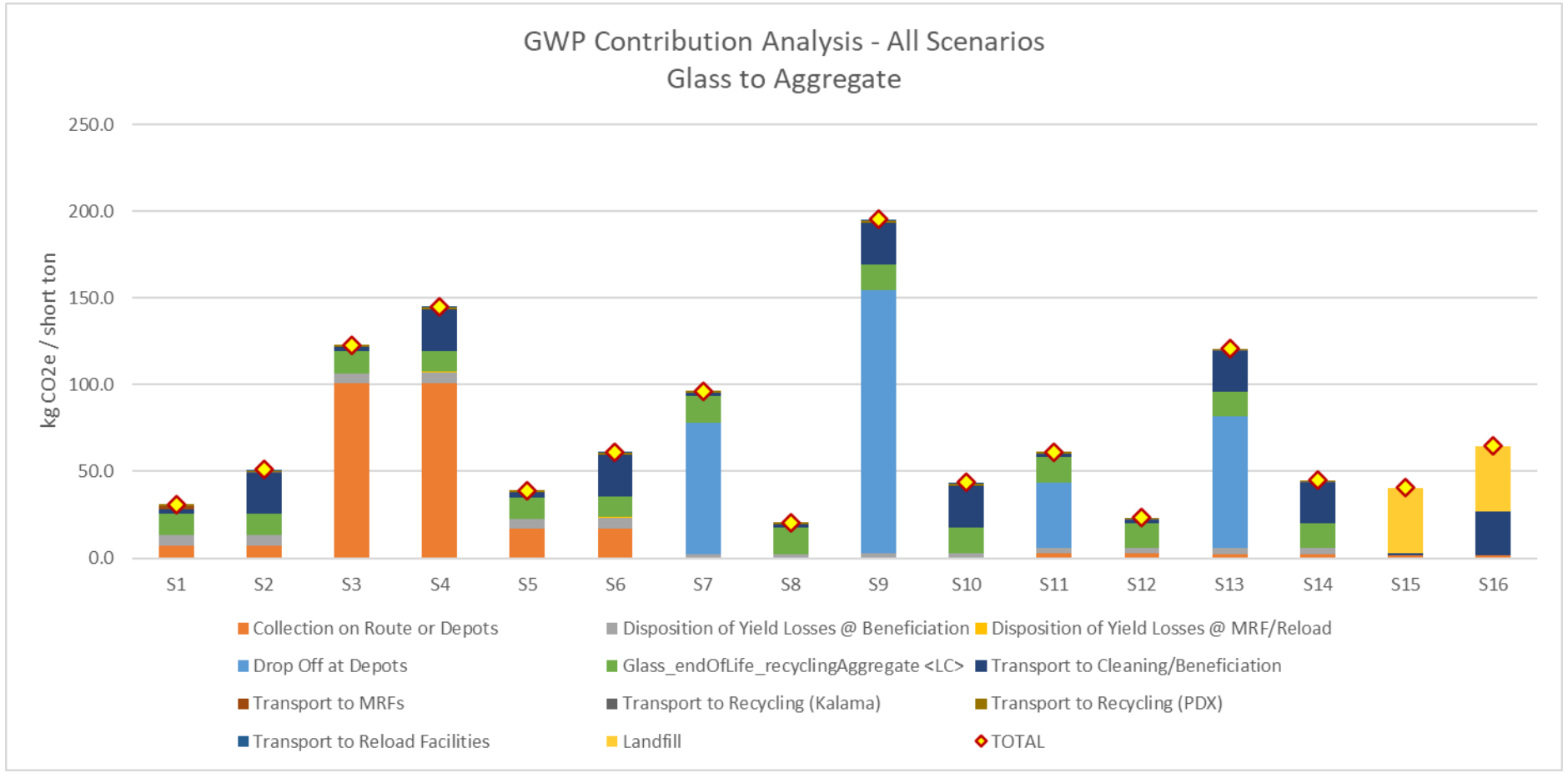


“Glass to Aggregate” Results

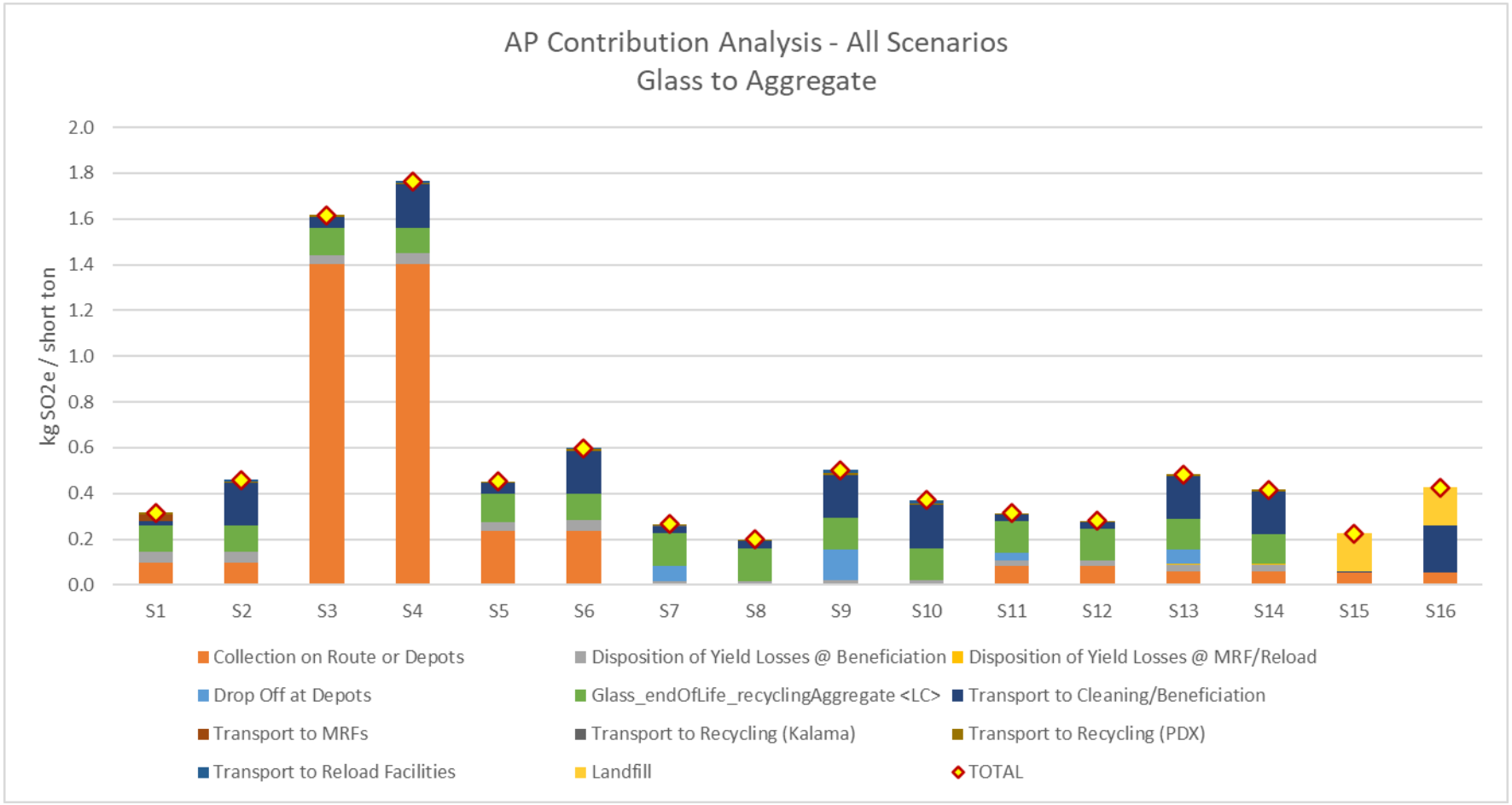
Hypothetical Location

Oregon

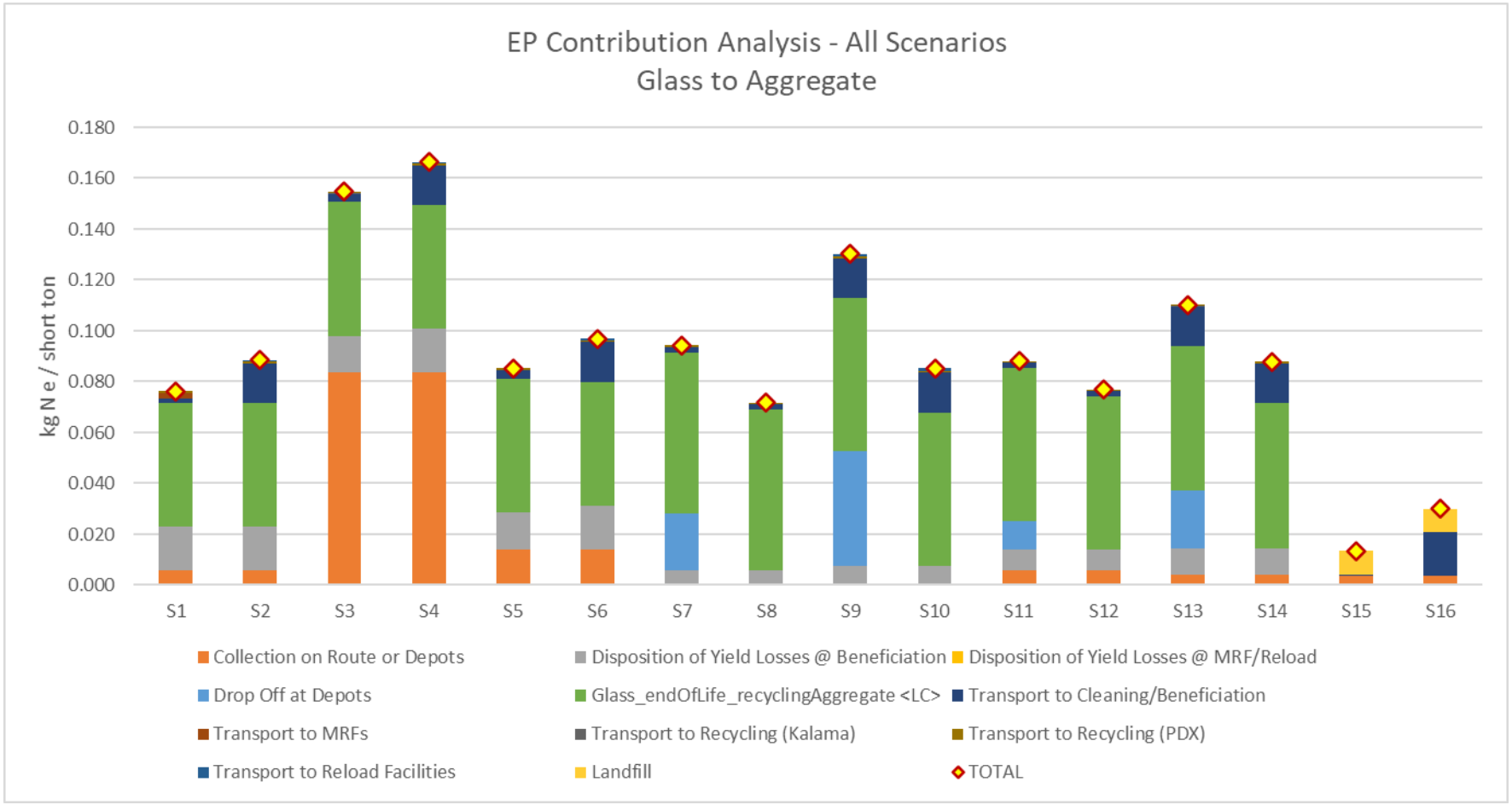
LCIA Results – Global Warming Potential (GWP)



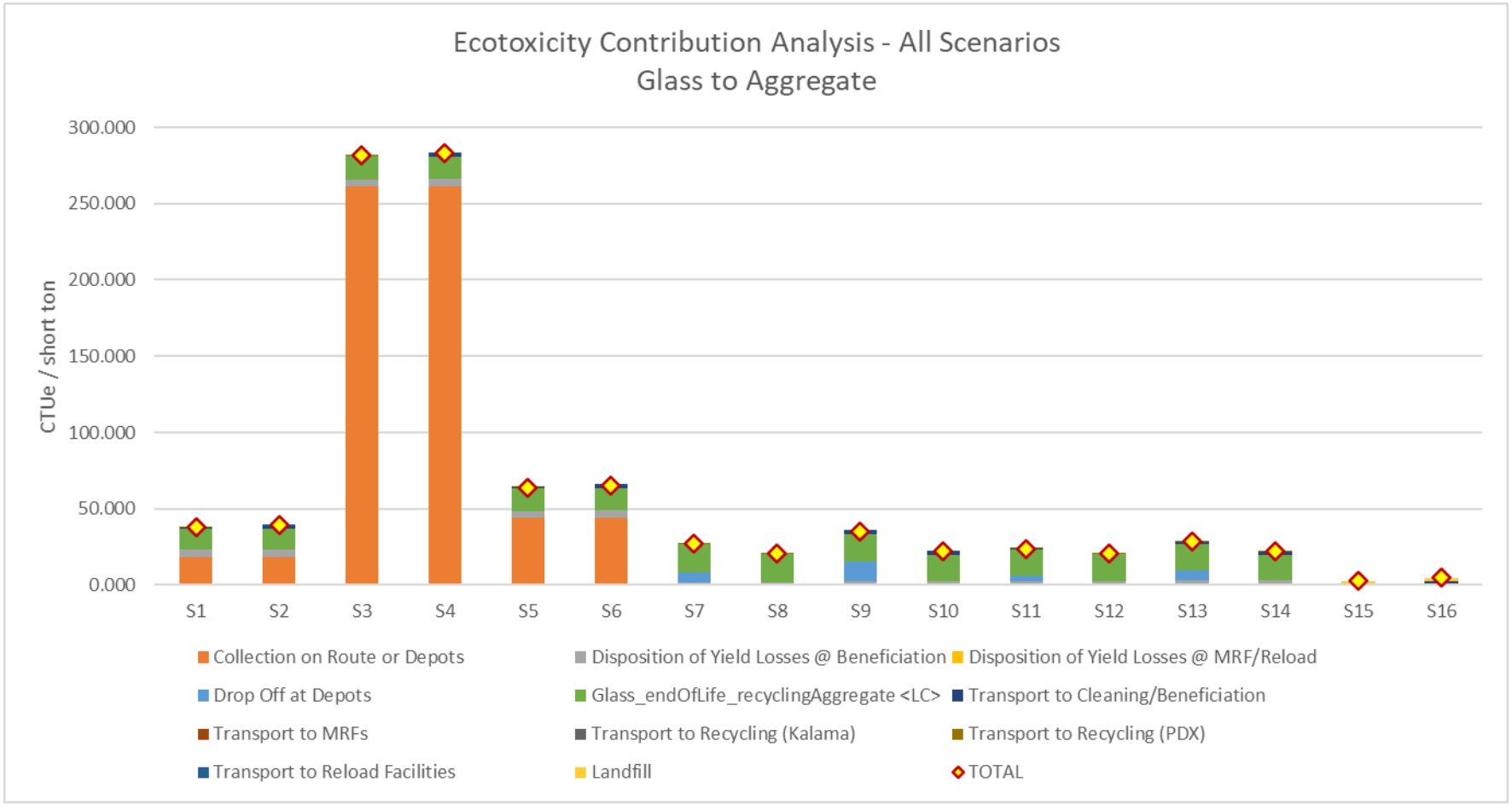
LCIA Results – Acidification Potential (AP)



