

Supplemental Material

Tables S1 and S2 show various inputs related to material and specifications for 203 mm (8 in.), 254 mm (10 in.), and 305 mm (12 in.) CIPP, respectively.

Table S1. CIPP Material Input in SimaPro Software.

| Materials/Assemblies | Unit | Amount 203 mm (8 in.) | Amount 254 mm (10 in.) | Amount 305 mm (12 in.) | Remark/Reference |
|---|---------|-----------------------------|------------------------------|------------------------------|--|
| Glassfiber reinforced plastic (polyester resin, hand layup, at plant/US-US-EI U)* | kg (lb) | 20,543 (45,289) | 5,578 12,298 | 4,093 9,024 | Weight = Volume x Density, Density = 158.6 lb/CF, Volume = 453 CF (Alsadi, 2019) |
| Dummy Plastic* (unspecified) | Kg (lb) | 88.4 (195) | 24 (53) | 17.7 (39) | Weight = Volume x Density, Density of vinyl ester = 6 lb/CF, Volume = 51.5 CF (Alsadi, 2019) |
| Polyester resin (unsaturated, at plant/US-US-EI U)* | Kg (lb) | 2,361 (5,205) | 641.3 (1,414) | 470.3 (1,037) | Weight = Volume x Density, Density of polyester resin = 106 lb/CF, Volume = 77.9 CF (Alsadi, 2019) |
| Styrene E* | kg (lb) | 4,070 (8,972) | 1,105 (2,436) | 811 (1,788) | (Ajdari, 2016) |
| PET (amorphous) E* | kg (lb) | 473 (1,043) | 128.3 (283) | 94.3 (208) | (Ajdari, 2016) |
| Polyethylene (linear low density, resin, at plant, CTR/kg/RNA)* | kg (lb) | 4,732 (10,433) | 1,285 (2,833) | 943 (2,079) | (Ajdari, 2016) |

Note: The distribution of material for each diameter has been done after experts' interview and as per industry practice. According to this practice, as we go from 8 in. to 10 in., material increase by 25% and same way for going from 10 in. to 12 in.

*SimaPro code

Table S2. CIPP Specifications.

| Material Factor | Input | Remark/Reference |
|-------------------|---|-----------------------------------|
| Resin used | Alpha Owens Corning L010-PPA-38 Vinyl Ester | (Ajdari, 2016) |
| Thickness of felt | 4 mm (0.16 in.) | Calculated as per ASTM F1216 2016 |
| Internal pressure | 551.5 kPa (80 psi) | (Ajdari, 2016) |

Tables S3 and S4 show various equipment and processes related factors used for assessing the environmental impacts of CIPP, respectively.

Table S3. Equipment Related Factors used for EIA of CIPP.

| Factors | Equipment Used* | | | | | | |
|----------------|-----------------|----------|---------------|--------------|--------------|----------------|--------------------|
| | Air Compressor | TV Truck | Utility truck | Jetter truck | Signal board | Generator sets | Refrigerated Truck |
| Max horsepower | 250 | 500 | 250 | 500 | 50 | 500 | 500 |

| | | | | | | | |
|------------------------------------|----|-----|----|-----|-----|----|----|
| Operating hours per day | 2 | 8 | 1 | 0.5 | 8 | 2 | 4 |
| Construction days | 22 | 22 | 22 | 22 | 22 | 22 | 22 |
| Total onsite operating hours (hrs) | 44 | 176 | 22 | 11 | 176 | 44 | 88 |

*Number of equipment used for each type is 1.

Table S4. CIPP Processes Input in SimaPro Software.

| Processes | Unit | Amount 203 mm (8 in.) | Amount 254 mm (10 in.) | Amount 305 mm (12 in.) | Remark/Reference |
|---|----------|-----------------------------|------------------------------|------------------------------|--|
| Air compressor (screw-type compressor, 300 kW, at plant/US-/I US-EI U)* | Piece | 0.007 | 0.002 | 0.001 | Considering 1% of total emissions from production of an air compressor |
| Transport (single unit truck, diesel powered/US)* | Ton-mile | 711 | 155 | 150 | Total material weight*Transportation distance |
| Van (<3.5t/US-/I US-EI U)* | Piece | 0.025 | 0.005 | 0.005 | Ajdari, 2016 |
| On-site steam average E* | kg (lb) | 35,883 (79,110) | 7,795 (17,186) | 7,569 (16,687) | Ajdari, 2016 |
| Generator (200kWe/US-/I US-EI U)* | Piece | 0.021 | 0.005 | 0.004 | 3 generators, considering 1% of total emissions from production of generator |
| Electricity (mix, California/US US-EI U)* | HP.hr | 187,163 | 40,659 | 39,479 | HP of each equipment x Number of hours equipment used (Ajdari, 2016) |

*SimaPro code

Table S5 shows various equipment related factors used for assessing the environmental impacts of OC, respectively. Table S6 shows unit costs of emissions used for calculating the environmental costs for CIPP and OC. Table S7 shows various inputs related to processes for 203 mm (8 in.), 254 mm (10 in.), and 305 mm (12 in.) diameter OC.

