

行政院環境保護署

104 年度土壤及地下水污染整治基金補助研究與模場試驗專案工作

整治場址能耗與環境足跡之本土化評估 系統建立及應用 期末報告(定稿本)

主辦單位： 行政院環境保護署
專案執行單位：國立高雄海洋科技大學海洋環境工程系
專案主持人：林啟燦 教授
專案執行期間：103 年 12 月 01 日起至
104 年 11 月 30 日止

中華民國 104 年 12 月 印製

行政院環境保護署「土壤及地下水污染整治基金補助研究及模場試驗專案」

期中報告初審意見對照表

計畫年度	104 年度	計畫類型	☒ 研究計畫 ☐ 現地試驗
計畫類別	☐ 調查 ☐ 整治復育 ☒ 評估 ☐ 底泥	主持人：林啟燦	NO：
計畫名稱	整治場址能耗與環境足跡之本土化評估系統建立及應用		
委員審查意見		計畫單位回覆	
1. 能耗與環境足跡之定量評估試算軟體之系統架構，建議能更明確之描述。		感謝委員的指正。本計畫將與各利害關係人溝通並修正此系統架構，促使本計畫目標能更加明確且促進國內污染業者使用之意願。	
2. 期末報告中建議能有應用建立之試算軟體評估實際污染整治場址之能耗與環境足跡之案例。		感謝委員的指教。預期中石化台南安順廠為本計畫之案場。	
3. 本研究提出污染土地可持續性綠色整治架構流程，並利用三合法控管作業原則，建立一套流程及層次性整治策略；本研究亦將 ASTM 準則導入此系統，且草擬出可持續性綠色指標來因應污染案場之整治規劃；在兼顧環境、經濟及社會相輔相成之下，發展所需考量之各項因素，並區分各項因素之正向指標及負向指標。		感謝委員的肯定。	
4. 可說明如何進行實場應用，後續可補充如何克服可行性問題。		感謝委員指正。本計畫將與各利害關係人溝通，促進國內既有污染案場之整治意願及流暢度，提供更符合經濟與社群需求之綠色及可持續性整治評鑑系統與技術工具，且識別各種利害關係人，並促進合意共識形成。	
5. 本報告文獻收集及相關資料收集完整，成果具創新性。		感謝委員的肯定。	

6. 建議後續工作可補充如何將成果與管理政策結合。	感謝委員指教。本計畫將與中央及地方主管機關溝通協調，並導入國內相關法規以及環保署正在研擬各類行政管理措施、獎勵方案、標章規範等措施，以鼓勵利害關係人採行可持續性綠色整治，促使管理政策及本計畫之結合。
7. 已依計畫項目執行。	感謝委員的肯定。
8. 依據美國環保署提出之環境足跡分析減算表 (SEFA)，計算各種整治過程中之費用或參數，並導入可持續性綠色指標，應可建立本土化整治政策之定量模式化。	感謝委員指導。將整治政策之定量模式本土化本計畫導入國內法規、溫室氣體、能源、水資源等因素，並於期末報告呈現之。
9. 已提出建議項目及可能之執行方式與評估。	感謝委員的肯定。
10. 執行現況、流程及方法的說明具體詳盡。	感謝委員的肯定。
11. 計畫後續執行工作項目及內容已於 5.2.2 節簡要說明。	感謝委員的肯定。
12. 計畫執行進度與預定進度相符，已有初步的成果。	感謝委員的肯定。
13. 如何驗證本計畫的研究結果？是以既有的實場數據與成果為依據加以驗證？或是其他方式？建議說明。	感謝委員指教。本計畫將導入案場驗證研究結果，並且針對能耗與環境足跡之定量評估試算軟體做敏感度測試。
14. 關鍵性的因子為何？建議討論。	感謝委員指正。本計畫成果實際應用關鍵性因子為耗能排碳之因子，如：電力、燃料油、溫室氣體等，釐清並找出關鍵課題且聚焦瓶頸。
15. 如何實務性的定義”綠色整治”？擬建立一量化基準或仍只是原則性的闡述？	本計畫分析美國環保署提出之環境足跡分析試算表 (Spreadsheets for Environmental Footprint Analysis, SEFA)，其評估工具是用以計算整治過程之環境足跡等相關參數，以及定性描述土地及生態系統。使用 SEFA 評估工具導入可持續性綠色指標，協助我國綠