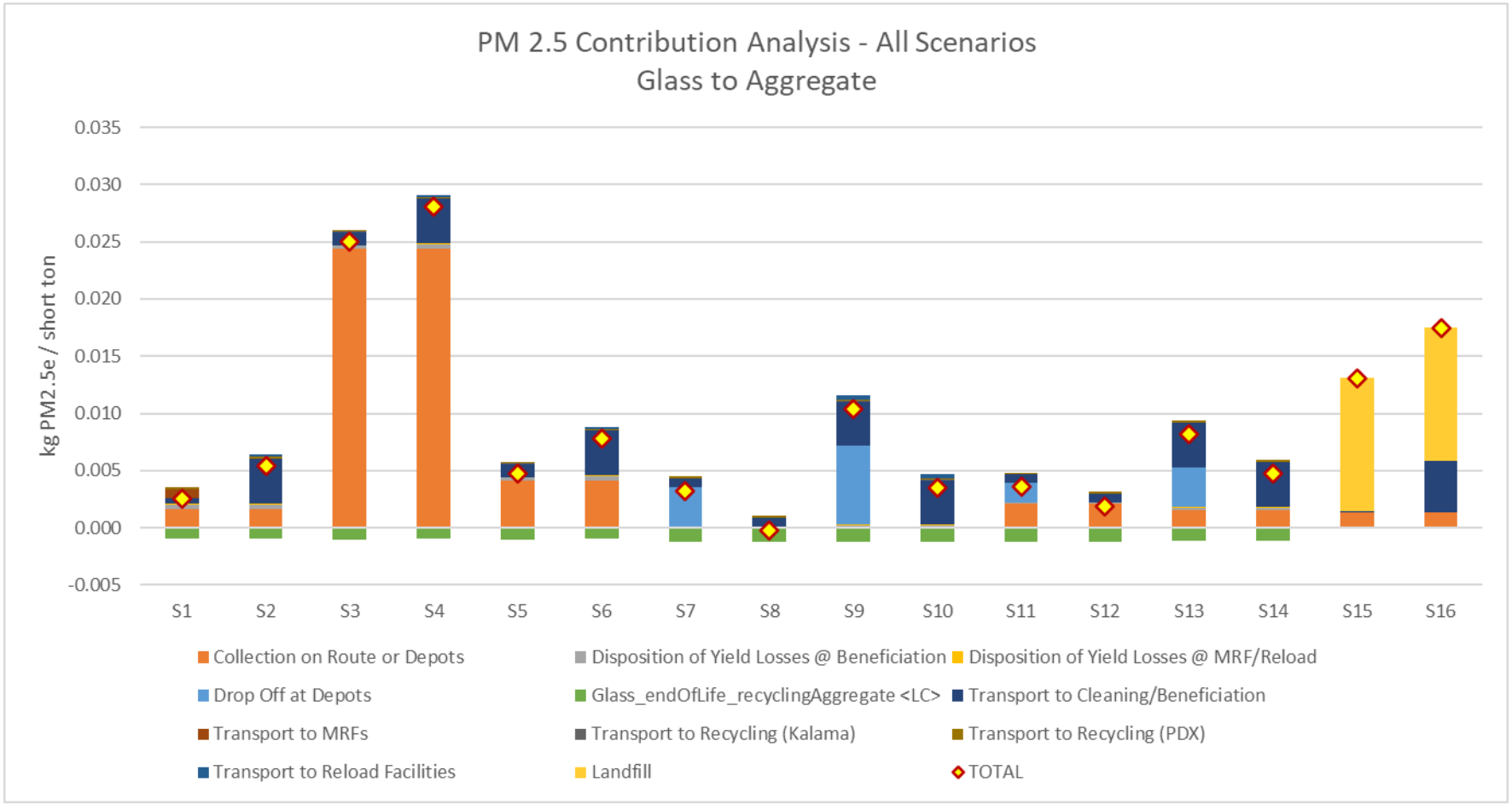
LCIA Results – Eutrophication Potential (EP)



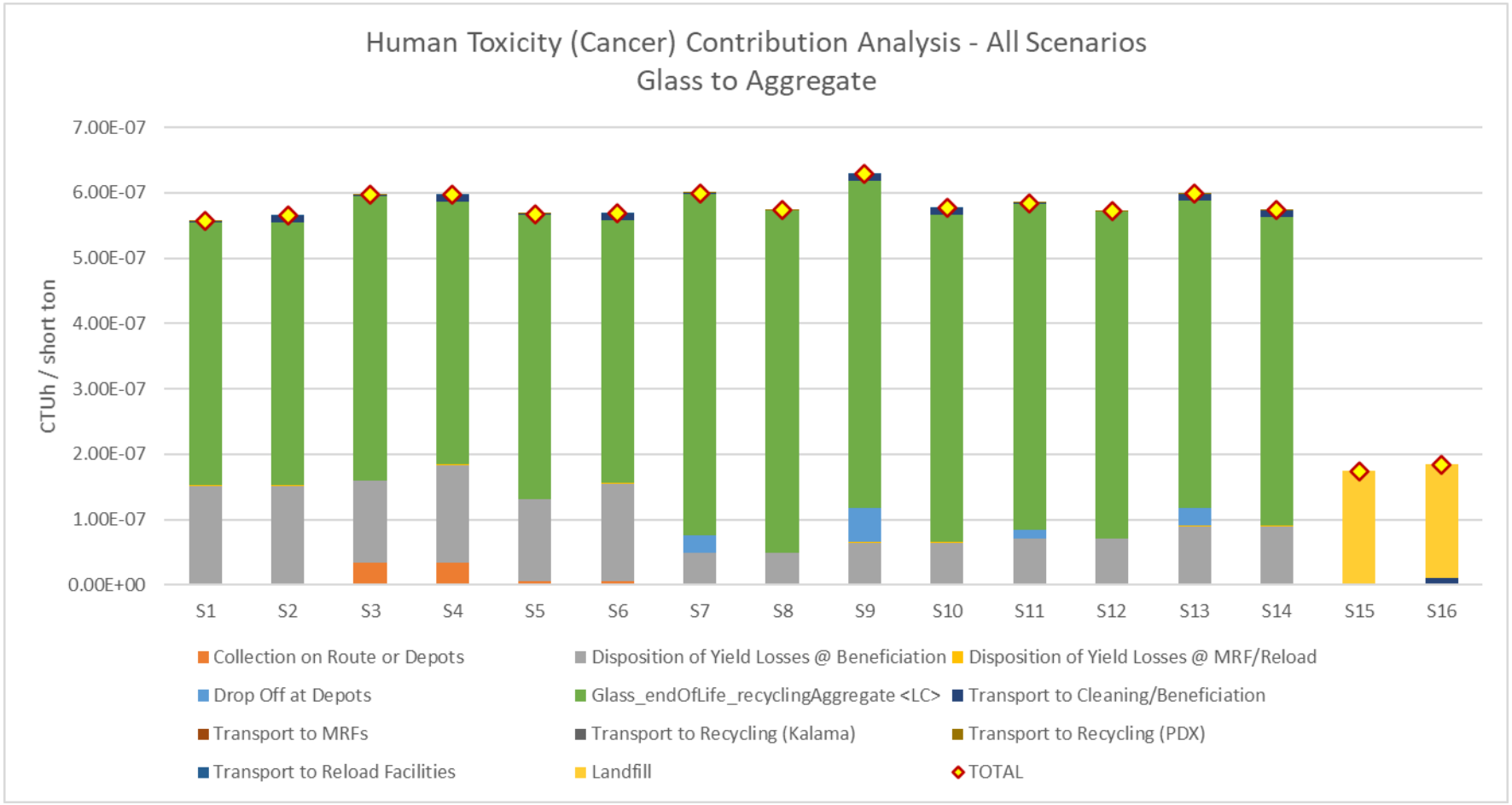
LCIA Results – Ecotoxicity Potential (ETP)



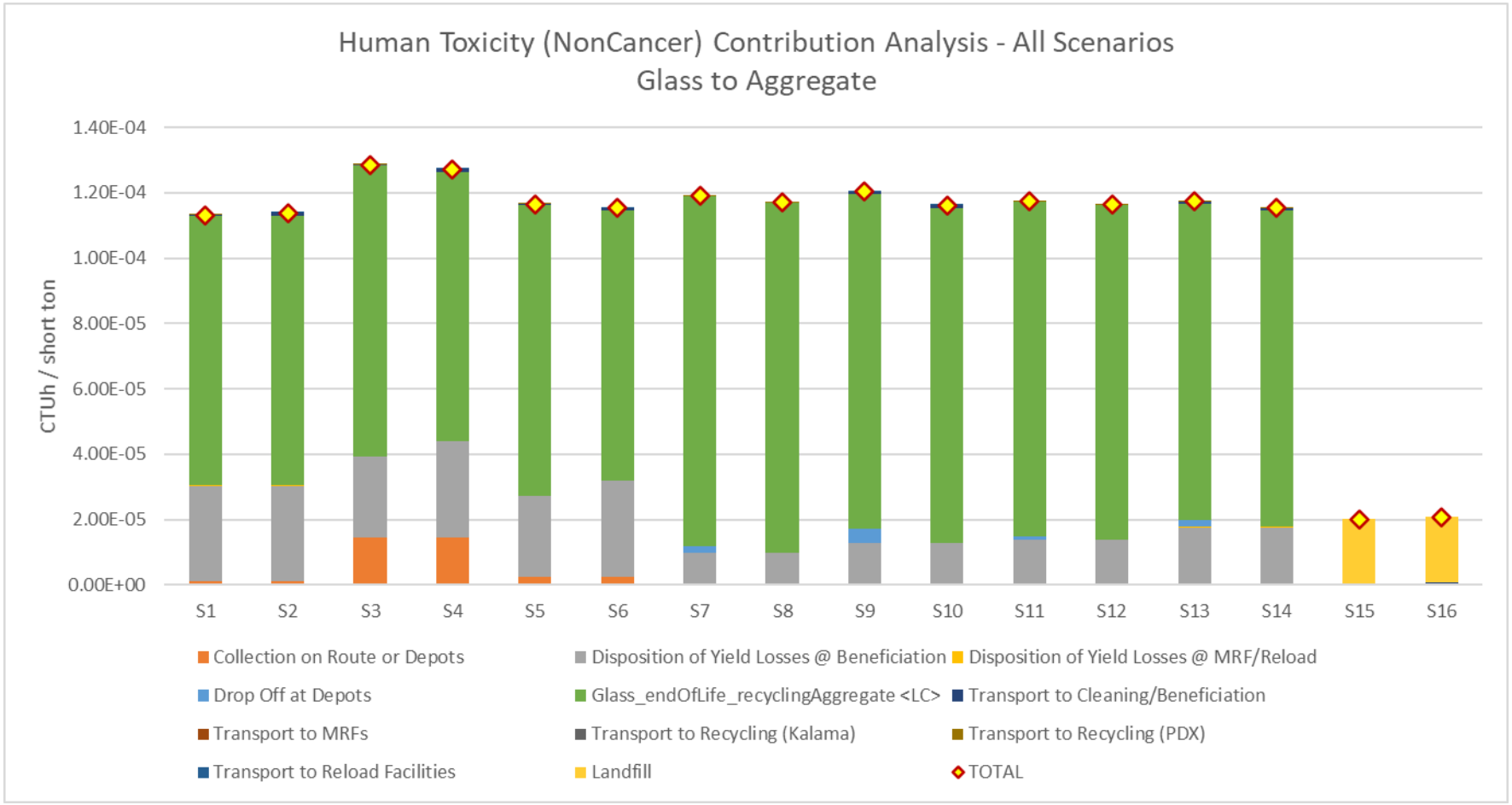
LCIA Results – Particulate Matter (PM 2.5)



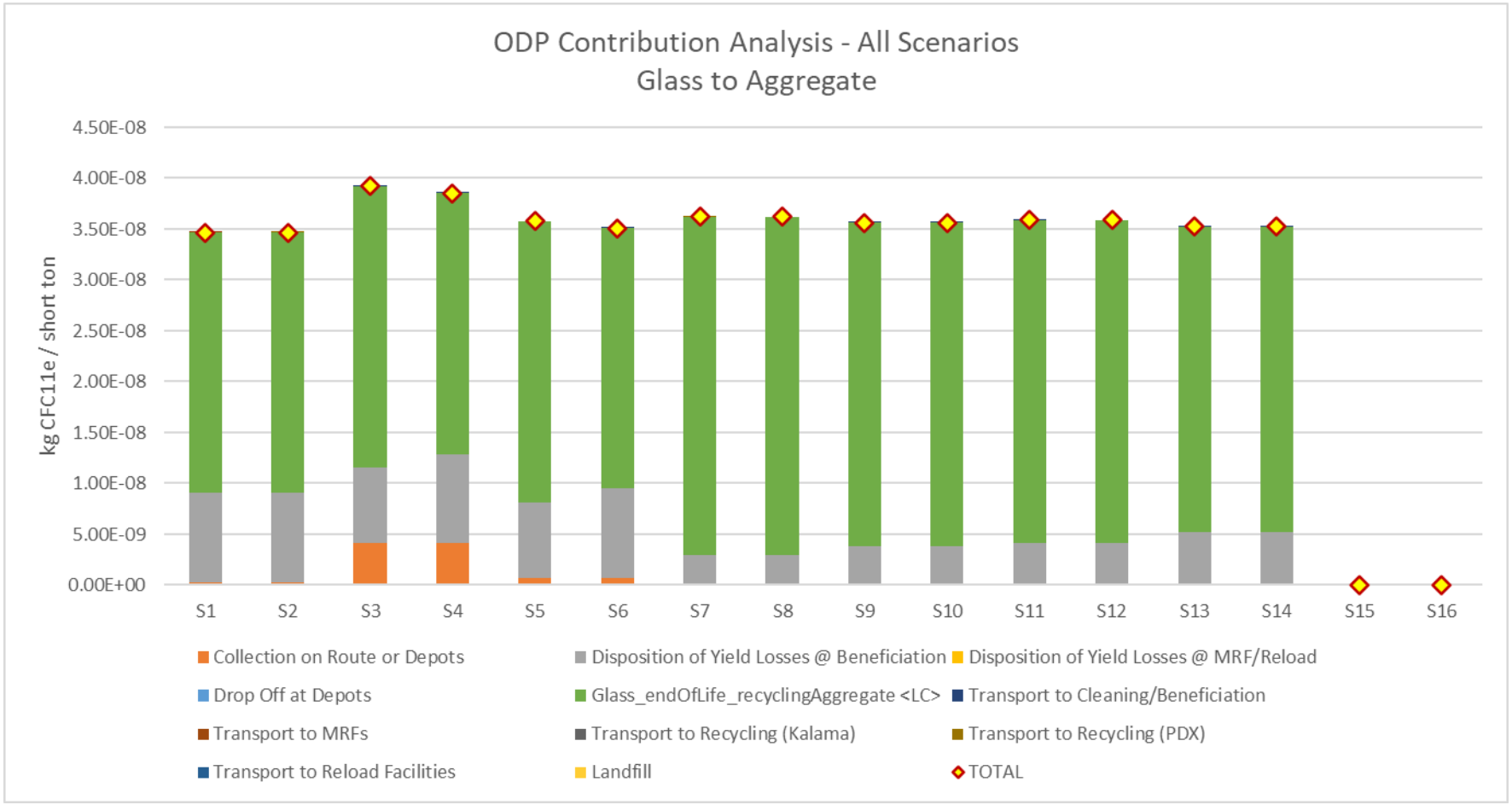
LCIA Results – Human Toxicity Potential (Cancer)



