

Supporting Information

Life Cycle Assessment of Lead Recycling Processes in Perovskite Solar Cells

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Table S1. Life cycle inventory of R1 method. ¹

Process	unit	Amount
Materials		
DMF	kg	1.120.E+02
PTFE	kg	5.545.E-03
2 M NH ₄ OH	kg	1.080.E+01
D.I water	kg	5.916.E+02
0.038 M HI	kg	1.193.E+02
Energy		
Centrifugation	kWh	2.327.E+02
Filtration	kWh	7.933.E-03
Stirring	kWh	4.351.E-03
Washing	kWh	3.747.E+02
Drying	kWh	4.019.E-01
Waste		
Spent Solvent Mixture	kg	2.421.E+02
Wastewater	m ³	4.733.E-01
Hazardous waste, for incineration	kg	5.545.E-03

Table S2. Life cycle inventory of R2 method. ²

Process	unit	Amount
Materials		
EA	kg	6.543.E+02
D.I water	kg	1.446.E+03
DMF	kg	6.848.E+02
Filter	kg	1.542.E-01
Energy		
Filtration	kWh	4.836.E-02
Heating	kWh	2.438.E+01
Cooling	kWh	3.143.E+00
Drying	kWh	1.082.E+02
Spent Solvent Mixture	kg	1.339.E+03
Wastewater	m ³	1.446.E+00
Hazardous waste, for incineration	kg	1.542.E-01

Table S3. Life cycle inventory of R3 method. ³

Process	unit	Amount
Materials		
D.I water	kg	9.495.E+02
Filter	kg	6.105.E-01
Energy		
Heating	kWh	4.167.E+01
Filtration	kWh	1.905.E-01
Cooling	kWh	8.254.E+00
Drying	kWh	5.581.E-01
Waste		
Wastewater	m3	9.495.E-01
Hazardous waste, for incineration	kg	6.105.E-01

Table S4. Life cycle inventory of R4 method. ⁴

Process	unit	Amount
Materials		
DMF	kg	5.155.E+01
Cationic Resin	kg	3.011.E+00
0.16 M HNO ₃	kg	5.500.E+01
NaI	kg	3.255.E-01
D.I water	kg	5.445.E+01
IPA	kg	4.287.E+01
Energy		
Washing	kWh	6.898.E+01
Drying	kWh	5.581.E-01
Waste		
Spent Solvent Mixture	kg	1.494.E+02
Wastewater	m ³	5.445.E-02

Table S5. Life cycle inventory of R5 method. ⁵

Process	unit	Amount
Materials		
D.I water	kg	1.617.E+03
WH	kg	1.920.E-01
HNO ₃	kg	9.001.E+01
KI	kg	3.601.E-01
Energy		
Sonication	kWh	8.571.E-01
Stirring	kWh	3.810.E-02
Filtration	kWh	9.524.E-02
Washing	kWh	1.218.E+02
Drying	kWh	7.974.E-02
Waste		
Wastewater	m3	1.617.E+00