	色整治策略朝向定量模式發展，最後以雷達圖來綜合呈現各項目中所定代表性指標之變化情形。
16. 適用的條件為何？所有的場址均可適用或是需符合某些篩選條件…等等，建議討論。	能耗與環境足跡之定量評估試算軟體可應用於場址整治之任一階段。最佳之情形為整治初期即以 GSR 觀點進行方案選擇與設計，包含物理、化學、生物整治之條件以及整治案場所需之經費，然而整治執行階段亦可藉由操作或管理之最佳化改善整治之環境足跡之影響。
17. 未提供後續工作重點。	感謝 貴署指正。後續工作重點於本計畫 5.2.2 節說明之。

行政院環境保護署「土壤及地下水污染整治基金補助研究及模場試驗專案」

期末報告初審意見對照表

計畫年度	104 年度	計畫類型	☒ 研究計畫 ☐ 現地試驗
計畫類別	☐ 調查 ☐ 整治復育 ☒ 評估 ☐ 底泥	主持人：林啟燦 NO：27	
計畫名稱	整治場址能耗與環境足跡之本土化評估系統建立及應用		
委員審查意見		計畫單位回覆	
1. 請更清楚說明本研究建立之整治場地能耗與環境足跡之本土化評估系統以及其如何應用。		本計畫研究整治場地能耗與環境足跡之本土化評估系統導入實際案場，場址負責人在提整治計劃過程當中，可利用本系統評估能耗與環境足跡之衝擊，據以選擇衝擊性較小之整治方案。亦可就已選定之整治方案，從能源、空氣、水資源、原物料與廢棄物及土地與生態五大面向知個項衝擊主要來源，調整施工方法，以降低總衝擊。	
2. 期末報告中 5.1.4 研究案場油污染土壤整治之評估，只定性呈現土地與生態系部分，未見其他四大範疇要素：能源、空氣、水資源、原料耗材與廢棄物之評估結果，請補充。		感謝委員指教，其他四大範疇要素：能源、空氣、水資源、原料耗材與廢棄物之評估結果修正補充至第 71~78 頁。	
3. 本計畫參考國內外相關報告、方法學、標準指引、計量軟體，同時參酌我國能源、溫室氣體、空、水、廢、土等相關法規標準或技術規範，透過與土基會及土水協會及業界專業人士間充分之溝通，建立本土化之整治場址能耗與環境足跡之本土化評估系統。本計畫之成果可用以補足我環保署國家溫室氣體登入平台 A-21 污染整治業之查驗規範。		感謝委員的支持，冀能將本計畫之成果可用以補足我環保署國家溫室氣體登入平台 A-21 污染整治業之查驗規範。	