Table S5. Equipment* Related Factors used for EIA of OC.

| Equipment | Air Compressor | Dump truck | Utility truck | Signal board | Mini excavator | Bypass pump | Concrete saw | Jack Hammer | Back hoe | Roller | Paver |
|------------------------------|----------------|------------|---------------|--------------|----------------|-------------|--------------|-------------|----------|--------|-------|
| Horsepower | 250 | 500 | 250 | 50 | 120 | 175 | 120 | 250 | 250 | 120 | 120 |
| Operating hours per day | 2 | 2.5 | 1 | 8 | 1 | 4 | 2 | 1 | 4 | 2 | 2 |
| Construction days | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 110 |
| Total onsite operating hours | 220 | 275 | 110 | 880 | 110 | 440 | 220 | 110 | 440 | 220 | 220 |

*Number of equipment used for each type is 1.

Table S6. OC Materials Input in SimaPro Software.

| Pipe used | PVC | | Remark/Reference |
|------------------|-----------------|-----------------|--|
| Weight of | 203 mm (8 in.) | 13,261 (29,235) | |
| PVC pipe, | 254 mm (10 in.) | 1,270 (2,801) | www.midcoonline.com . |
| kg (lb) | 305 mm (12 in.) | 1,802 (3,974) | |

Table S7. OC Processes Input in SimaPro.

| Processes | Unit | Amount 203 mm (8 in.) | Amount 254 mm (10 in.) | Amount 305 mm (12 in.) | Remark/Reference |
|---|-------------|--------------------------------------|---------------------------------------|---------------------------------------|--|
| Excavator (technology mix, 100 kW, Construction GLO)* | kg (lb) | 493047 (1,086,983) | 33,527 (73,915) | 33,527 (73,915) | (Ajdari, 2016) |
| Transport (combination truck, short-haul, diesel powered, Southeast/tkm/RNA)* | Ton-mile | 2,718 | 185 | 185 | Total material weight x Transportation distance (Ajdari, 2016) |
| Van (<3.St/US-/1 US-EI U)* | Piece | 0.0176 | 0.001 | 0.001 | 2 Vans, considering 1% of total emissions from production of van (Ajdari, 2016) |
| Pump (40W, at plant/US*/1 US-EI U)* | Piece | 0.07 | 0.004 | 0.004 | 8 Pumps, considering 1% of total emissions from production of pump (Ajdari, 2016) |
| Power saw (with catalytic converter/US-/1 US-EI U)* | Piece | 0.008 | 0.001 | 0.001 | 1 Power saw, considering 1% of total emissions from production of power saw (Ajdari, 2016) |
| Jack hammer (rock/US-US-EI U)* | kg (lb) | 164,350 (362,328) | 11,175 (24,638) | 11,175 (24,638) | (Ajdari, 2016) |
| Generator (200kWe/US-/1 US-EI U)* | Piece | 0.08 | 0.001 | 0.001 | 1 Generator, consuming 1% of energy per piece (Ajdari, 2016) |
| Electricity (mix, California/US US-EI U)* | HP.Hr | 415184 | 28233 | 28233 | HP of each equipment x Number of hours equipment used (Ajdari, 2016) |
| Air compressor, (screw-type compressor, 300 kW, at plant/US-/1 US-EI U)* | Piece | 0.08 | 0.001 | 0.001 | 1 Air compressor, consuming 1% of energy per piece (Ajdari, 2016) |
| Loader (operation, large, INW NREL/RNA U)* | hr | 387 | 26 | 26 | (Ajdari, 2016) |

*SimaPro code

Tables S8, S9, S10 illustrate EIA results for 203 mm (8 in.), 254 mm (10 in.), and 305 mm (12 in.) diameter CIPP.