Table S6. Life cycle impact assessment results for 1kg of R1 method

Impact category	Unit	Total	DMF	PTFE	2 M NH ₄ OH	D.I Water	0.038 M HI	Centrifugation	Filtration	Mixer	Washing	Drying	Spent solvent mixture	Wastewater	Hazardous waste
GWP	kg CO ₂ eq	1.151.E+03	4.140.E+02	7.598.E-01	8.829.E+00	2.865.E-01	4.774.E+00	1.640.E+02	5.590.E-03	3.066.E-03	2.641.E+02	2.832.E-01	2.942.E+02	1.347.E-01	1.404.E-02
ODP	kg CFC ⁻¹¹ eq	3.137.E-04	9.282.E-05	2.153.E-05	9.434.E-07	2.594.E-07	1.403.E-06	4.715.E-05	1.607.E-09	8.816.E-10	7.593.E-05	8.142.E-08	7.319.E-05	3.885.E-07	3.729.E-09
IRP	kBq Co-60 eq	1.439.E+02	2.827.E+01	3.940.E-03	4.671.E-02	1.898.E-02	2.160.E-01	4.373.E+01	1.491.E-03	8.176.E-04	7.042.E+01	7.552.E-02	1.153.E+00	4.984.E-03	1.859.E-04
HOFPP	kg NO _x eq	2.057.E+00	8.672.E-01	1.062.E-04	1.161.E-02	6.757.E-04	8.055.E-03	3.972.E-01	1.354.E-05	7.427.E-06	6.397.E-01	6.859.E-04	1.314.E-01	3.217.E-04	1.208.E-05
PMFP	kg PM2.5 eq	1.133.E+00	5.131.E-01	1.066.E-04	6.001.E-03	7.414.E-04	5.277.E-03	2.135.E-01	7.278.E-06	3.992.E-06	3.438.E-01	3.687.E-04	4.992.E-02	2.011.E-04	6.063.E-06
EOFP	kg NO _x eq	2.162.E+00	9.442.E-01	1.125.E-04	1.225.E-02	6.973.E-04	8.481.E-03	4.059.E-01	1.384.E-05	7.590.E-06	6.537.E-01	7.010.E-04	1.355.E-01	3.318.E-04	1.270.E-05
TAP	kg SO ₂ eq	2.241.E+00	1.141.E+00	2.690.E-04	1.589.E-02	1.853.E-03	1.232.E-02	3.675.E-01	1.253.E-05	6.872.E-06	5.919.E-01	6.347.E-04	1.097.E-01	3.923.E-04	1.341.E-05
FEP	kg P eq	5.111.E-01	1.389.E-01	1.837.E-05	2.040.E-03	1.286.E-04	1.084.E-03	1.178.E-01	4.017.E-06	2.203.E-06	1.897.E-01	2.035.E-04	5.821.E-02	2.995.E-03	4.389.E-06
MEP	kg N eq	3.739.E-01	3.455.E-01	1.246.E-06	1.319.E-04	9.982.E-06	3.536.E-04	7.995.E-03	2.725.E-07	1.495.E-07	1.287.E-02	1.381.E-05	5.865.E-03	1.068.E-03	2.743.E-07
TETP	kg 1,4-DCB	2.764.E+03	1.320.E+03	5.150.E-01	1.395.E+01	4.244.E+00	4.599.E+01	4.955.E+02	1.689.E-02	9.264.E-03	7.979.E+02	8.556.E-01	8.405.E+01	5.708.E-01	1.585.E-02
FETP	kg 1,4-DCB	4.542.E+01	1.454.E+01	5.262.E-03	1.689.E-01	4.174.E-02	4.165.E-01	1.124.E+01	3.833.E-04	2.102.E-04	1.811.E+01	1.942.E-02	8.608.E-01	1.843.E-02	2.407.E-04
METP	kg 1,4-DCB	5.819.E+01	1.874.E+01	6.899.E-03	2.262.E-01	5.461.E-02	2.093.E-01	1.446.E+01	4.928.E-04	2.703.E-04	2.328.E+01	2.497.E-02	1.166.E+00	2.507.E-02	3.289.E-04
HTPc	kg 1,4-DCB	4.726.E+01	2.033.E+01	7.747.E-03	2.659.E-01	3.199.E-02	1.655.E-01	9.324.E+00	3.178.E-04	1.743.E-04	1.502.E+01	1.610.E-02	2.074.E+00	2.323.E-02	1.528.E-03
HTPnc	kg 1,4-DCB	8.940.E+02	2.986.E+02	1.544.E-01	4.233.E+00	8.266.E-01	3.367.E+00	2.160.E+02	7.363.E-03	4.038.E-03	3.478.E+02	3.730.E-01	2.156.E+01	1.038.E+00	5.738.E-03
LOP	m2a crop eq	1.632.E+01	7.797.E+00	1.119.E-03	1.411.E-01	7.118.E-03	5.898.E-02	2.977.E+00	1.015.E-04	5.566.E-05	4.794.E+00	5.141.E-03	5.342.E-01	2.712.E-03	7.939.E-05
SOP	kg Cu eq	6.703.E+00	1.190.E+00	3.732.E-04	1.626.E-02	3.437.E-03	4.518.E+00	3.352.E-01	1.143.E-05	6.267.E-06	5.398.E-01	5.788.E-04	9.815.E-02	1.035.E-03	1.109.E-05
FFP	kg oil eq	3.150.E+02	1.885.E+02	1.451.E-02	2.302.E+00	6.756.E-02	1.291.E+00	4.322.E+01	1.473.E-03	8.081.E-04	6.960.E+01	7.464.E-02	9.821.E+00	2.730.E-02	1.492.E-03
WCP	m ³	8.305.E+00	5.743.E+00	7.074.E-04	1.630.E-01	5.709.E-01	1.446.E-01	8.441.E-01	2.877.E-05	1.578.E-05	1.359.E+00	1.458.E-03	3.734.E-01	-8.954.E-01	4.580.E-05