4. 本報告撰寫詳實完整，文獻收集及相關資料收集非常齊全，討論亦相當精闢，執行成效佳。	感謝委員的肯定。
5. 整體研究成果符合預期，主要成果符合計畫書之內容，進度並無落後情形。	感謝委員的肯定。
6. 期末報告格式均依規定撰寫，符合規定。	感謝委員的肯定。
7. 研究項目及進度符合計畫內容，已達到計畫目標。	感謝委員的肯定。
8. 初步成果已達預期。計畫發展出可量化能耗與環境足跡之試算表單，以及可評估能耗與環境足跡之軟體工具。成果也可用以補足我環保署國家溫室氣體登入平台 A-21 污染整治業之查驗規範。	感謝委員的支持。
9. 未來可依初步成果應用於污染實場之操作試驗之可行性。	感謝委員的肯定。
10. 本研究屬於初期研究階段(雖然本計畫是延續主持人已完成的其他機構的研究計畫與成果)，研究內容&討論與建議仍屬初期的討論，就研究成果的實務應用性而言，仍未具體提出實務可行的操作方式(流程)，尤其未對國內的現況(各相關部門間的規範、限制、對相關參數的共識…等等)加以檢討討論。	1. 感謝委員指導，依據本計畫之初期研究成果，此政策方向若能獲土基會及委員們認同，建議應另編列上位計畫(Superior Plan)，就左列委員關心議題持續研究，深入探討政策可執行政及政策風險。 2. 本計畫亦已初步建議各案場整治計畫書應交代施工法及參數，以利主管機關查驗及評選 GSR 優良案場。
11. 計畫成果的驗證(流程? 可信度? ...等等)。	本評估工具開發完成後，以兩件本土案例進行試算測試，據以檢討本土化改進措施；然而，本計畫仍屬初期研究階段，就成果實務應用性而言，仍有許多持續研究深入探討之空間，請參見前項(第十項)答覆。
12. 國內對場址的關切項目(一般而言)是整治成效與時間，若由耗能與碳足跡而言，較符合綠色觀念的工法可能均屬”	委員所提意見確實是本評估工具本土化應用之關鍵議題。對於施工期較趕之案場，可能會選用總體較耗能排碳之工法；但仍可透過本工具比較選擇環境衝擊較低之機具或透過

緩不濟急”的工法，此特殊的需求如何於本計畫中呈現?或是需將場址的土地利用加以分類，部分場址可能適用於本計畫所建議的對象，部分則不適用，其關鍵因子與評估項目為何?...等等建議討論。(例如：本計畫所建議的示範場址的基本要件為何?...)	案場管理以降低衝擊，已於測試案例結果，補充討論。
13. 本計畫的成果(或是建議，或是流程，或是評估因子與權重...等等)與 EPA 其他已完成的計畫的觀點之間的關係是否可加以比對?	感謝委員指教，本計畫執行過程已參考行政院環保署「污染場址綠色及永續整治策略研擬計畫」以及「綠色整治決策支援系統建立」。前項計畫使用之軟體對於五大核心要素之參數考量較未完全；後項計畫則著重在生命週及評估及風險評估。與本計畫觀點類似，但本計畫涵蓋之面向更廣泛，可前述五大面向之探討，更包含現地、離場及場外活動之總體環境衝擊之考量，亦可比較不同工法、不同機具選用之環境足跡。
14. 計畫執行進度與預定進度相符。	感謝委員肯定。
15. 進度並無落後。	感謝委員肯定。
16. 執行現況、研究流程及方法說明具體。	感謝委員肯定。
17. 請檢附修正、期中審查意見。	遵照辦理。

專案基本資料表

專案性質		☐ 實驗性質 ☒ 非實驗性質		專案類別(單選)		☒ 研究專案 ☐ 模場試驗	
研究主題		☐ 調查 ☐ 整治 ☒ 評估 ☐ 底泥					
申請機構系所		國立高雄海洋科技大學					
機構地址		高雄市楠梓區海專路 142 號					
專案主持人		林啟燦		職等/職稱		教授	
協同主持人				職等/職稱			
專案名稱	中文	整治場址能耗與環境足跡之本土化評估系統建立及應用					
	英文	Development and application of a localized system to evaluate energy consumption and environmental footprint for contaminated land remediation projects in Taiwan					
	關鍵字	綠色整治、環境足跡、整治場址、控制場址、能耗評估模式					
執行期程		自 民國 103 年 11 月 01 日 起 至 民國 104 年 11 月 30 日 止					
計畫主持人		姓名：林啟燦		E-mail： ctlm@webmail.nkmu.edu.tw		專線：07-3617141#3756 手機：0939904043	
專任助理		姓名：陳葦亭		E-mail： weiting40@yahoo.com.tw		專線：07-3617141#3756 手機：0955835297	
經費分析表	專案預估經費		金額		編列說明		
	1.	人事費用	548,686		(1~5 項相加之 50%為限)		
	2.	貴重儀器使用含維護費	0		(與計畫實驗相關)		
	3.	消耗性器材與主要費用	80,000		(與計畫主體相關)		
	4.	其它研究相關費用	0		(差旅與租賃費用)		
	5.	雜項費用	7,670		(1~6 項相加之 5%為限)		
	6.	行政管理費	63,635		(1~5 項相加之 10%為限)		
	專案計畫申請總金額		699,991				