Table S8. EIA Results for 8 in. CIPP.

| Impact category | Unit | Glassfiber reinforced plastic | Dummy plastic | Polyester resin | Styrene E | PET (amorphous) | Polyethylene (linear low density, resin, at plant, CTR/ kg/ RNA)* | Total Emissions |
|-----------------------|-----------------------|-------------------------------|---------------|-----------------|-----------|-----------------|---|-----------------|
| Ozone depletion | kg CFC-11 eq | 0.00766 | N/A | 0.00167 | N/A | N/A | 2.83E-5 | 0.0108 |
| Global warming | kg CO ₂ eq | 1.11E5 | N/A | 1.89E4 | 1.26E4 | 1.55E3 | 8.93E3 | 2.24E5 |
| Smog | kg O ₃ eq | 4.73E3 | N/A | 540 | 435 | 87 | 287 | 8.01E3 |
| Acidification | kg SO ₂ eq | 408 | N/A | 48.4 | 38.6 | 7.27 | 27.3 | 706 |
| Eutrophication | kg N eq | 170 | N/A | 31.7 | 0.913 | 0.221 | 0.541 | 230 |
| Carcinogenics | CTUh | 0.00366 | N/A | 0.000496 | 2.83E-6 | 4.01E-6 | 2.35E-5 | 0.0052 |
| Non carcinogenics | CTUh | 0.0236 | N/A | 0.00273 | 2.38E-6 | 1.2E-6 | 0.000249 | 0.0315 |
| Respiratory effects | kg PM2.5 eq | 30.1 | N/A | 3.92 | 1.74 | 0.317 | 1.61 | 51.3 |
| Ecotoxicity | CTUe | 3.27E5 | N/A | 4.84E4 | 474 | 58.8 | 4.11E3 | 4.61E5 |
| Fossil fuel depletion | MJ surplus | 1.93E5 | N/A | 3.4E4 | 4.8E4 | 4.84E3 | 5.2E4 | 4.81E5 |

N/A = Not available

Table S9. EIA results for 10 in. CIPP.

| Impact category | Unit | Glassfiber reinforced plastic | Dummy plastic | Polyester resin | Styrene E | PET (amorphous) | Polyethylene (linear low density, resin, at plant, CTR/ kg/ RNA)* | Total Emissions |
|-----------------------|-----------------------|-------------------------------|---------------|-----------------|-----------|-----------------|---|-----------------|
| Ozone depletion | kg CFC-11 eq | 0.00208 | N/A | 0.000453 | N/A | N/A | 7.7E-6 | 0.00286 |
| Global warming | kg CO ₂ eq | 3.01E4 | N/A | 5.13E3 | 3.42E3 | 420 | 2.43E3 | 5.7E4 |
| Smog | kg O ₃ eq | 1.28E3 | N/A | 147 | 118 | 23.6 | 77.9 | 2.07E3 |
| Acidification | kg SO ₂ eq | 111 | N/A | 13.1 | 10.5 | 1.97 | 7.41 | 182 |
| Eutrophication | kg N eq | 46.2 | N/A | 8.62 | 0.248 | 0.0598 | 0.147 | 61.2 |
| Carcinogenics | CTUh | 0.000995 | N/A | 0.000135 | 7.7E-6 | 1.09E-6 | 6.37E-6 | 0.00136 |
| Non carcinogenics | CTUh | 0.00642 | N/A | 0.000743 | 6.47E-6 | 3.26E-7 | 6.75E-5 | 0.00832 |
| Respiratory effects | kg PM2.5 eq | 8.17 | N/A | 1.07 | 0.472 | 0.086 | 0.437 | 13.2 |
| Ecotoxicity | CTUe | 8.88E4 | N/A | 1.32E4 | 129 | 16 | 1.12E3 | 1.21E5 |
| Fossil fuel depletion | MJ surplus | 5.24E4 | N/A | 9.24E3 | 1.3E4 | 1.31E3 | 1.41E4 | 1.23E5 |

N/A = Not available.

Table S10. EIA results for 12 in. CIPP.