Table S7. Life cycle impact assessment results for 1kg of R2 method

Impact category	Unit	Total	EA	D.I water	DMF	Filter	Filtration	Heating	Cooling	Drying	Spent solvent mixture	Wastewater	Hazardous waste
GWP	kg CO ₂ eq	6.440.E+03	2.184.E+03	7.005.E-01	2.531.E+03	5.346.E-02	3.408.E-02	1.718.E+01	2.215.E+00	7.612.E+01	1.627.E+03	4.130.E-01	3.905.E-01
ODP	kg CFC ⁻¹¹ eq	1.525.E-03	5.229.E-04	6.341.E-07	5.675.E-04	1.837.E-08	9.798.E-09	4.939.E-06	6.368.E-07	2.189.E-05	4.048.E-04	1.191.E-06	1.037.E-07
IRP	kBq Co-60 eq	2.962.E+02	9.142.E+01	4.640.E-02	1.728.E+02	2.614.E-03	9.087.E-03	4.581.E+00	5.906.E-01	2.030.E+01	6.377.E+00	1.528.E-02	5.169.E-03
HOFp	kg NO _x eq	1.186.E+01	5.600.E+00	1.652.E-03	5.302.E+00	2.091.E-04	8.255.E-05	4.161.E-02	5.365.E-03	1.844.E-01	7.267.E-01	9.860.E-04	3.358.E-04
PMFP	kg PM2.5 eq	6.622.E+00	3.081.E+00	1.813.E-03	3.137.E+00	1.147.E-04	4.437.E-05	2.236.E-02	2.884.E-03	9.911.E-02	2.761.E-01	6.163.E-04	1.686.E-04
EOFp	kg NO _x eq	1.291.E+01	6.148.E+00	1.705.E-03	5.773.E+00	2.159.E-04	8.436.E-05	4.252.E-02	5.483.E-03	1.884.E-01	7.495.E-01	1.017.E-03	3.532.E-04
TAP	kg SO ₂ eq	1.512.E+01	7.322.E+00	4.531.E-03	6.975.E+00	2.538.E-04	7.638.E-05	3.850.E-02	4.964.E-03	1.706.E-01	6.068.E-01	1.202.E-03	3.730.E-04
FEP	kg P eq	2.171.E+00	9.213.E-01	3.144.E-04	8.492.E-01	2.702.E-05	2.449.E-05	1.234.E-02	1.591.E-03	5.469.E-02	3.220.E-01	9.179.E-03	1.220.E-04
MEP	kg N eq	2.210.E+00	5.717.E-02	2.441.E-05	2.113.E+00	4.648.E-06	1.661.E-06	8.374.E-04	1.080.E-04	3.711.E-03	3.244.E-02	3.273.E-03	7.628.E-06
TETP	kg 1,4-DCB	1.608.E+04	7.238.E+03	1.038.E+01	8.071.E+03	4.099.E-01	1.030.E-01	5.190.E+01	6.692.E+00	2.300.E+02	4.648.E+02	1.749.E+00	4.406.E-01
FETP	kg 1,4-DCB	1.822.E+02	8.189.E+01	1.020.E-01	8.887.E+01	3.845.E-03	2.337.E-03	1.178.E+00	1.519.E-01	5.220.E+00	4.761.E+00	5.648.E-02	6.693.E-03
METP	kg 1,4-DCB	2.373.E+02	1.077.E+02	1.335.E-01	1.146.E+02	5.185.E-03	3.004.E-03	1.514.E+00	1.953.E-01	6.711.E+00	6.448.E+00	7.684.E-02	9.146.E-03
HTPc	kg 1,4-DCB	2.545.E+02	1.131.E+02	7.822.E-02	1.243.E+02	9.970.E-03	1.938.E-03	9.767.E-01	1.259.E-01	4.328.E+00	1.147.E+01	7.120.E-02	4.249.E-02
HTPnc	kg 1,4-DCB	3.871.E+03	1.794.E+03	2.021.E+00	1.826.E+03	8.970.E-02	4.489.E-02	2.263.E+01	2.917.E+00	1.003.E+02	1.192.E+02	3.182.E+00	1.596.E-01
LOP	m ² a crop eq	1.028.E+02	5.042.E+01	1.740.E-02	4.767.E+01	1.374.E-03	6.186.E-04	3.118.E-01	4.021.E-02	1.382.E+00	2.954.E+00	8.313.E-03	2.208.E-03
SOP	kg Cu eq	1.452.E+01	6.497.E+00	8.403.E-03	7.277.E+00	9.377.E-04	6.966.E-05	3.511.E-02	4.527.E-03	1.556.E-01	5.428.E-01	3.172.E-03	3.083.E-04
FFP	kg oil eq	2.281.E+03	1.048.E+03	1.652.E-01	1.153.E+03	1.285.E-02	8.982.E-03	4.527.E+00	5.837.E-01	2.006.E+01	5.432.E+01	8.367.E-02	4.149.E-02
WCP	m ³	6.706.E+01	3.074.E+01	1.396.E+00	3.511.E+01	3.093.E-04	1.754.E-04	8.842.E-02	1.140.E-02	3.918.E-01	2.065.E+00	-2.744.E+00	1.274.E-03