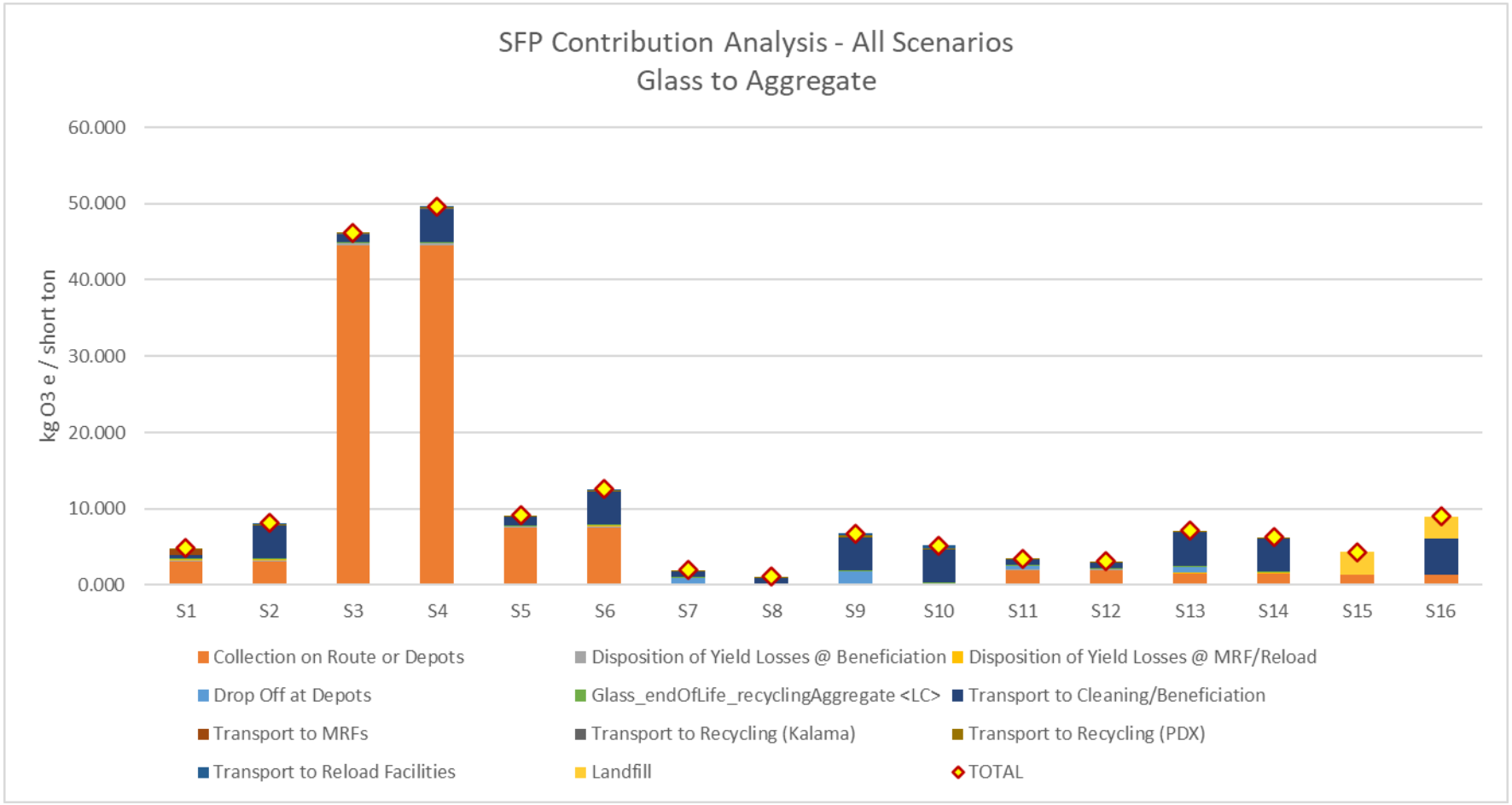
LCIA Results - Human Toxicity Potential (NonCancer)



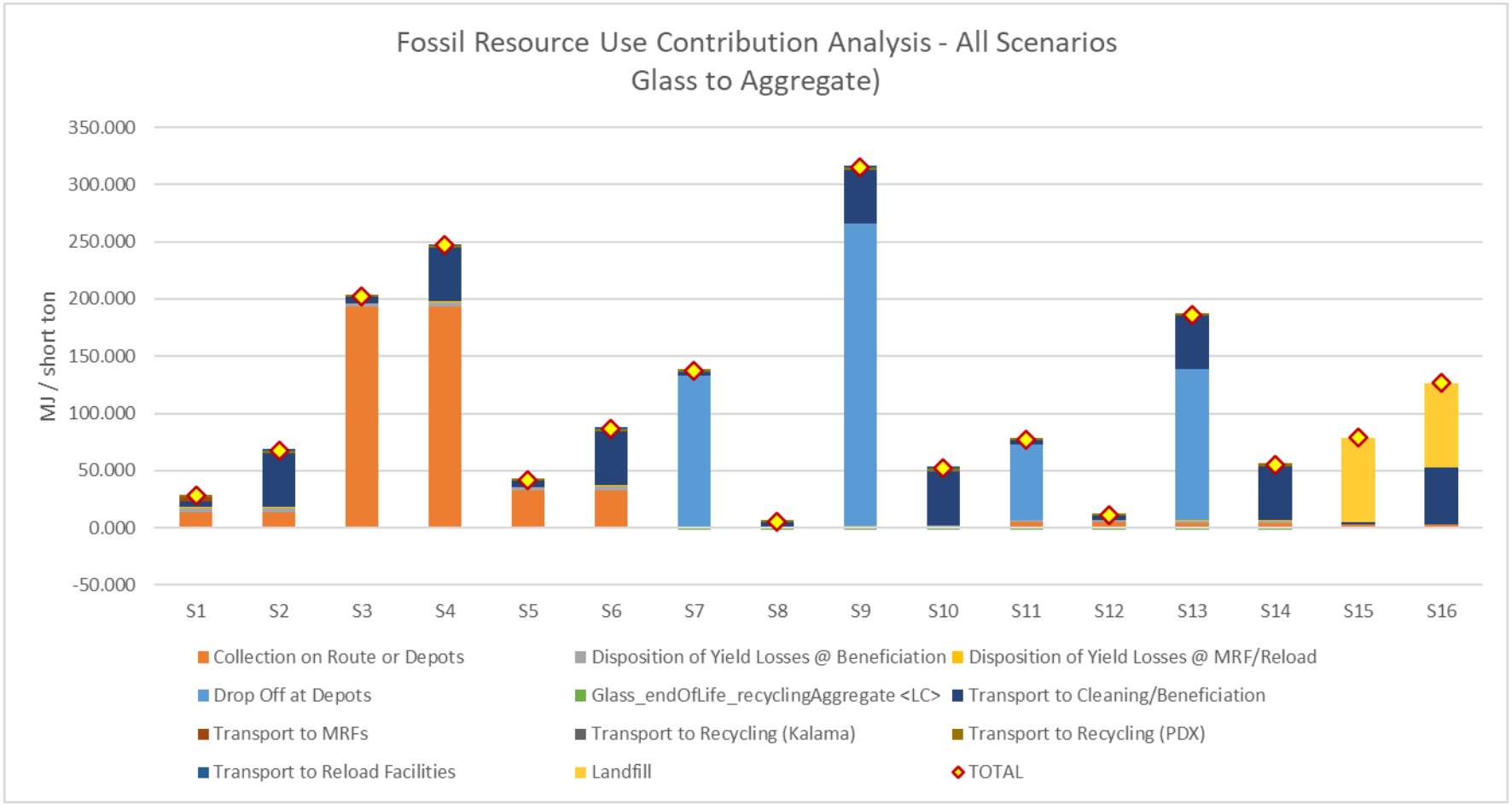
LCIA Results – Ozone Depletion Potential (ODP)



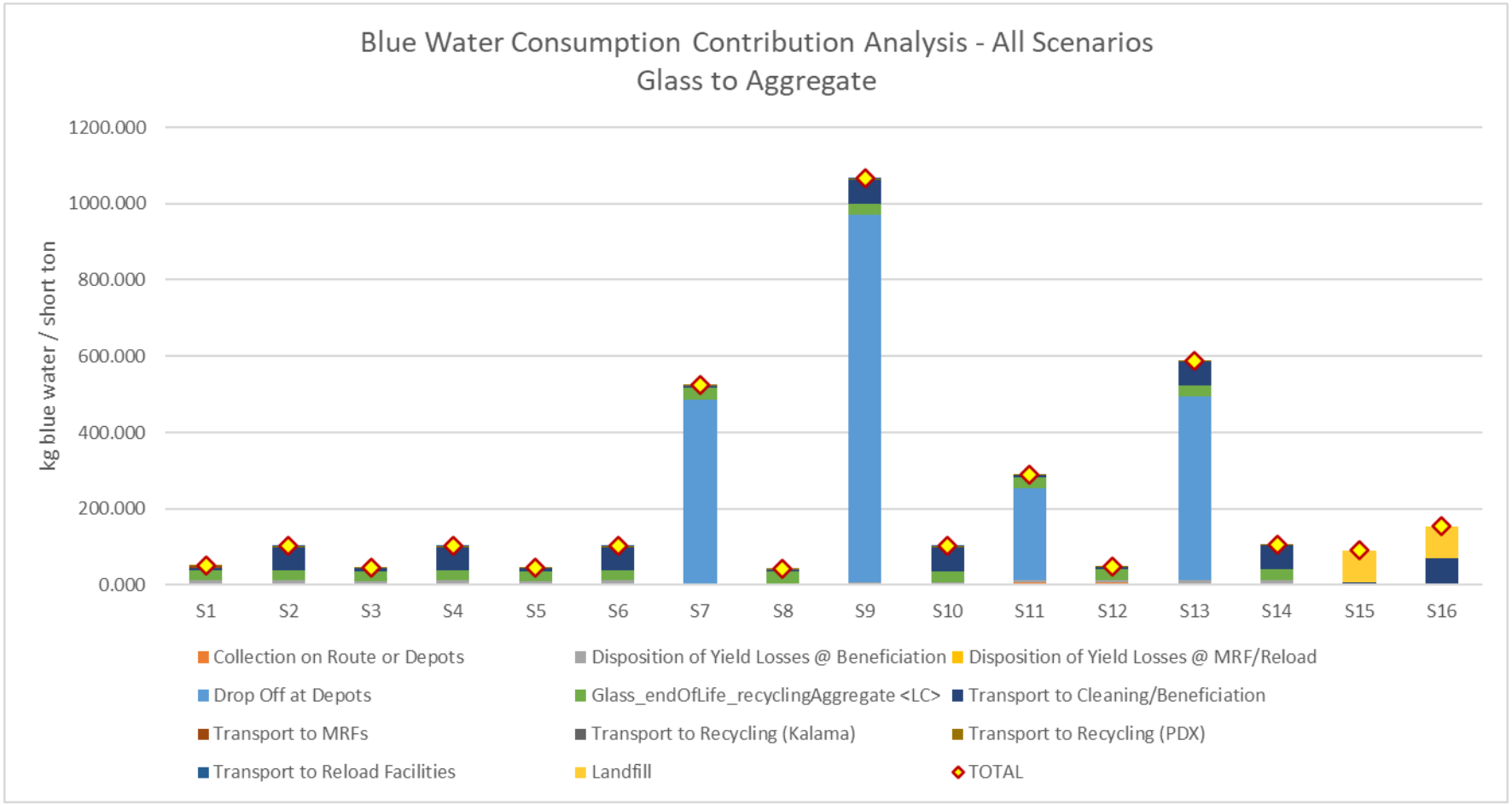
LCIA Results – Smog Formation Potential (SFP)