| Impact category | Unit | Glassfiber reinforced plastic | Dummy plastic | Polyester resin | Styrene E | PET (amorphous) | Polyethylene (linear low density, resin, at plant, CTR/ kg/ RNA)* | Total Emissions |
|-----------------------|-----------------------|-------------------------------|---------------|-----------------|-----------|-----------------|---|-----------------|
| Ozone depletion | kg CFC-11 eq | 0.00153 | N/A | 0.000332 | N/A | N/A | 5.65E-6 | 0.00218 |
| Global warming | kg CO ₂ eq | 2.21E4 | N/A | 3.76E3 | 2.51E3 | 309 | 1.78E3 | 4.55E4 |
| Smog | kg O ₃ eq | 943 | N/A | 108 | 86.6 | 17.4 | 57.2 | 1.62E3 |
| Acidification | kg SO ₂ eq | 81.2 | N/A | 9.63 | 7.7 | 1.45 | 5.44 | 143 |
| Eutrophication | kg N eq | 33.9 | N/A | 6.32 | 0.182 | 0.044 | 0.108 | 46.1 |
| Carcinogenics | CTUh | 0.00073 | N/A | 9.89E-5 | 5.65E-6 | 8E-8 | 4.68E-6 | 0.00104 |
| Non carcinogenics | CTUh | 0.00471 | N/A | 0.000545 | 4.75E-6 | 2.4E-7 | 4.95E-5 | 0.0063 |
| Respiratory effects | kg PM2.5 eq | 5.99 | N/A | 0.781 | 0.346 | 0.0632 | 0.321 | 10.4 |
| Ecotoxicity | CTUe | 6.52E4 | N/A | 9.65E3 | 94.4 | 11.7 | 819 | 9.21E4 |
| Fossil fuel depletion | MJ surplus | 3.85E4 | N/A | 6.78E3 | 9.56E3 | 965 | 1.04E4 | 9.76E4 |

N/A = Not available.

Tables S11, S12, and S13 illustrate EIA results for 203 mm (8 in.), 254 mm (10 in.), and 305 mm (12 in.) diameter OC.

Table S11. EIA results for 8 in. OC.

| Impact category | Unit | PVC Pipe E | Excavator | Total Emissions |
|-----------------------|-----------------------|------------|-----------|-----------------|
| Ozone depletion | kg CFC-11 eq | N/A | 2.16E-6 | 0.00345 |
| Global warming | kg CO ₂ eq | 4.29E4 | 987 | 2.04E5 |
| Smog | kg O ₃ eq | 2.01E3 | 98.5 | 1.52E4 |
| Acidification | kg SO ₂ eq | 187 | 4.68 | 735 |
| Eutrophication | kg N eq | 14 | 0.266 | 108 |
| Carcinogenics | CTUh | 0.00889 | 5.14E-7 | 0.0122 |
| Non carcinogenics | CTUh | 0.00355 | 3.11E-6 | 0.0214 |
| Respiratory effects | kg PM2.5 eq | 8.47 | 0.256 | 38.4 |
| Ecotoxicity | CTUe | 2.07E3 | 31.8 | 3.5E5 |
| Fossil fuel depletion | MJ surplus | 1.01E5 | 1.98E3 | 4.47E5 |

Table S12. EIA results for 10 in. OC.

| Impact category | Unit | PVC Pipe E | Excavator | Total Emissions |
|-----------------------|-----------------------|------------|-----------|-----------------|
| Ozone depletion | kg CFC-11 eq | N/A | 1.47E-7 | 0.000231 |
| Global warming | kg CO ₂ eq | 4.11E3 | 67.1 | 1.5E4 |
| Smog | kg O ₃ eq | 192 | 6.7 | 1.08E3 |
| Acidification | kg SO ₂ eq | 17.9 | 0.318 | 54.3 |
| Eutrophication | kg N eq | 1.35 | 0.0181 | 6.53 |
| Carcinogenics | CTUh | 0.000852 | 3.49E-8 | 0.00102 |
| Non carcinogenics | CTUh | 0.000341 | 2.11E-7 | 0.00125 |
| Respiratory effects | kg PM2.5 eq | 0.811 | 0.0174 | 2.73 |
| Ecotoxicity | CTUe | 198 | 2.16 | 1.73E4 |
| Fossil fuel depletion | MJ surplus | 9.68E3 | 135 | 3.31E4 |

N/A = Not available.

Table S13. EIA results for 12 in. OC.

| Impact category | Unit | PVC Pipe E | Excavator | Total Emissions |
|-----------------------|-----------------------|------------|-----------|-----------------|
| Ozone depletion | kg CFC-11 eq | N/A | 1.47E-7 | 0.000231 |
| Global warming | kg CO ₂ eq | 5.83E3 | 67.1 | 1.67E4 |
| Smog | kg O ₃ eq | 273 | 6.7 | 1.16E3 |
| Acidification | kg SO ₂ eq | 25.4 | 0.318 | 61.8 |
| Eutrophication | kg N eq | 1.91 | 0.0181 | 7.09 |
| Carcinogenics | CTUh | 0.00121 | 3.49E-8 | 0.00137 |
| Non carcinogenics | CTUh | 0.000483 | 2.11E-7 | 0.0014 |
| Respiratory effects | kg PM2.5 eq | 1.15 | 0.0174 | 3.07 |
| Ecotoxicity | CTUe | 281 | 2.16 | 1.74E4 |
| Fossil fuel depletion | MJ surplus | 1.37E4 | 135 | 3.71E4 |

N/A = Not available.