Table S8. Life cycle impact assessment results for 1kg of R3 method

Impact category	Unit	Total	D.I water	Filter	Heating	Filtration	Cooling	Drying	Wastewater	Hazardous waste
GWP	kg CO ₂ eq	3.820.E+01	4.599.E-01	2.117.E-01	2.937.E+01	1.342.E-01	5.816.E+00	3.933.E-01	2.712.E-01	1.546.E+00
ODP	kg CFC ⁻¹¹ eq	1.195.E-05	4.163.E-07	7.274.E-08	8.445.E-06	3.859.E-08	1.672.E-06	1.131.E-07	7.818.E-07	4.106.E-07
IRP	kBq Co-60 eq	9.595.E+00	3.046.E-02	1.035.E-02	7.832.E+00	3.579.E-02	1.551.E+00	1.049.E-01	1.003.E-02	2.046.E-02
HOFP	kg NO _x eq	9.040.E-02	1.084.E-03	8.277.E-04	7.114.E-02	3.251.E-04	1.409.E-02	9.527.E-04	6.474.E-04	1.330.E-03
PMFP	kg PM2.5 eq	4.921.E-02	1.190.E-03	4.540.E-04	3.824.E-02	1.747.E-04	7.573.E-03	5.121.E-04	4.047.E-04	6.675.E-04
EOFP	kg NO _x eq	9.245.E-02	1.119.E-03	8.550.E-04	7.271.E-02	3.323.E-04	1.440.E-02	9.736.E-04	6.677.E-04	1.398.E-03
TAP	kg SO ₂ eq	8.629.E-02	2.975.E-03	1.005.E-03	6.583.E-02	3.008.E-04	1.304.E-02	8.815.E-04	7.896.E-04	1.477.E-03
FEP	kg P eq	3.249.E-02	2.064.E-04	1.070.E-04	2.110.E-02	9.644.E-05	4.179.E-03	2.826.E-04	6.027.E-03	4.832.E-04
MEP	kg N eq	3.955.E-03	1.602.E-05	1.840.E-05	1.432.E-03	6.544.E-06	2.836.E-04	1.917.E-05	2.149.E-03	3.020.E-05
TETP	kg 1,4-DCB	1.192.E+02	6.811.E+00	1.623.E+00	8.874.E+01	4.055.E-01	1.757.E+01	1.188.E+00	1.149.E+00	1.745.E+00
FETP	kg 1,4-DCB	2.595.E+00	6.698.E-02	1.522.E-02	2.014.E+00	9.204.E-03	3.988.E-01	2.697.E-02	3.709.E-02	2.650.E-02
METP	kg 1,4-DCB	3.344.E+00	8.764.E-02	2.053.E-02	2.589.E+00	1.183.E-02	5.128.E-01	3.468.E-02	5.045.E-02	3.621.E-02
HTPc	kg 1,4-DCB	2.336.E+00	5.135.E-02	3.947.E-02	1.670.E+00	7.632.E-03	3.307.E-01	2.236.E-02	4.675.E-02	1.682.E-01
HTPnc	kg 1,4-DCB	5.144.E+01	1.327.E+00	3.551.E-01	3.869.E+01	1.768.E-01	7.661.E+00	5.180.E-01	2.090.E+00	6.317.E-01
LOP	m2a crop eq	6.794.E-01	1.142.E-02	5.441.E-03	5.332.E-01	2.436.E-03	1.056.E-01	7.140.E-03	5.459.E-03	8.741.E-03
SOP	kg Cu eq	8.553.E-02	5.516.E-03	3.713.E-03	6.003.E-02	2.743.E-04	1.189.E-02	8.039.E-04	2.083.E-03	1.221.E-03
FFP	kg oil eq	9.792.E+00	1.084.E-01	5.087.E-02	7.741.E+00	3.537.E-02	1.533.E+00	1.037.E-01	5.494.E-02	1.643.E-01
WCP	m ³	-6.956.E-01	9.162.E-01	1.225.E-03	1.512.E-01	6.909.E-04	2.994.E-02	2.024.E-03	-1.802.E+00	5.043.E-03