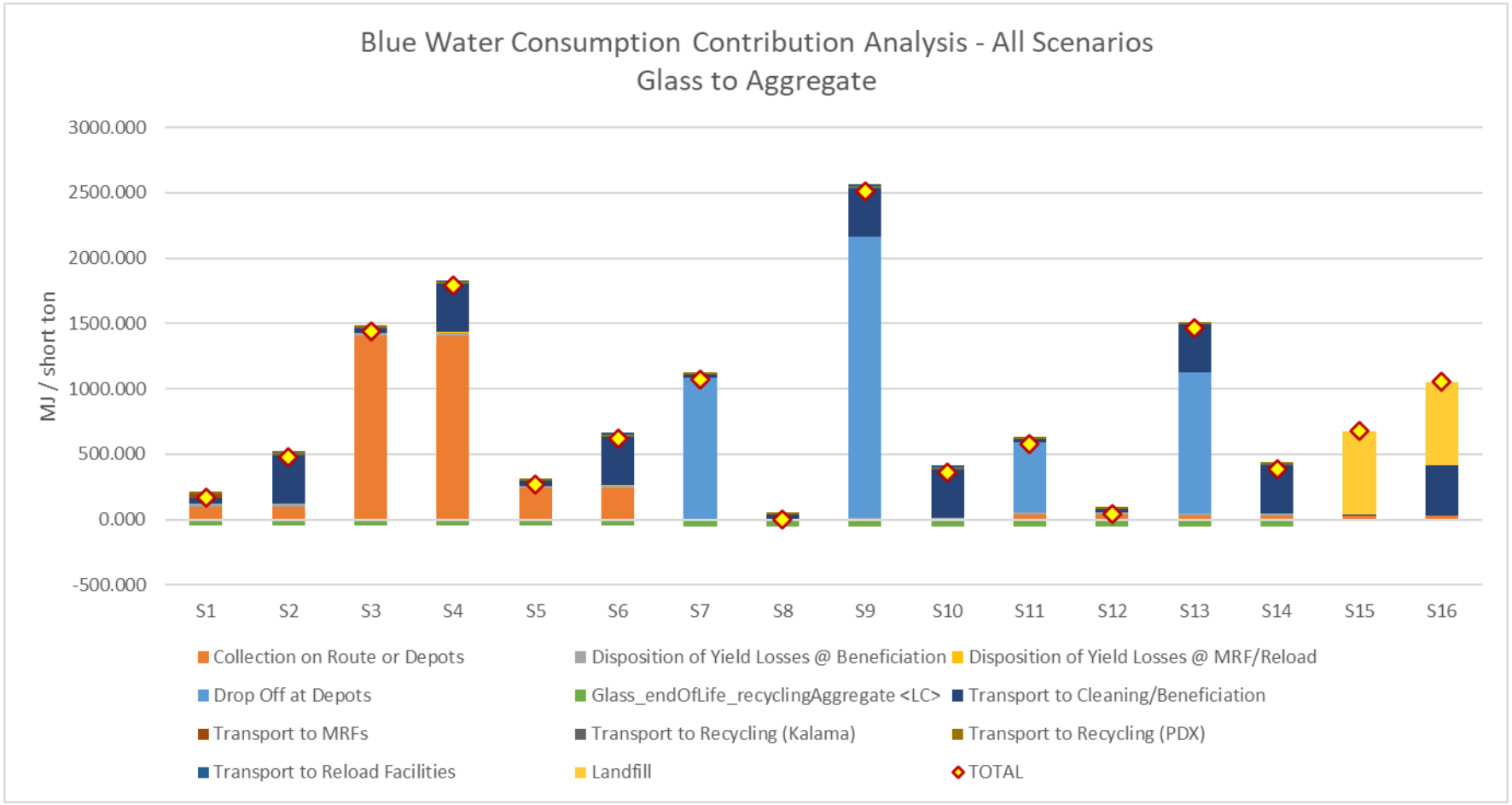
Indicator Results – Fossil Resource Use



Indicator Results – Bluewater Consumption



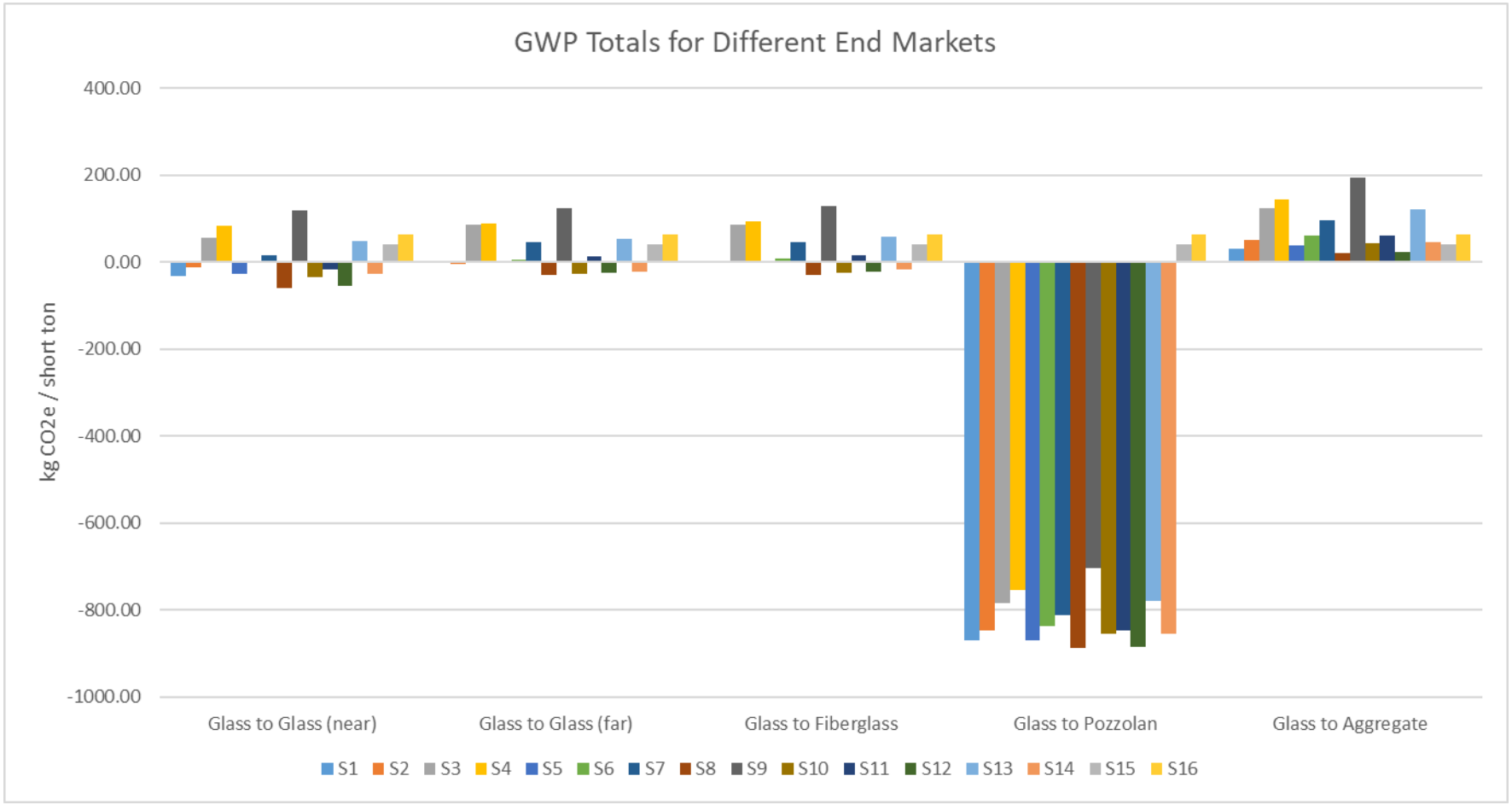
Indicator Results – Primary Energy Demand (PED)



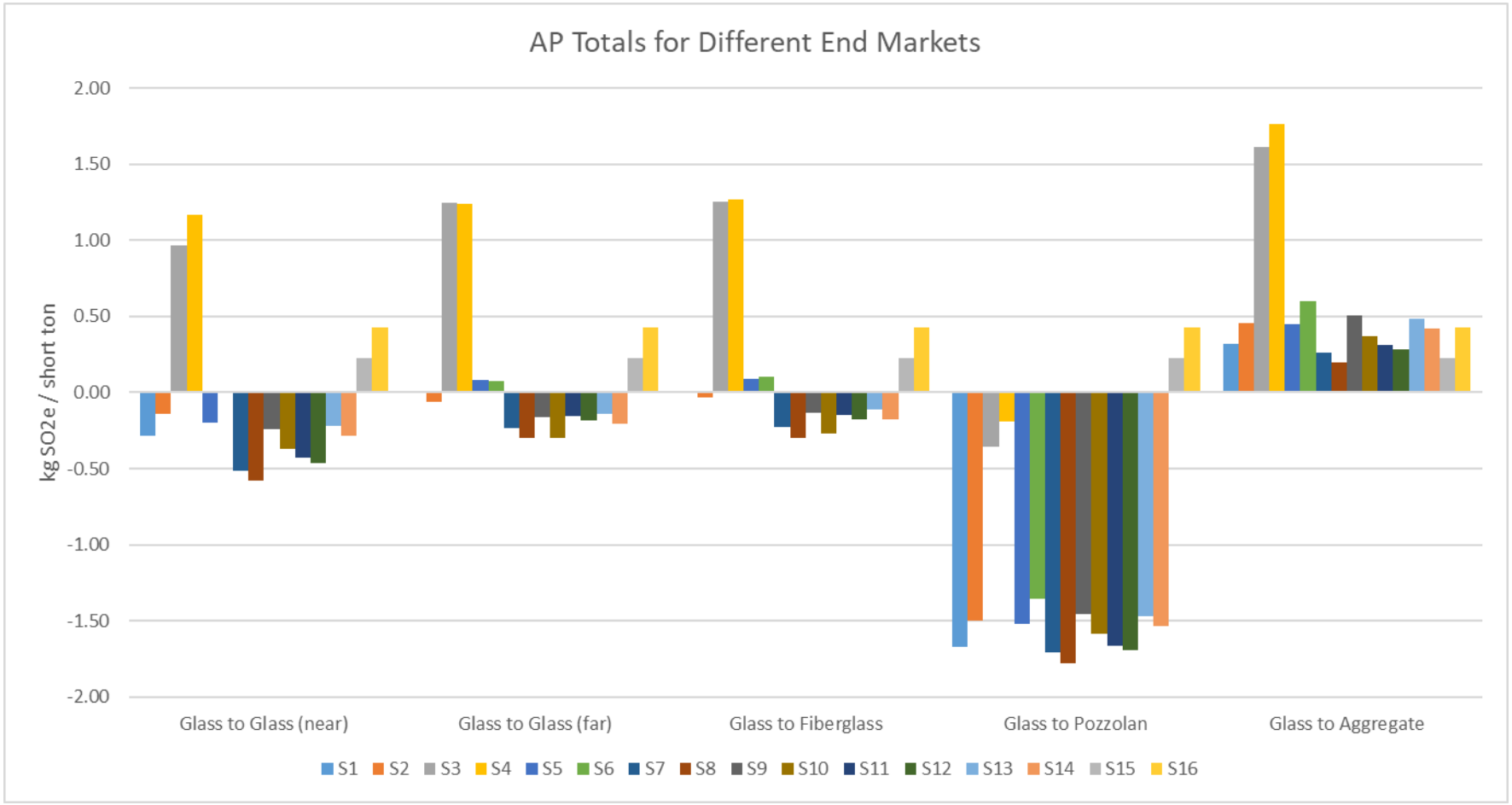
Comparison of End Markets

Glass to Glass vs. Glass to Fiberglass vs. Glass to Pozzolan vs. Glass to Aggregate

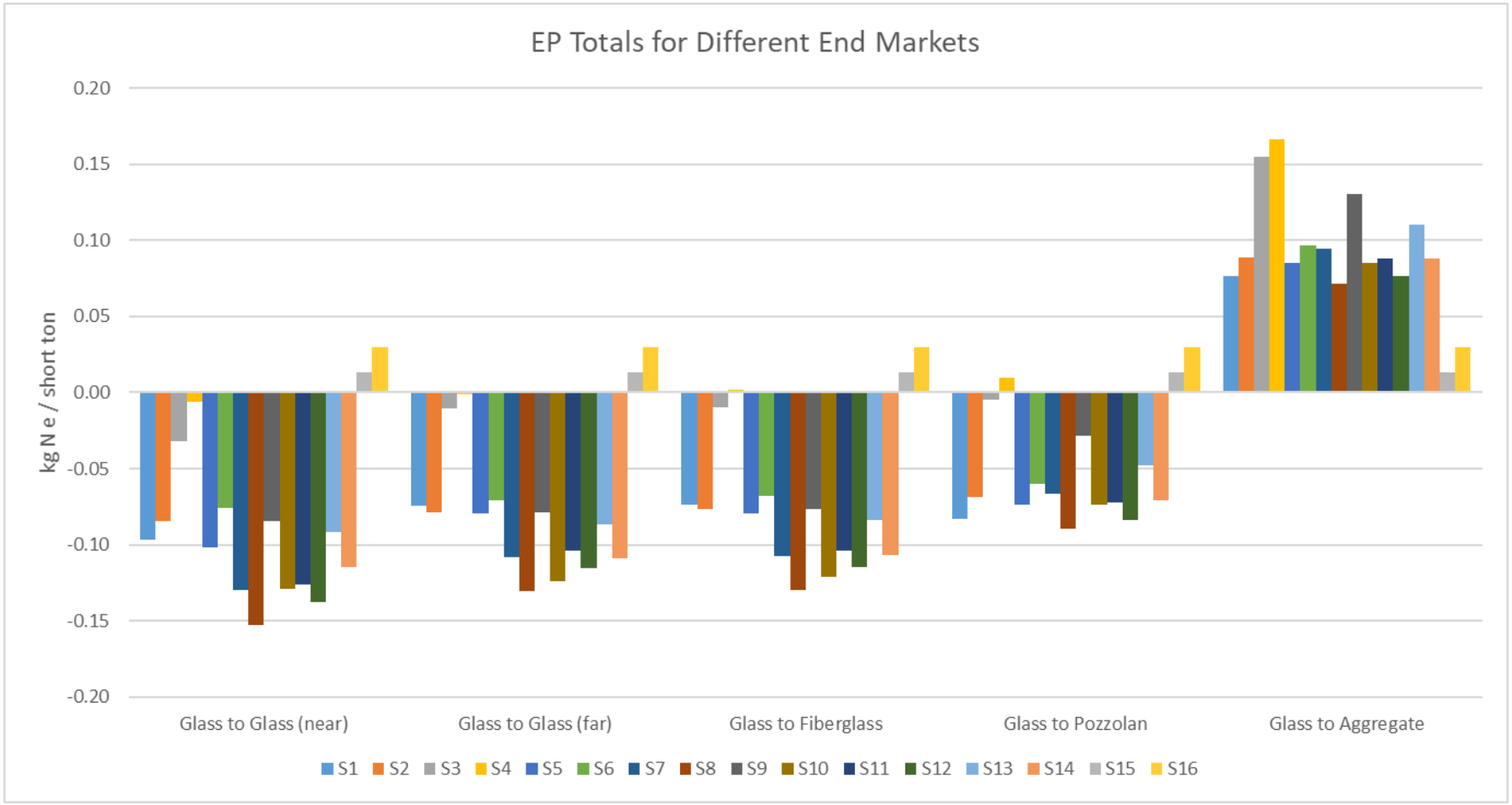
LCIA Results – Global Warming Potential (GWP)



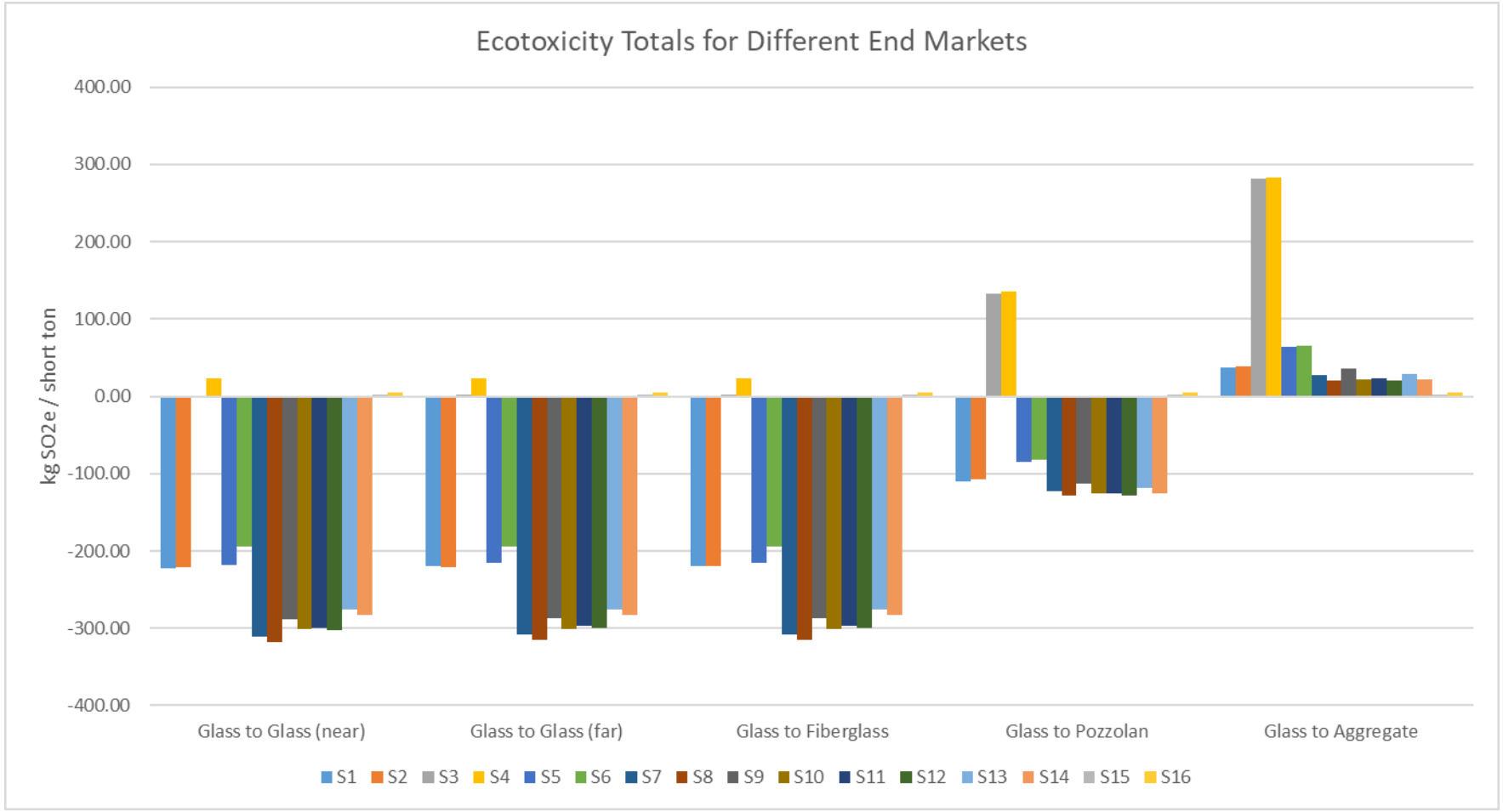
LCIA Results – Acidification Potential (AP)