專案主持人：

林啟燦



(簽名及蓋章)

日期：

104.11.24

**行政院環境保護署土壤及地下水污染整治基金管理會
土壤及地下水污染整治基金補助研究與模場試驗專案
104 年度專案成果績效自評表**

一、專案基本資料

填表日期：104 年 10 月 21 日

專案性質	☐ 實驗性質 ☒ 非實驗性質	專案類別	☒ 研究專案 ☐ 模場試驗
研究主題	☐ 調查 ☐ 整治 ☒ 評估 ☐ 底泥		
申請機構系所	海 洋 環 境 工 程 系	計畫主持人	林 啟 燦
專案名稱	整治場址能耗與環境足跡之本土化評估系統建立及應用		
專案執行期程	☐ 申請階段 ☐ 期中 ☒ 期末		

二、成果績效自評

「計畫總預估數」應與計畫審查核定值相符，請執行單位依實際達成之量化成果填寫於「結案達成數」欄位中。

(一) 學術面

項目 \ 目標達成程度			申請 預估數	期中 達成數	期末 達成數	結案 達成率	備註 (說明未達成原因或學術產出 發表日期、發表處、發表名稱、 影響指數等)
A 學 術 產 出 及 活 動	1.國內投稿 (篇數)	(1)論文					
		(2)研討會論文	3	0	0		預計結案前達標
	2.國外投稿 (篇數)	(1)期刊論文					
		(2)研討會論文	1	1	1		已達標
	3.報告 (篇數)	(1)技術報告					
		(2)研究報告	1	0	0		預計 10 月底前產出
	4.專著 (本數)						
	5.辦理學術 會議(場數)	(1)研討/說明會					
		(2)成果發表會					
		(3)論壇					
	6.研發改良 技術(項數)	(1)已開發技術					
		(2)技術平台					
B 人 才 培 育	7.研發人員 (人數)	(1)碩士	2	1	1		預計 11 月底前達標
		(2)博士					
	8.研究團隊 (個數)	(1)跨領域團隊	1	0	0		預計結案前達標
		(2)跨國團隊					
		(3)跨機構團隊					
		(4)形成研究中心					
		(5)形成實驗室					
9.其他指標		(請自填)					

項目		目標達成程度	申請 預估數	期中 達成數	期末 達成數	結案 達成率	備註 (說明未達成原因或學術產出 發表日期、發表處、發表名稱、 影響指數等)
(請自行命名)							

(二) 產業面

項目			目標達成程度	申請 預估數	期中 達成數	期末 達成數	結案 達成率	備註 (說明未達成原因或專利、技 術轉移相關詳細資料)
A 智慧 財產 權	1.專利 (件數)	已	發明					
		核	新型/設計					
		准	合計					
		申	發明					
		請	新型/設計					
		中	合計					
B 研 發 技 術 轉 移	2.先期技術 成果移轉	件數						
		授權金(仟元)						
		衍生利益金(仟元)						
	3.技術移轉 (專利)	件數						
		授權金(仟元)						
		衍生利益金 (仟元)						
	4.技術移轉 (應用技術)	件數						
		授權金(仟元)						
		衍生利益金(仟元)						
	5.可移轉 產業技術	(1)技術(件數)						
		(2)品種/系(件數)						
	6.其他指標 (請自行命名)	(請自填)						

(三) 政策面

項目			目標達成程度	申請預 估數	期中 達成數	期末 達成數	結案 達成率	備註 (說明未達成原因或 其他詳細資料)
A 服 務 便 民	1.技術服務	次數						
		收入(仟元)						
	2.諮詢服務	次數						
		收入(仟元)						
B 支 援	3.協助政府制 定 (件數)	(1)政策						
		(2)法規						
		(3)規範						