Table S9. Life cycle impact assessment results for 1kg of R4 method

Impact category	Unit	Total	DMF	Cationic Resin	0.16 M Nitric acid	Nal	D.I water	IPA	Washing	Drying	Spent solvent mixture	Wastewater
GWP	kg CO ₂ eq	5.346.E+02	1.906.E+02	5.597.E+00	1.192.E+00	1.801.E+00	2.637.E-02	1.042.E+02	4.931.E+01	3.933.E-01	1.816.E+02	1.555.E-02
ODP	kg CFC ⁻¹¹ eq	1.396.E-04	4.272.E-05	6.687.E-07	2.370.E-05	4.882.E-07	2.387.E-08	1.246.E-05	1.418.E-05	1.131.E-07	4.517.E-05	4.483.E-08
IRP	kBq Co-60 eq	2.850.E+01	1.301.E+01	1.446.E-01	7.991.E-03	5.599.E-02	1.747.E-03	1.314.E+00	1.315.E+01	1.049.E-01	7.115.E-01	5.752.E-04
HOFP	kg NO _x eq	8.407.E-01	3.991.E-01	1.170.E-02	1.073.E-03	2.880.E-03	6.219.E-05	2.243.E-01	1.194.E-01	9.527.E-04	8.109.E-02	3.713.E-05
PMFP	kg PM2.5 eq	4.620.E-01	2.362.E-01	8.175.E-03	8.526.E-04	1.825.E-03	6.824.E-05	1.194.E-01	6.420.E-02	5.121.E-04	3.080.E-02	2.321.E-05
EOFP	kg NO _x eq	9.101.E-01	4.346.E-01	1.223.E-02	1.115.E-03	3.049.E-03	6.418.E-05	2.524.E-01	1.221.E-01	9.736.E-04	8.363.E-02	3.829.E-05
TAP	kg SO ₂ eq	1.062.E+00	5.251.E-01	2.181.E-02	3.920.E-03	4.448.E-03	1.706.E-04	3.279.E-01	1.105.E-01	8.815.E-04	6.770.E-02	4.528.E-05
FEP	kg P eq	1.636.E-01	6.392.E-02	1.278.E-03	1.593.E-04	3.273.E-04	1.184.E-05	2.592.E-02	3.543.E-02	2.826.E-04	3.592.E-02	3.457.E-04
MEP	kg N eq	1.666.E-01	1.590.E-01	9.636.E-05	9.832.E-06	3.281.E-05	9.187.E-07	1.301.E-03	2.404.E-03	1.917.E-05	3.619.E-03	1.233.E-04
TETP	kg 1,4-DCB	1.300.E+03	6.076.E+02	3.575.E+01	2.665.E+00	6.251.E+00	3.906.E-01	4.452.E+02	1.490.E+02	1.188.E+00	5.186.E+01	6.587.E-02
FETP	kg 1,4-DCB	1.488.E+01	6.690.E+00	3.351.E-01	3.031.E-02	4.946.E-02	3.841.E-03	3.825.E+00	3.382.E+00	2.697.E-02	5.312.E-01	2.127.E-03
METP	kg 1,4-DCB	1.935.E+01	8.624.E+00	4.406.E-01	3.972.E-02	6.705.E-02	5.026.E-03	5.066.E+00	4.348.E+00	3.468.E-02	7.195.E-01	2.893.E-03
HTPc	kg 1,4-DCB	1.741.E+01	9.358.E+00	2.340.E-01	3.141.E-02	5.456.E-02	2.945.E-03	3.617.E+00	2.804.E+00	2.236.E-02	1.280.E+00	2.681.E-03
HTPnc	kg 1,4-DCB	3.043.E+02	1.375.E+02	6.570.E+00	5.766.E-01	1.096.E+00	7.608.E-02	7.960.E+01	6.495.E+01	5.180.E-01	1.330.E+01	1.198.E-01
LOP	m2a crop eq	5.824.E+00	3.589.E+00	6.437.E-02	1.195.E-02	1.996.E-02	6.551.E-04	9.064.E-01	8.952.E-01	7.140.E-03	3.296.E-01	3.130.E-04
SOP	kg Cu eq	3.018.E+00	5.478.E-01	2.240.E-02	2.602.E-03	2.002.E+00	3.163.E-04	2.807.E-01	1.008.E-01	8.039.E-04	6.057.E-02	1.194.E-04
FFP	kg oil eq	1.686.E+02	8.678.E+01	2.253.E+00	1.429.E-01	4.941.E-01	6.218.E-03	5.973.E+01	1.300.E+01	1.037.E-01	6.061.E+00	3.151.E-03
WCP	m ³	3.876.E+00	2.643.E+00	7.184.E-02	6.150.E-02	8.216.E-03	5.254.E-02	6.560.E-01	2.538.E-01	2.024.E-03	2.304.E-01	-1.033.E-01