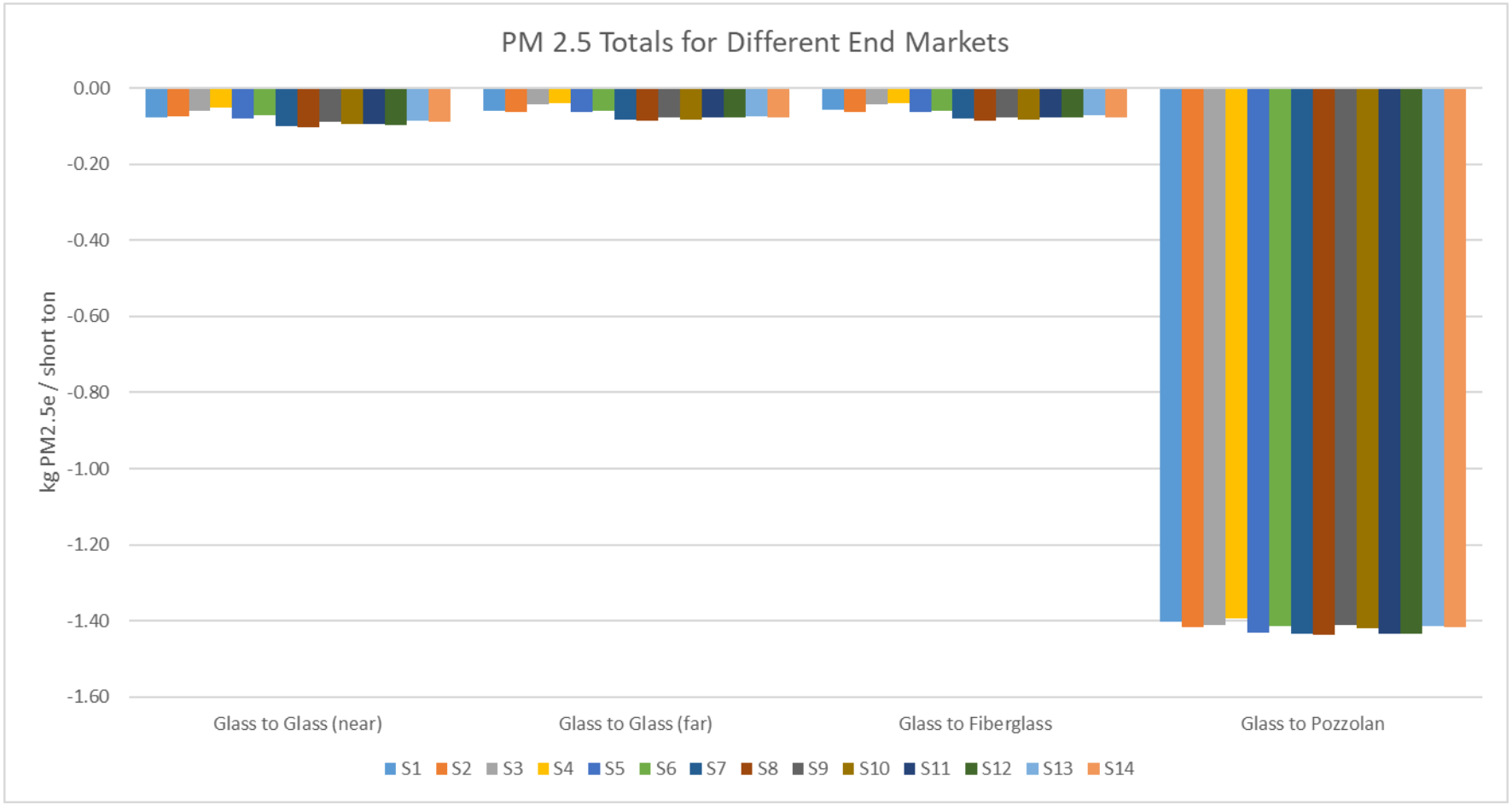
LCIA Results – Eutrophication Potential (EP)



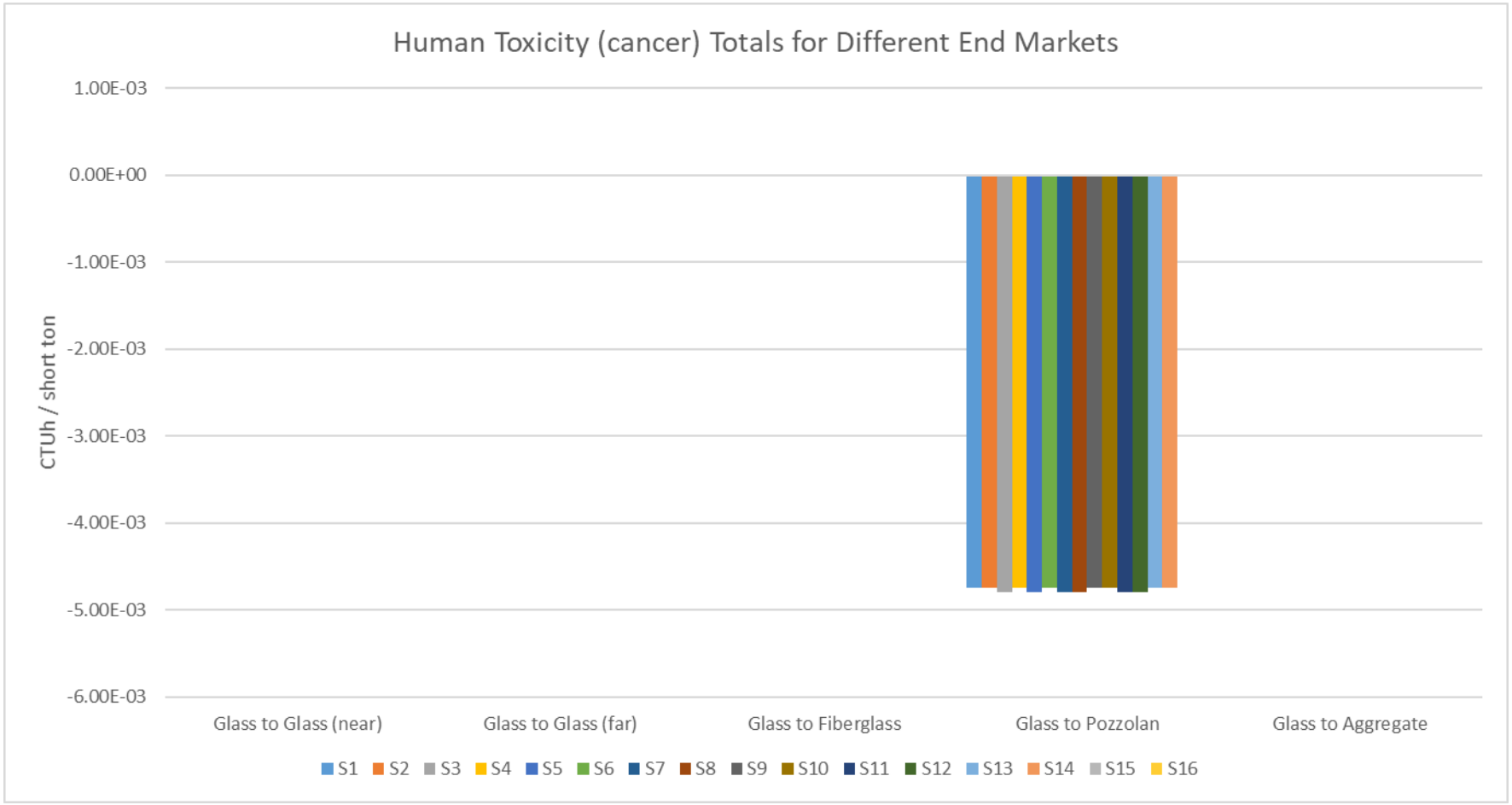
LCIA Results – Ecotoxicity Potential (ETP)



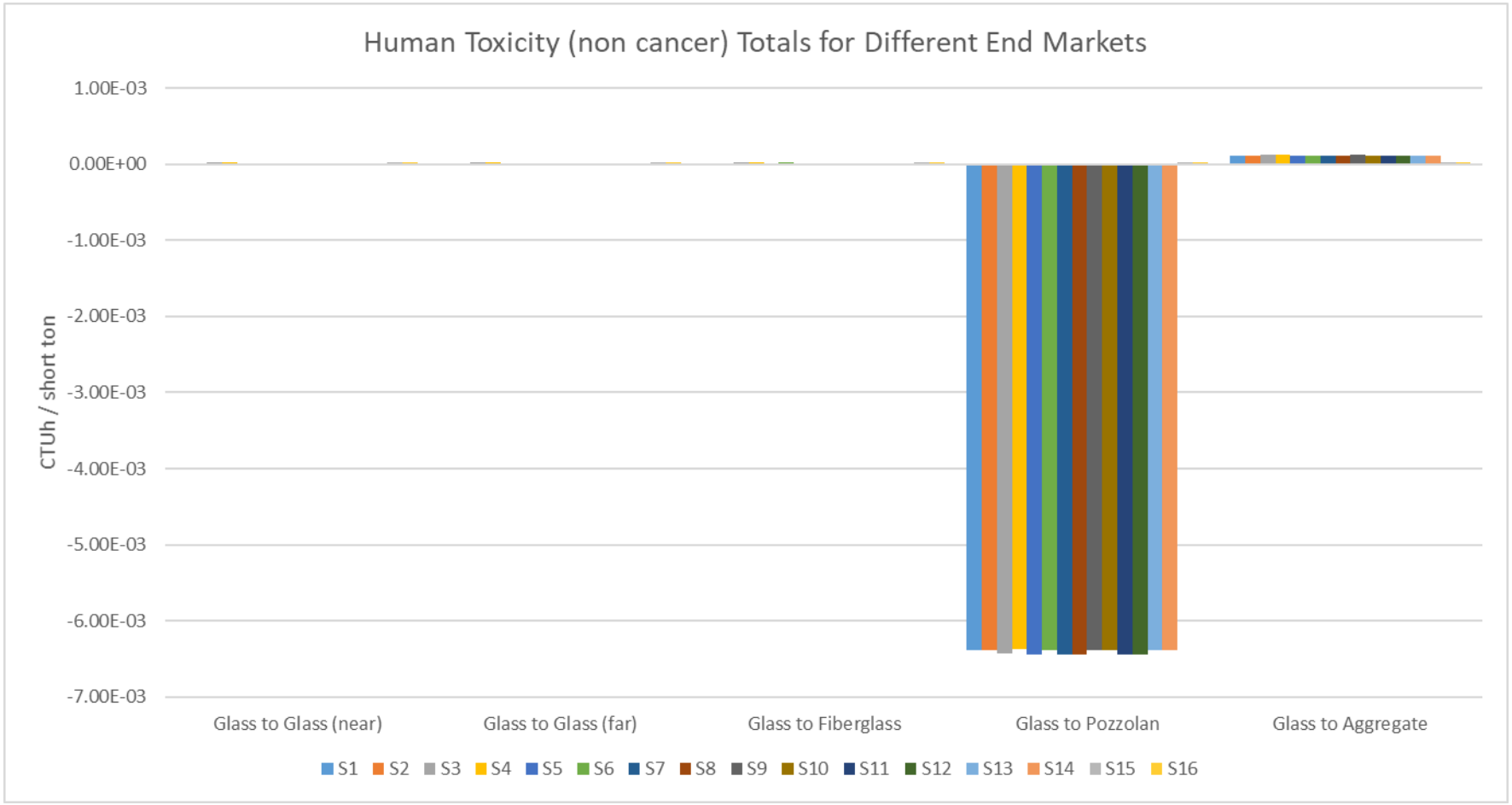
LCIA Results – Particulate Matter (PM 2.5)



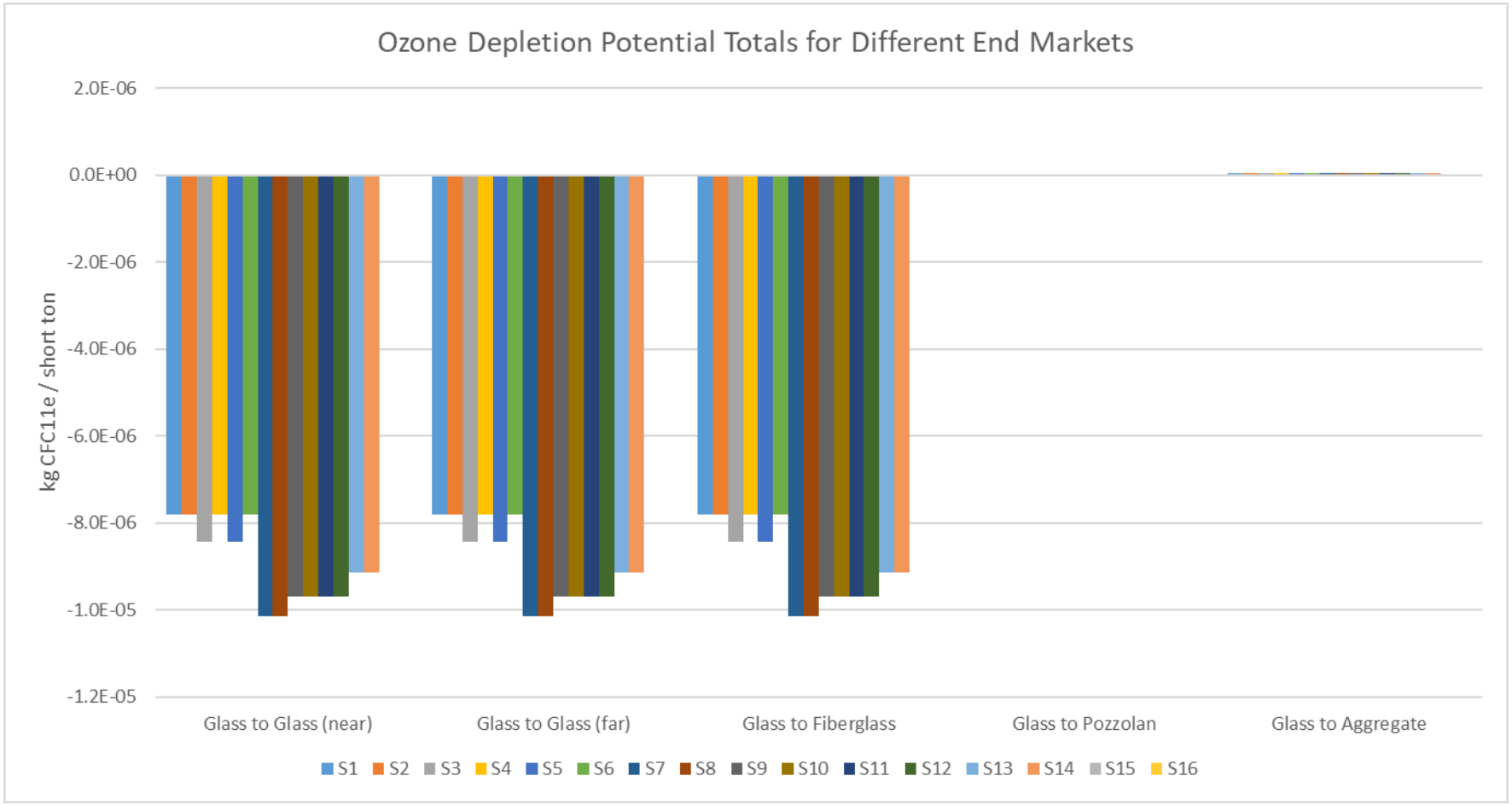
LCIA Results – Human Toxicity Potential (Cancer)



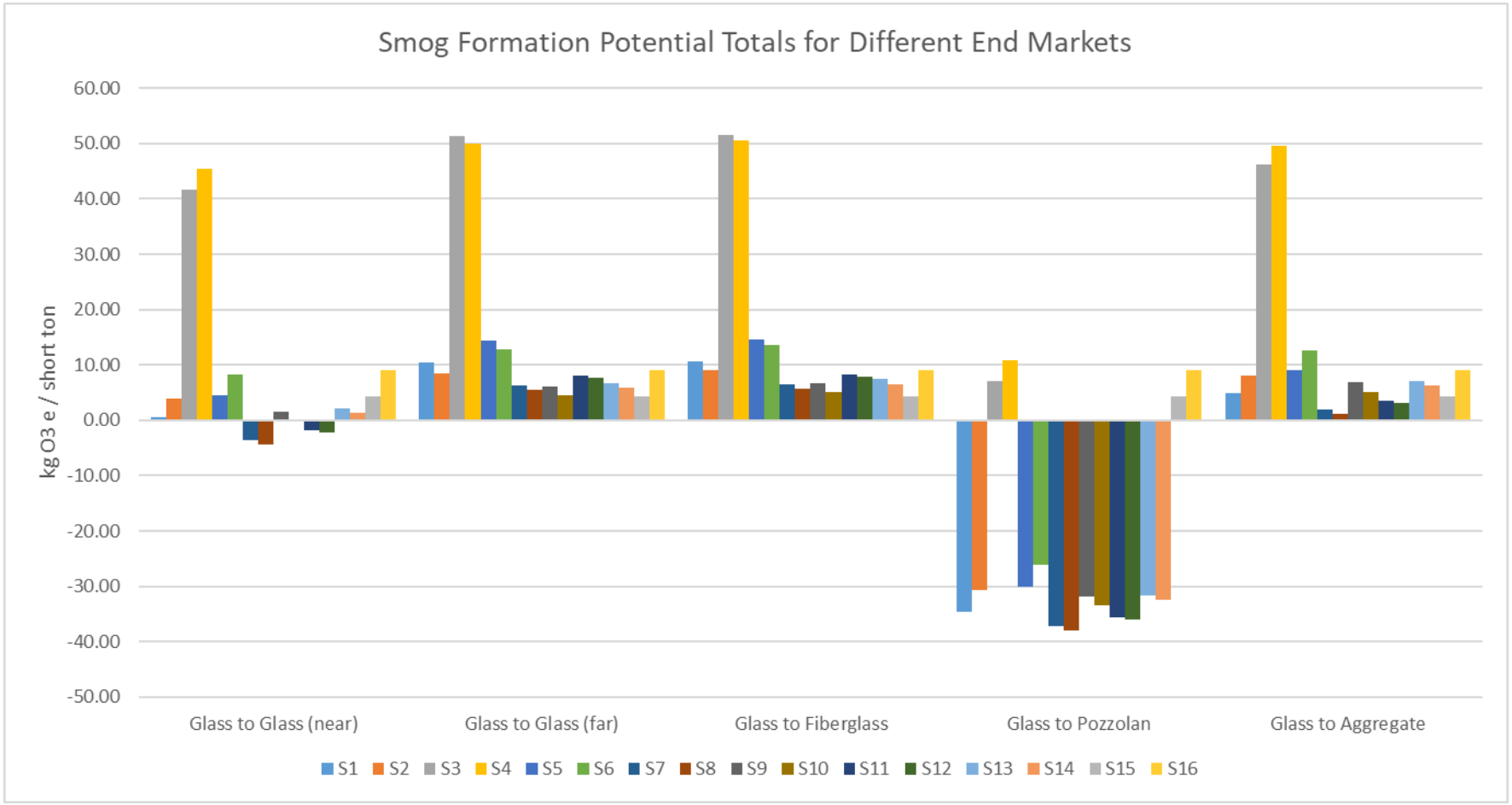
LCIA Results - Human Toxicity Potential (NonCancer)