Table S10. Life cycle impact assessment results for 1kg of R5 method

Impact category	Unit	Total	D.I water	Whitlockite	HNO ₃	KI	Sonication	Stirring	Filtration	Washing	Drying	Wastewater
GWP	kg CO ₂ eq	2.804.E+02	6.897.E-01	6.442.E-03	1.906.E+02	2.026.E+00	9.314.E-02	6.040.E-01	2.684.E-02	6.711.E-02	8.583.E+01	5.619.E-02
ODP	kg CFC ⁻¹¹ eq	3.897.E-03	6.243.E-07	1.635.E-09	3.870.E-03	4.797.E-07	8.430.E-08	1.737.E-07	7.719.E-09	1.930.E-08	2.468.E-05	1.616.E-08
IRP	kBq Co-60 eq	2.425.E+01	4.568.E-02	2.147.E-04	1.021.E+00	6.962.E-02	6.169.E-03	1.611.E-01	7.159.E-03	1.790.E-02	2.289.E+01	1.498.E-02
HOFP	kg NO _x eq	3.814.E-01	1.626.E-03	5.065.E-06	1.653.E-01	3.497.E-03	2.196.E-04	1.463.E-03	6.502.E-05	1.626.E-04	2.079.E-01	1.361.E-04
PMFP	kg PM2.5 eq	2.459.E-01	1.785.E-03	3.493.E-06	1.282.E-01	2.207.E-03	2.410.E-04	7.864.E-04	3.495.E-05	8.738.E-05	1.117.E-01	7.316.E-05
EOFP	kg NO _x eq	3.928.E-01	1.678.E-03	5.211.E-06	1.718.E-01	3.688.E-03	2.266.E-04	1.495.E-03	6.645.E-05	1.661.E-04	2.125.E-01	1.391.E-04
TAP	kg SO ₂ eq	8.187.E-01	4.461.E-03	8.641.E-06	6.130.E-01	5.255.E-03	6.025.E-04	1.354.E-03	6.017.E-05	1.504.E-04	1.924.E-01	1.259.E-04
FEP	kg P eq	9.733.E-02	3.095.E-04	1.949.E-06	2.410.E-02	4.018.E-04	4.180.E-05	4.340.E-04	1.929.E-05	4.822.E-05	6.167.E-02	4.037.E-05
MEP	kg N eq	9.403.E-03	2.403.E-05	1.524.E-07	1.457.E-03	3.751.E-05	3.245.E-06	2.945.E-05	1.309.E-06	3.272.E-06	4.184.E-03	2.740.E-06
TETP	kg 1,4-DCB	6.546.E+02	1.021.E+01	1.151.E-02	3.719.E+02	7.579.E+00	1.379.E+00	1.825.E+00	8.111.E-02	2.028.E-01	2.593.E+02	1.698.E-01
FETP	kg 1,4-DCB	1.050.E+01	1.005.E-01	1.467.E-04	4.328.E+00	6.242.E-02	1.357.E-02	4.142.E-02	1.841.E-03	4.602.E-03	5.886.E+00	3.853.E-03
METP	kg 1,4-DCB	1.362.E+01	1.314.E-01	1.940.E-04	5.671.E+00	8.415.E-02	1.775.E-02	5.325.E-02	2.367.E-03	5.917.E-03	7.567.E+00	4.954.E-03
HTPc	kg 1,4-DCB	9.814.E+00	7.701.E-02	3.123.E-04	4.654.E+00	6.995.E-02	1.040.E-02	3.434.E-02	1.526.E-03	3.816.E-03	4.880.E+00	3.195.E-03
HTPnc	kg 1,4-DCB	2.030.E+02	1.990.E+00	3.153.E-03	8.182.E+01	1.351.E+00	2.687.E-01	7.956.E-01	3.536.E-02	8.840.E-02	1.130.E+02	7.401.E-02
LOP	m2a crop eq	3.474.E+00	1.713.E-02	9.617.E-05	1.846.E+00	2.795.E-02	2.314.E-03	1.096.E-02	4.873.E-04	1.218.E-03	1.558.E+00	1.020.E-03
SOP	kg Cu eq	2.572.E+00	8.273.E-03	1.675.E-05	3.737.E-01	2.009.E+00	1.117.E-03	1.235.E-03	5.487.E-05	1.372.E-04	1.754.E-01	1.149.E-04
FFP	kg oil eq	4.599.E+01	1.626.E-01	4.330.E-04	2.234.E+01	5.559.E-01	2.196.E-02	1.592.E-01	7.075.E-03	1.769.E-02	2.262.E+01	1.481.E-02
WCP	m ³	4.097.E-01	1.374.E+00	3.897.E-05	1.465.E+00	8.452.E-03	1.856.E-01	3.109.E-03	1.382.E-04	3.454.E-04	4.418.E-01	2.892.E-04

Table S11. Life cycle impact assessment result for 1kg of solvent.

Impact category	Unit	DMF	EA	D.I water	IPA
GWP	kg CO ₂ eq	3.977056	3.611415	0.000484	2.374733
ODP	kg CFC-11 eq	8.70E-07	8.99E-07	4.38E-10	2.73E-07
IRP	kBq Co-60 eq	0.15297	0.145592	3.21E-05	0.029841
HOFP	kg NO _x eq	0.008349	0.009095	1.14E-06	0.004801
PMFP	kg PM2.5 eq	0.005422	0.005206	1.25E-06	0.002671
EOFP	kg NO _x eq	0.009021	0.009945	1.18E-06	0.005445
TAP	kg SO ₂ eq	0.011276	0.012391	3.13E-06	0.007361
FEP	kg P eq	0.001282	0.001599	2.17E-07	0.000598
MEP	kg N eq	0.003084	9.33E-05	1.69E-08	2.87E-05
TETP	kg 1,4-DCB	11.38575	11.25815	0.007173	9.801656
FETP	kg 1,4-DCB	0.130121	0.136616	7.05E-05	0.08794
METP	kg 1,4-DCB	0.167746	0.179351	9.23E-05	0.116215
HTPc	kg 1,4-DCB	0.184845	0.189567	5.41E-05	0.080192
HTPnc	kg 1,4-DCB	2.749669	3.067043	0.001397	1.822147
LOP	m ² a crop eq	0.071067	0.08174	1.20E-05	0.018583
SOP	kg Cu eq	0.010354	0.01075	5.81E-06	0.006363
FFP	kg oil eq	1.718571	1.668445	0.000114	1.376752
WCP	m ³	0.04984	0.043128	0.000965	0.015134

Figure S2. Life cycle impact assessment results of PbI_2 Recycling methods versus the number of dissolution solvent reuses between the 100 reuses and 150 reuses (a) Human carcinogenic Toxicity

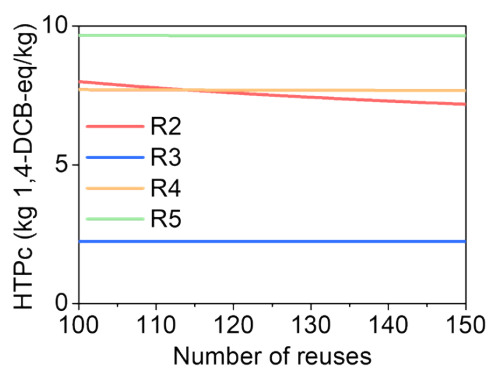


Figure S3. Life cycle impact assessment results of Lead Recycling methods(R1~R5) versus the number of dissolution solvent reuses (a) Human non-carcinogenic Toxicity