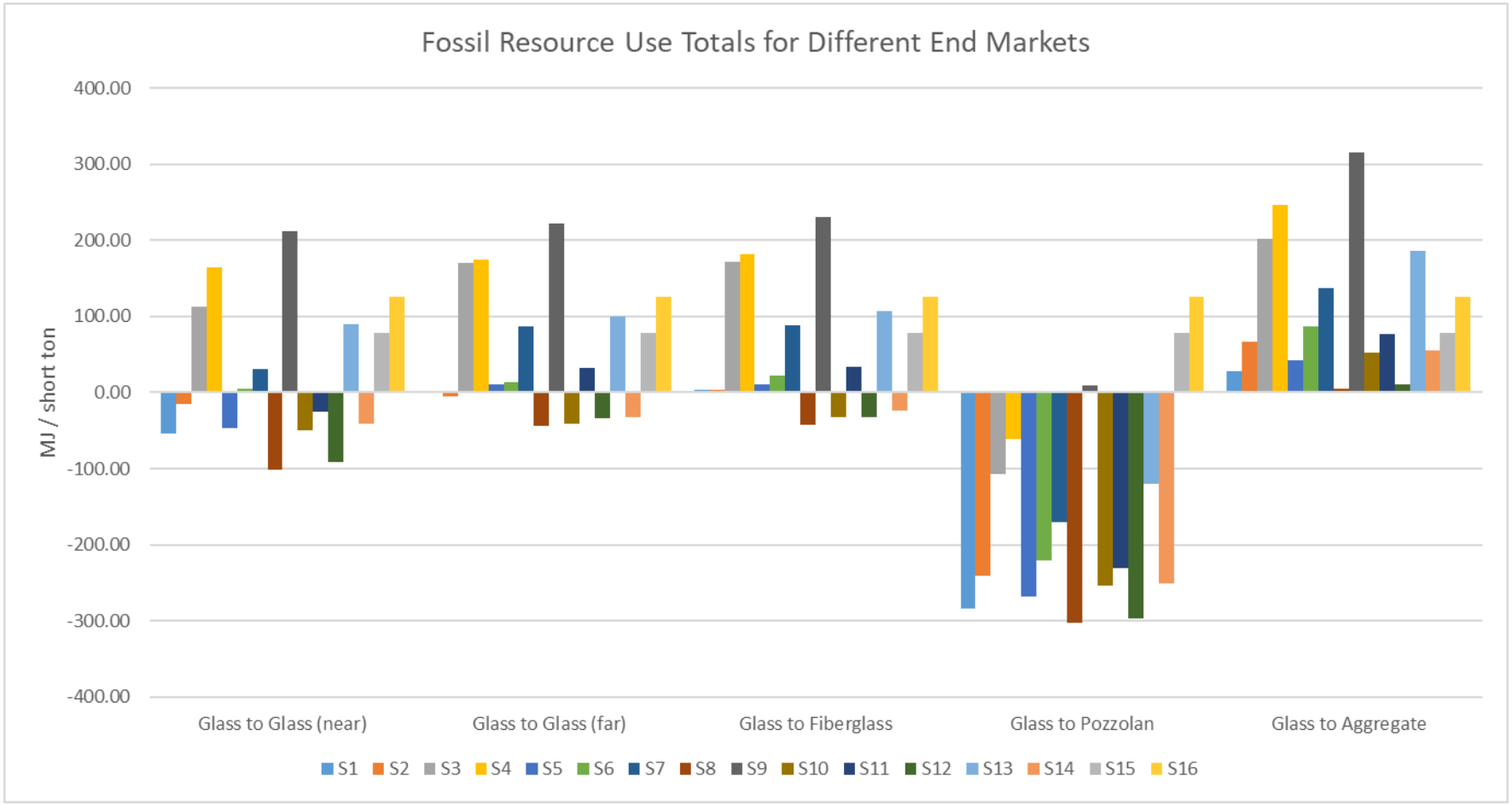
LCIA Results – Ozone Depletion Potential (ODP)



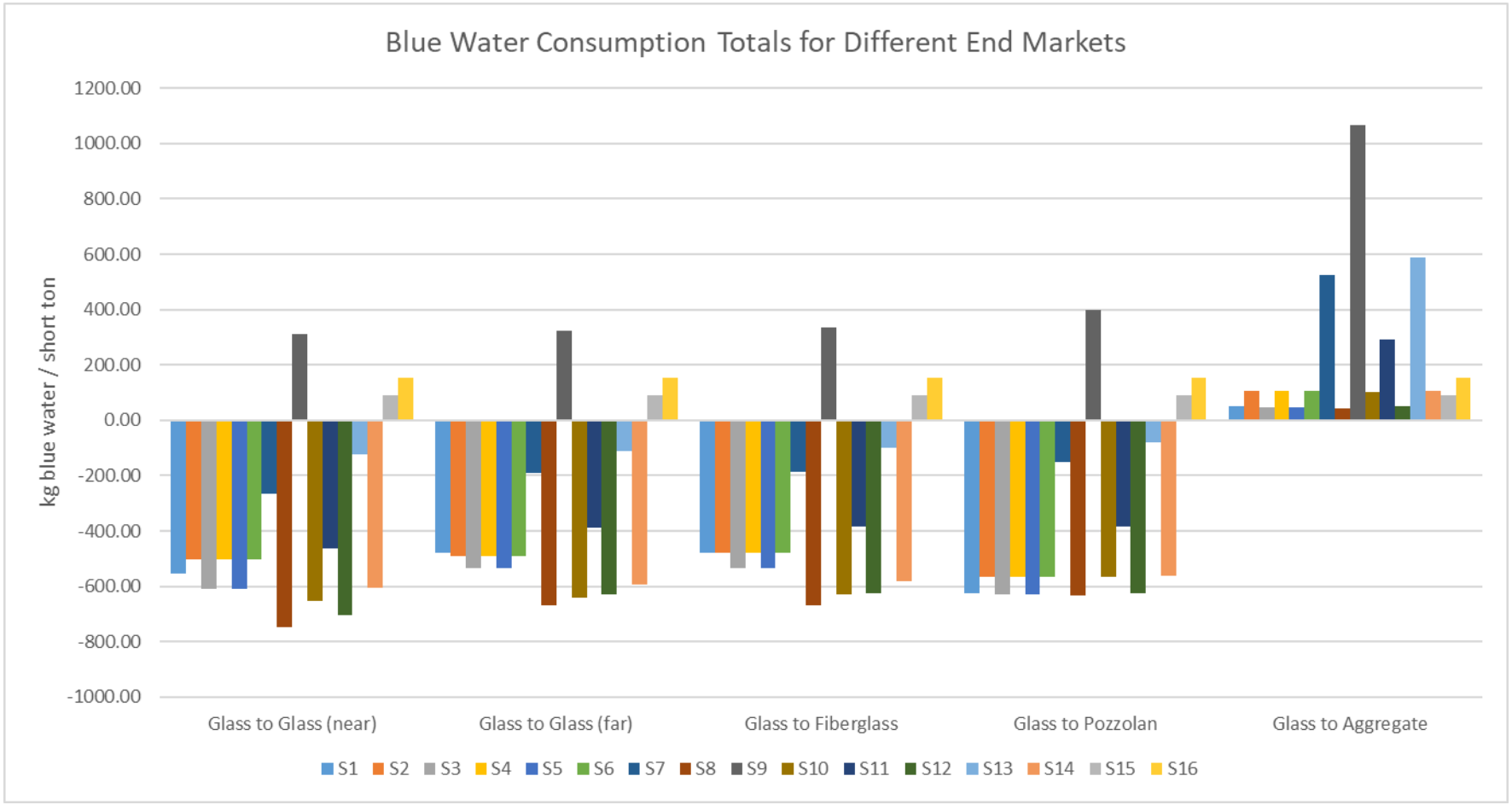
LCIA Results – Smog Formation Potential (SFP)



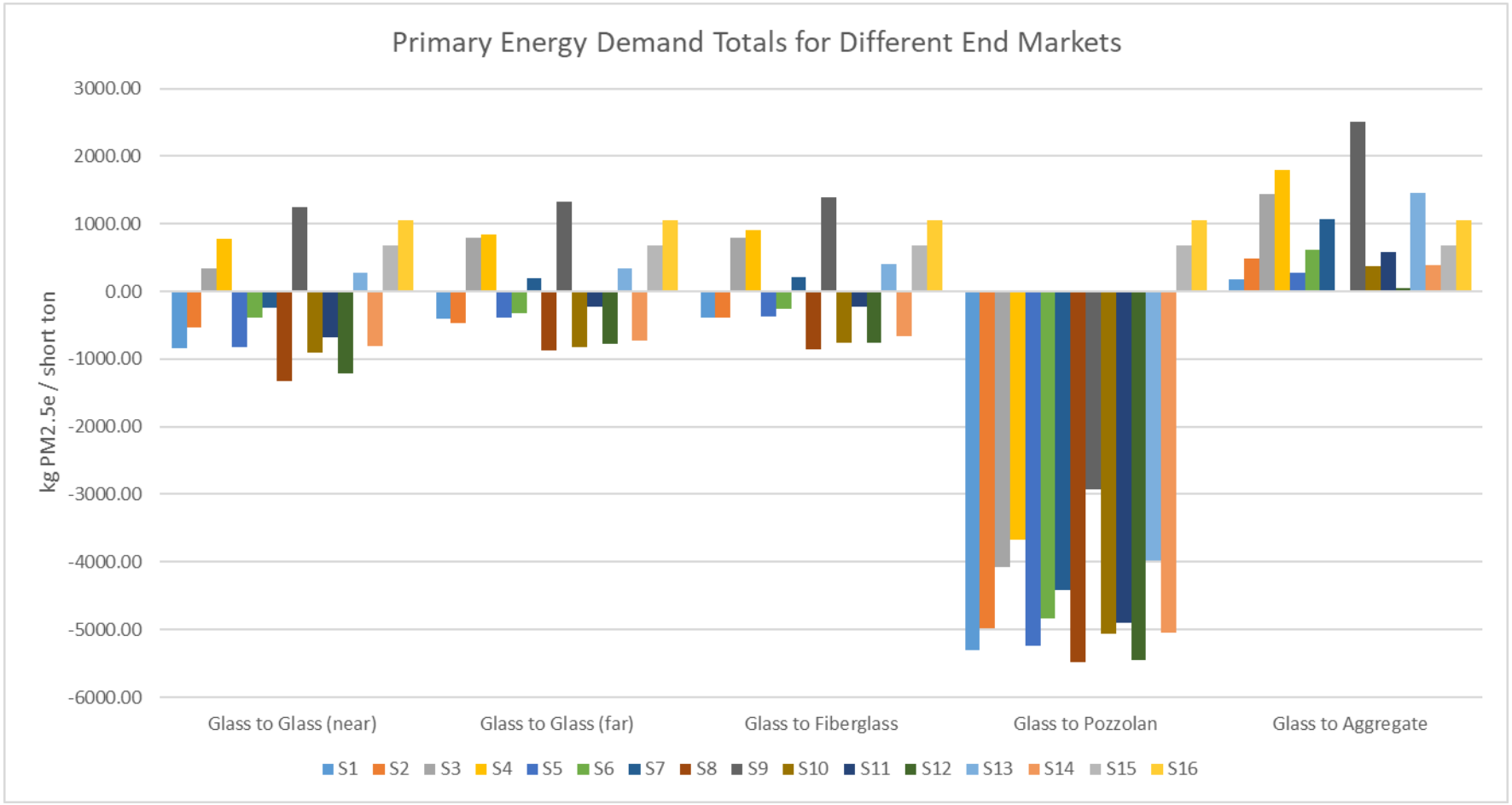
Indicator Results – Fossil Resource Use



Indicator Results – Bluewater Consumption

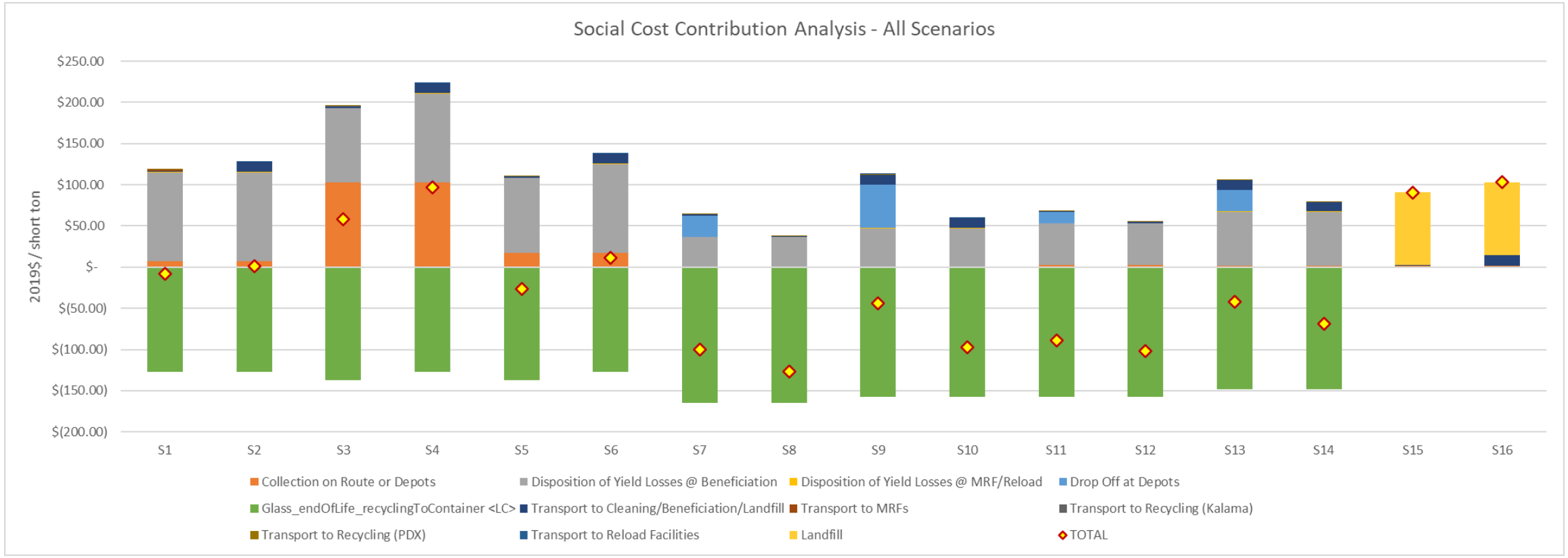


Indicator Results – Primary Energy Demand (PED)