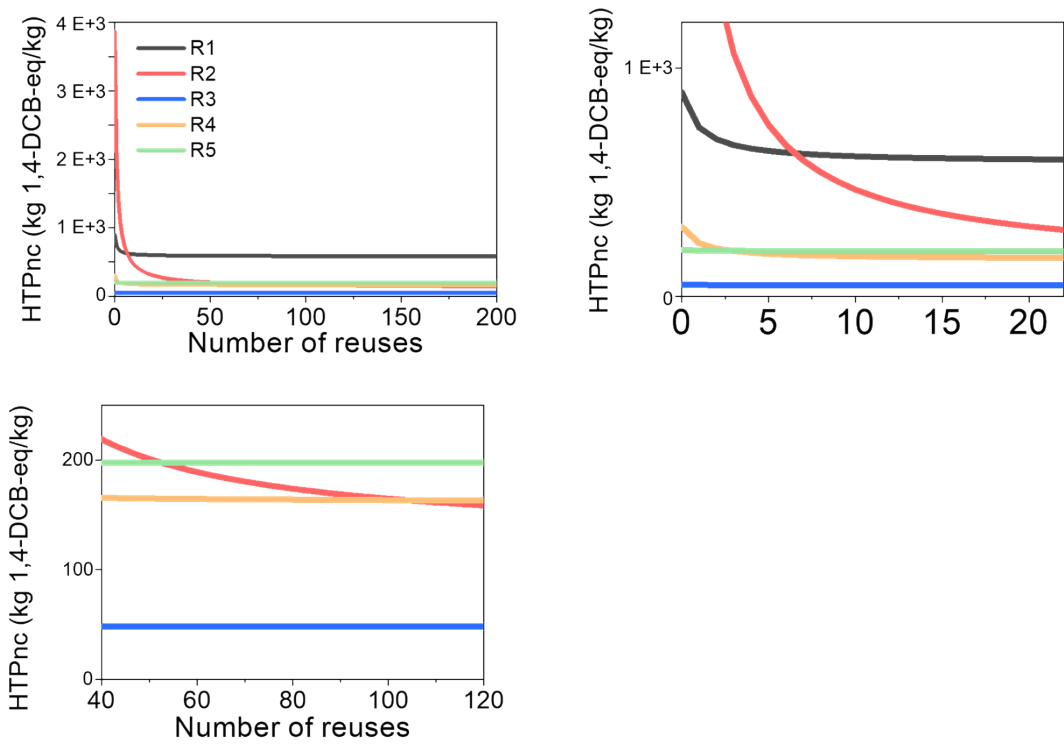


Table S12. Table of the reduction rate of life cycle impact assessment result according to the number of dissolution solvent reuses in GWP

GWP Number of reuses	Reduction rate (%)				
	R1	R2	R3	R4	R5
1	23.89	49.25	0.96	23.68	0.21
10	43.44	89.55	1.74	43.05	0.39
20	45.50	93.81	1.82	45.10	0.40
30	46.24	95.33	1.85	45.83	0.41
40	46.61	96.10	1.87	46.20	0.41
50	46.84	96.57	1.88	46.43	0.42
60	47.00	96.89	1.88	46.58	0.42
70	47.11	97.12	1.89	46.69	0.42
80	47.19	97.29	1.89	46.77	0.42
90	47.25	97.42	1.89	46.83	0.42
100	47.31	97.53	1.89	46.89	0.42
150	47.46	97.85	1.90	47.04	0.42
200	47.54	98.02	1.90	47.12	0.42

Table S13. Table of the reduction rate of life cycle impact assessment result according to the number of dissolution solvent reuses in HTPc

HTPc Number of reuses	Reduction rate (%)				
	R1	R2	R3	R4	R5
1	22.53	48.91	2.10	28.15	0.80
10	40.96	88.93	3.82	51.18	1.46
20	42.91	93.17	4.00	53.62	1.53
30	43.60	94.67	4.06	54.48	1.55
40	43.96	95.44	4.10	54.93	1.57
50	44.17	95.91	4.12	55.19	1.57
60	44.32	96.22	4.13	55.38	1.58
70	44.42	96.45	4.14	55.51	1.58
80	44.50	96.62	4.15	55.60	1.59
90	44.56	96.75	4.15	55.68	1.59
100	44.61	96.86	4.16	55.74	1.59
150	44.76	97.18	4.17	55.93	1.59
200	44.83	97.34	4.18	56.02	1.60

Table S14. Table of the reduction rate of life cycle impact assessment result according to the number of dissolution solvent reuses in HTPnc

HTPnc Number of reuses	Reduction rate (%)				
	R1	R2	R3	R4	R5
1	17.26	48.35	3.32	23.34	0.22
10	31.38	87.91	6.04	42.44	1.32
20	32.88	92.09	6.32	44.46	1.43
30	33.41	93.58	6.43	45.18	1.48
40	33.68	94.34	6.48	45.54	1.50
50	33.84	94.80	6.51	45.77	1.51
60	33.95	95.11	6.53	45.92	1.52
70	34.03	95.34	6.55	46.02	1.52
80	34.09	95.50	6.56	46.11	1.53
90	34.14	95.64	6.57	46.17	1.53
100	34.18	95.74	6.58	46.22	1.54
150	34.29	96.06	6.60	46.37	1.54
200	34.35	96.22	6.61	46.45	1.55

Table S15. The weight of recycled PbI_2 and volume of dissolution solvent for lead recycling process in previous researchers. The PbI_2 solubility is 368.8g per litter in DMF and 0.76g per litter in water. ^{6, 7}

		Recycled PbI_2 (g)	Lead dissolution solvent	Volume (ml)	Dissolved PbI_2 ratio based on solubility at room temperature
R1	Zhang et al.	0.1685 g	DMF	20	~2.28 %
R2	Binek et al.	0.0193 g	DMF	14	~0.37 %
R3	Schmidt et al.	1.05 g	Water	1000	~138 %
R4	Chen et al.	0.1831 g	DMF	10	~4.96 %
R5	Hong et al.	0.7 g	Water	1000	~92 %

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