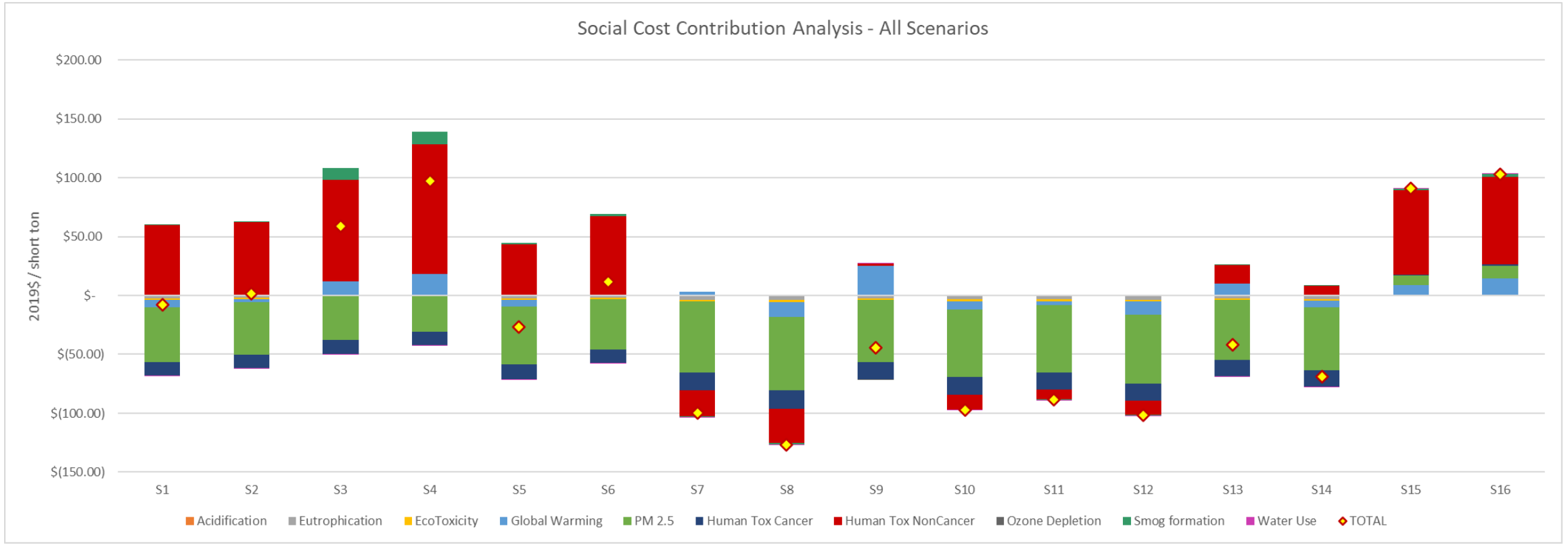


Damage Costs

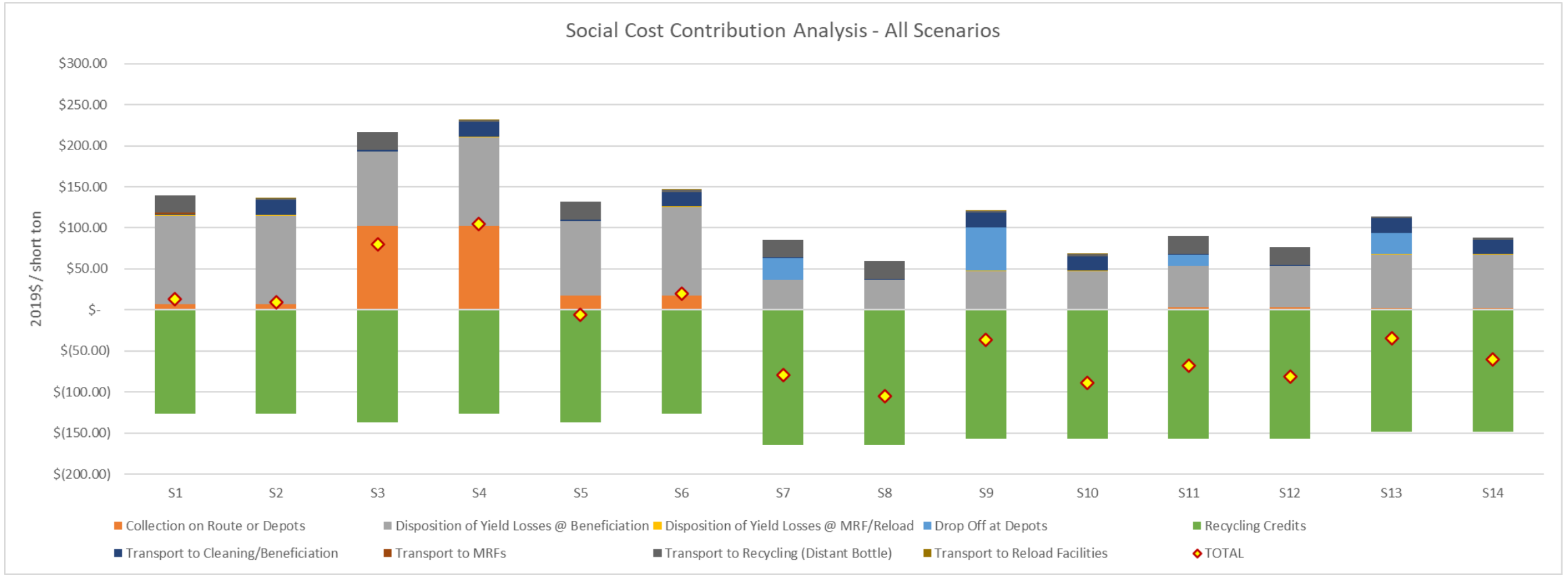
Damage Costs by Life Cycle Stage for Glass to Glass (Near)



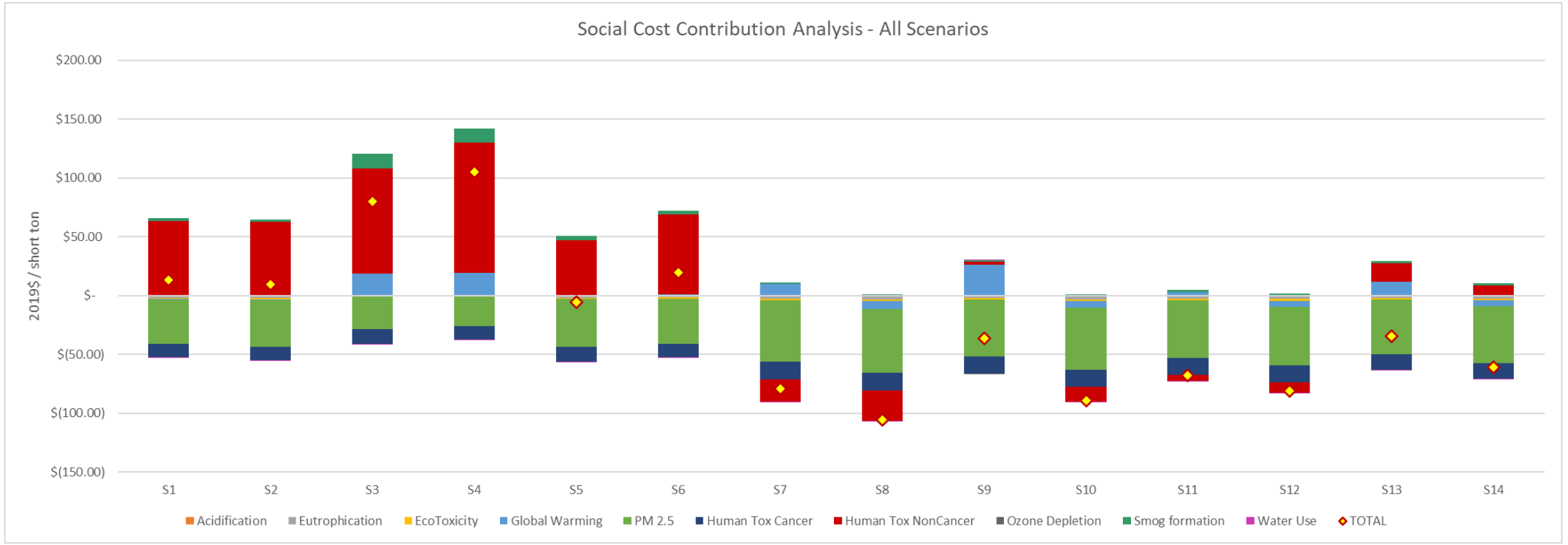
Damage Costs by Impact Category for Glass to Glass (Near)



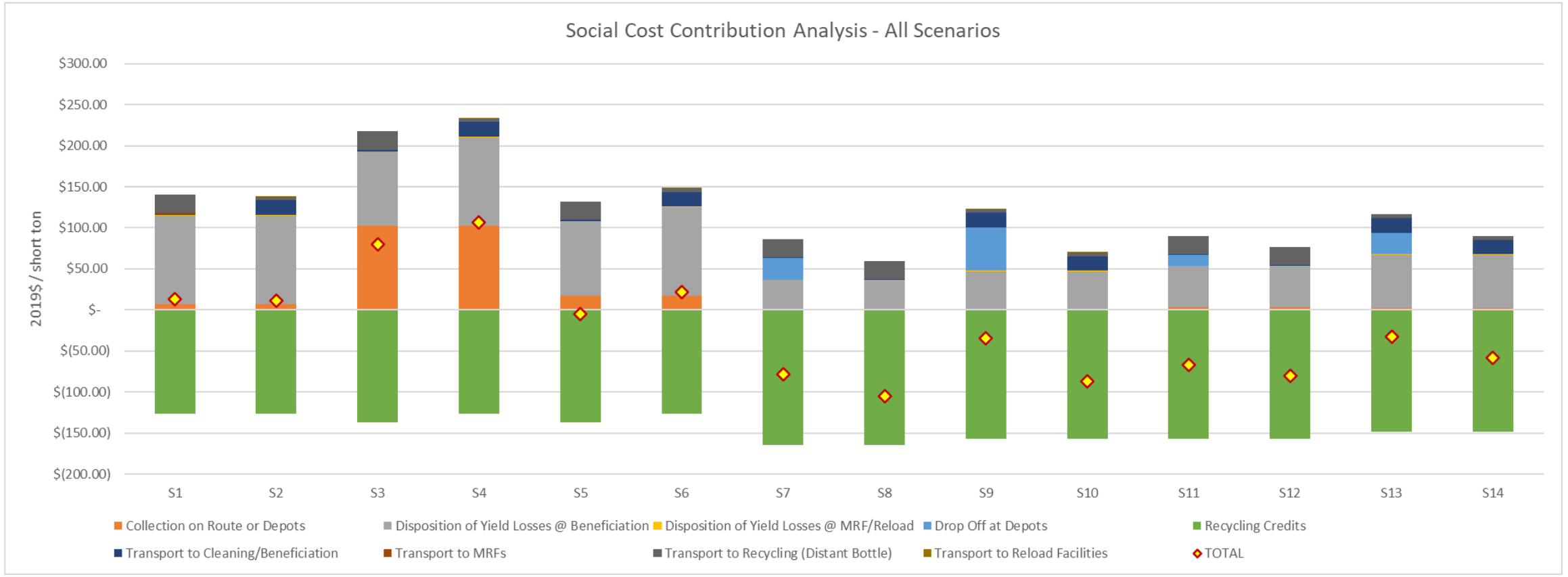
Damage Costs by Life Cycle Stage for Glass to Glass (Far)



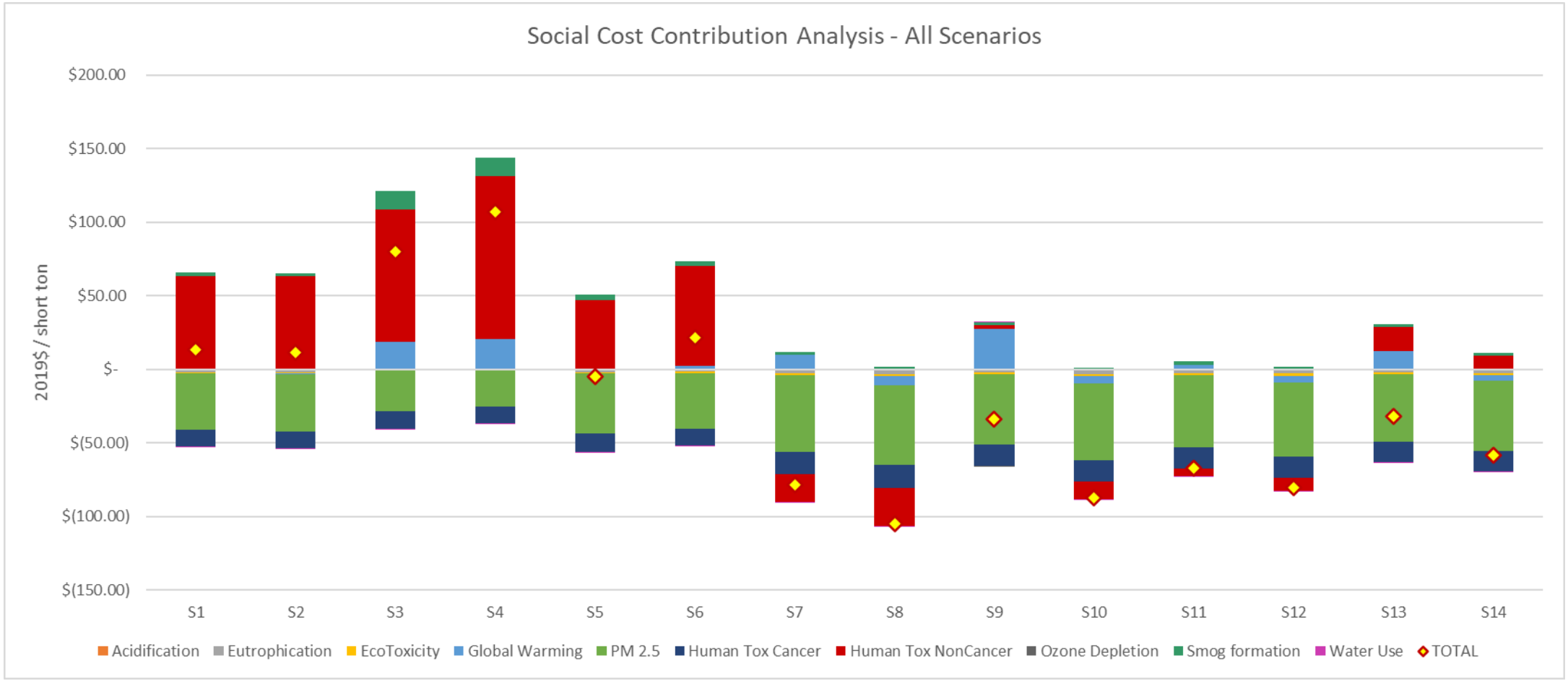
Damage Costs by Impact Category for Glass to Glass (Far)



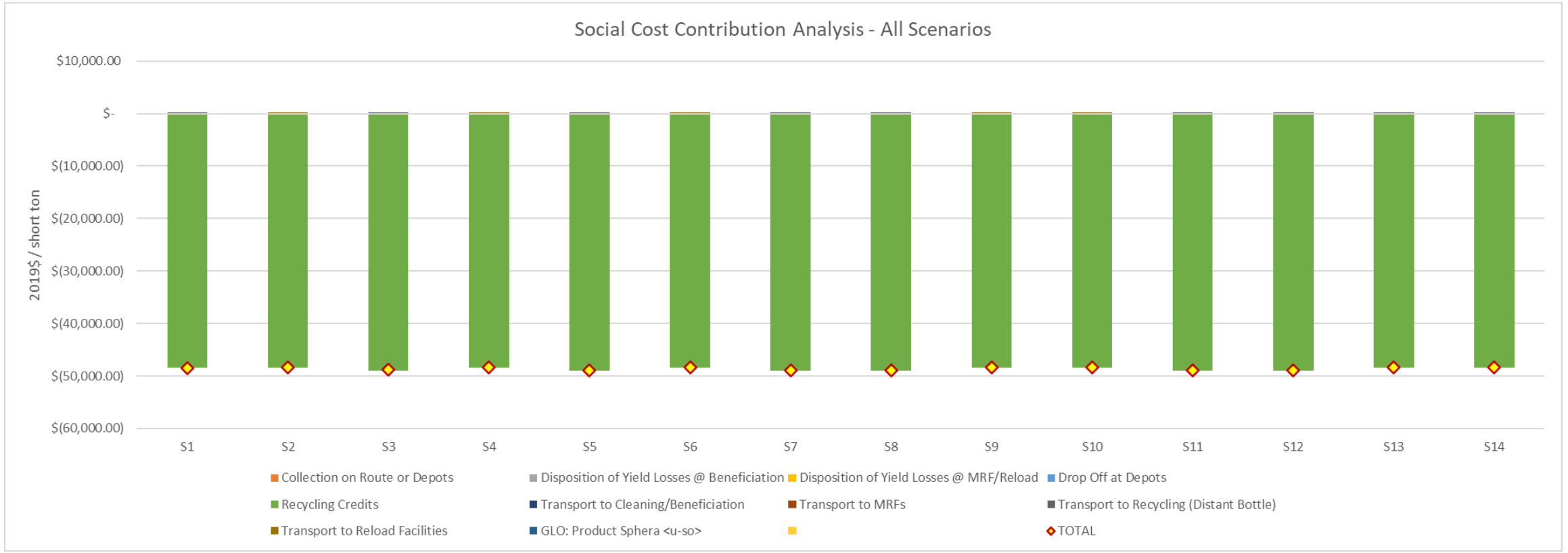
Damage Costs by Impact Category for Glass to Fiberglass



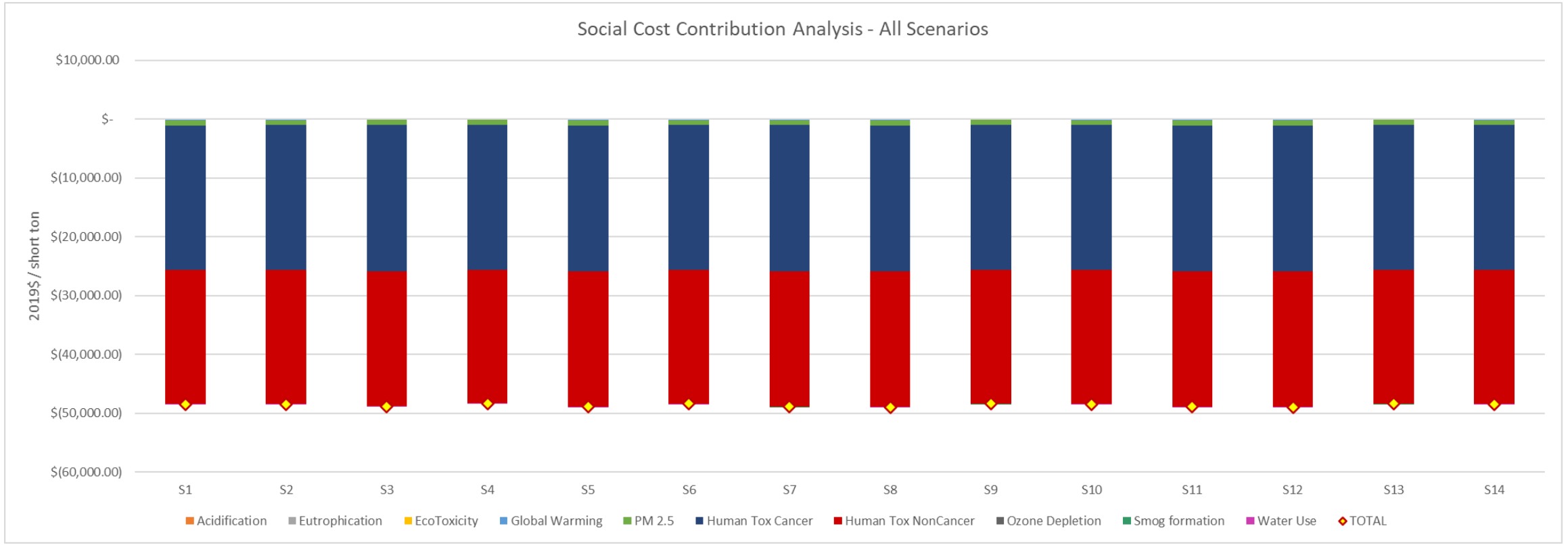
Damage Costs by Impact Category for Glass to Fiberglass



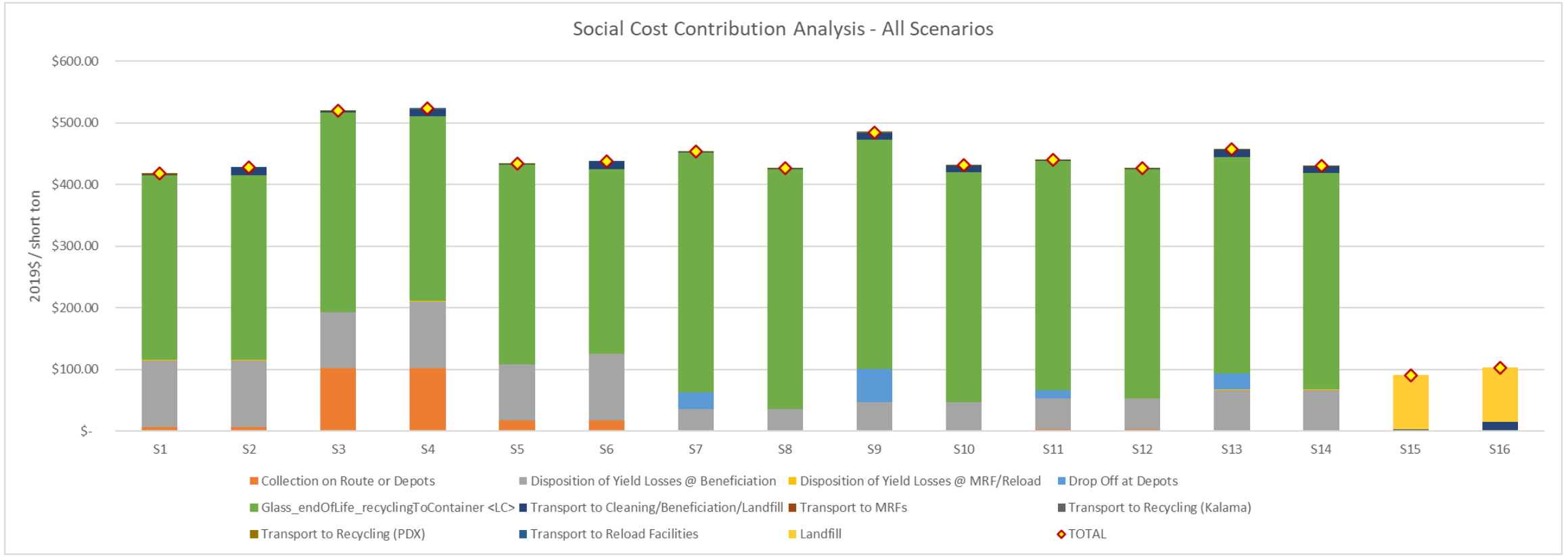
Damage Costs by Impact Category for Glass to Pozzolan



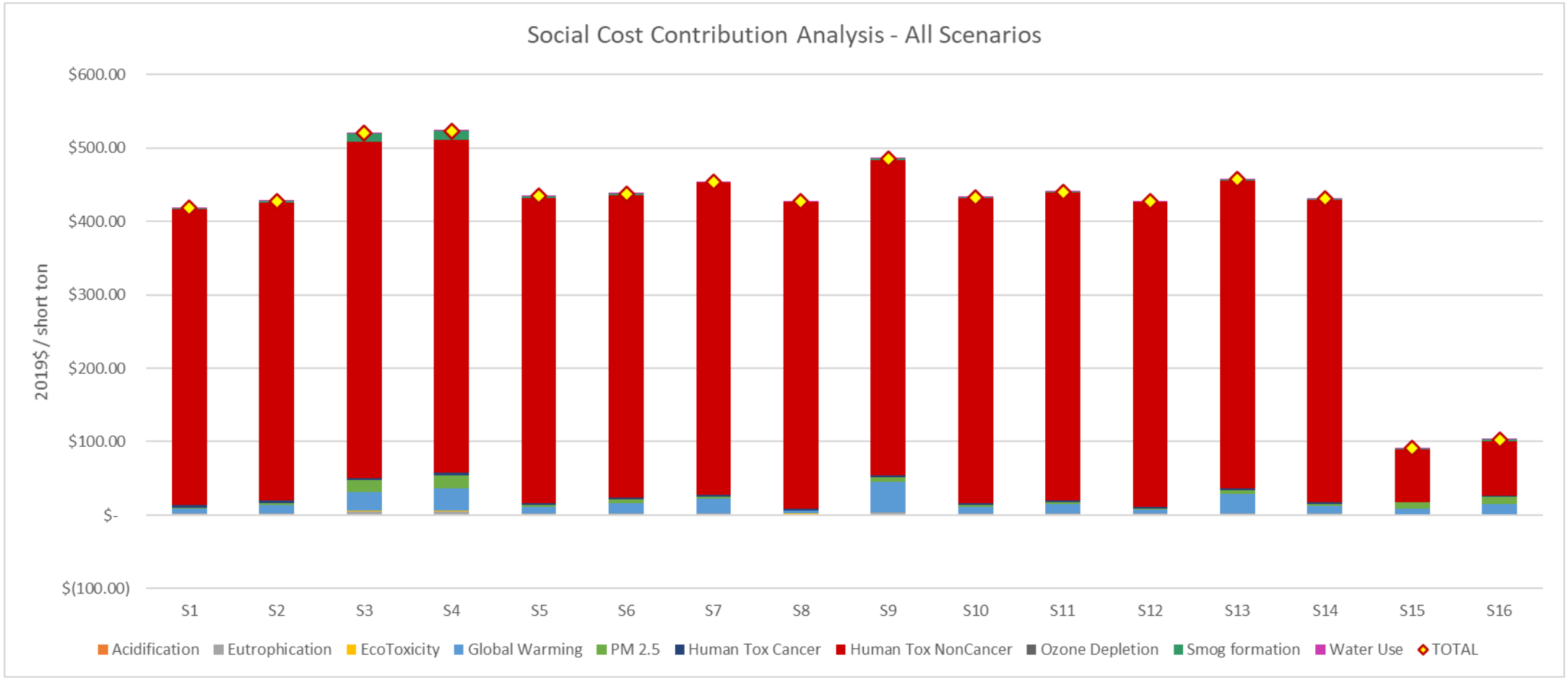
Damage Costs by Impact Category for Glass to Pozzolan



Damage Costs by Impact Category for Glass to Aggregate

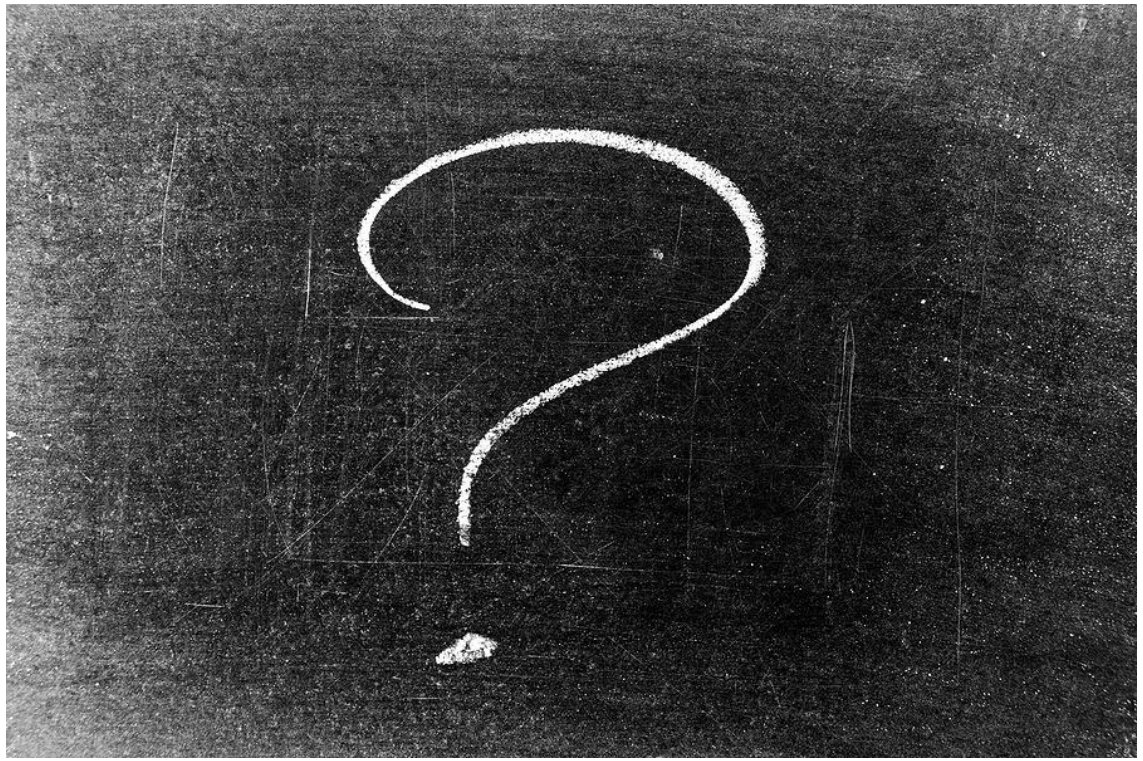


Damage Costs by Impact Category for Glass to Aggregate



Interpretation

Key Findings



- **The End Market is critical** for realizing the benefits of glass recycling.
  - Closed loop recycling is not necessarily better than open loop.
- **Convenience of drop-off sites matters**
  - idea of marginal vs additional transport was an important variable influencing results.
  - Site density seemed to influence results, though not consistently across impacts and scenarios.
  - Less transport was required in the Metro region leading to fewer impacts
- **On-route collection in a dedicated truck** led to higher impacts than a combined truck
- **Drop-off and on-route recycling may (or may not) be comparable**, it depends on the factors associated with drop-off site convenience and user behavior.
- **Landfilling can be less impactful** than some recycling end markets, particularly if drop-off depots are not conveniently located.

Assumptions and Limitations

Assumptions

- Average distance traveled for drop-off (additional) is 4-16 miles (so 8-32 miles round trip) all of these emissions are allocated to glass recovery and so do count towards the impacts of this system.
- Average distance traveled for drop-off (marginal) is 4-16 miles (so 8-32 miles round trip) however the emissions are allocated to the primary purpose for the trip (e.g. grocery store) and so do not count towards the impacts of this system.
- Transport for drop-off is by passenger vehicle
- Transport to mechanical recycling is by truck
- Model assumes 1:1 substitution for primary material production as a recycling credit. In other words, for each unit of glass recovered (after losses are accounted for) an equivalent unit of primary production is avoided (e.g. Primary Glass, Fiberglass or Portland Cement).

Assumptions and Limitations (cont.)

Limitations

- No direct human health exposures are accounted for by processors of this material (e.g. those handling glass at the recycling facility)
- The effects of mismanagement of these materials (e.g. litter) are not accounted for in the model or impact results.
- The model is sensitive to assumptions of yield loss (10-30% for bottle and fiberglass, whereas this is not an issue for pozzolan, since small particles/fines are recovered for use as a cement replacement).

Feedback and/or Questions

Thank You!

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