合 作		(4)標準					
4.其他指標 (請自行命名)		(請自填)					

三、請依學術成就、技術創新、經濟效益、社會影響等方面，評估研究成果對現況或本署之學術或應用價值。（簡述成果所代表之意義、價值、影響或進一步發展之可能性，500 字為限）

近年國際環保先進國家，積極推動綠色可持續性整治（GSR）策略，希望在進行污染整治時，亦能兼顧環境、經濟及社會之需求。此一國際趨勢及規範，一經建立後，不僅歐美等先進國家在環境整治市場，可以佔得主導市場之經濟優勢，亦可享有技術規範之指標性作用；影響市場甚巨。經 15 年來的努力，我國土基會已成功整合及引領環境工程、顧問、及學術研究機構，不論是在環境檢測、場址調查、控制整治技術、及生態風險評估等面向，均建立起相當技術經驗基礎，逐漸培養出，在東南亞及大陸之區域性技術輸出實力。

本計畫之執行成果可以使我國持續維持前述優勢，且在台灣建立完善的「整治案場評估系統」有其急迫性之重要政策引領方向；有了一致性之規範，方能落實對環境生態友善，並可持續性推動污染淨化方案。爰此，本團隊已參考國內外相關報告、方法學（Methodology）、標準指引（Standard Guide）、計量軟體，同時參酌我國能源、溫室氣體、空、水、廢、土等相關法規標準或技術規範，在綜合考量各利害關係人之立場下，執行「整治場址能耗與環境足跡之本土化評估系統建立及應用」計畫。透過與土基會及土水協會及業界專業人士間充分之溝通，以嚴謹之專案計畫執行流程管理，建立本土化之「整治場址能耗與環境足跡之本土化評估系統」。經過測試及結案前持續調整後，成熟之系統即可建立為共同遵循之規範。

為了符合我國及亞洲國家之民情需求及工程經濟之可持續性發展需求，本計畫執行時特別加強本土化之需求，以達有利於我國環境污染整治技術總體輸出之目標。最終所發展出之可量化能耗與環境足跡之試算表單，以及可評估能耗與環境足跡之評估軟體工具，有助於業者選擇與決定污染場址整治之最佳控管實務，識別各種利害關係人所關注之利益；在維護生態及保護人類健康之同時，協助達成整治目標，同時兼顧環保與節省經濟成本，達到褐地再利用之目的。透過本計畫之執行，再與查驗機構合作，本計畫之成果也可用以補足我環保署國家溫室氣體登入平台 A-21 污染整治業之查驗規範。期能健全我環保署土基會於土水整治領域之系統與技術規範，維持在東南亞(含大陸)區域性之領先優勢，且對東亞等國家環保輸出。

中文摘要

國內推動土壤地下水污染防治工作，已近十五年。諸多控制以及整治場址，礙於技術以及經費，經常耗時多年，而且費用高昂所費不貲，甚至整治無以為繼。不僅戟傷案場土地復育時程，亦影響案場及鄰近社區與經濟發展甚鉅；致使案場業主等污染土地關係人、社區居民及/或政府機關等利害關係人均蒙其害。究其關鍵，應與整治過程未評估能源耗用特性，且缺乏評估其他環境介質足跡之方法，以致連帶影響環境會計/成本、整治經濟/成本、甚至社群乃至社會成本。為了彌補這方面之不足，本研究已規劃協助環保署全面導入並且極力推動對環境更為友善之可持續性綠色整治（Green Sustainable Remediation, 簡稱 GSR）。希望在進行污染整治時，亦能兼顧環境保護、經濟發展及社群共識，取得三者之間均衡發展。

目前，國際間正開發環境足跡分析工具，且無統一之評估工具，因此由於各工具評估範疇與邊界不同，不同工具間評估結果並不適合互相比較，而本研究分析美國環保署提出之環境足跡分析試算表(Spreadsheets for Environmental Footprint Analysis ,SEFA)，其評估工具是用以計算整治過程之環境足跡等相關參數，以及定性描述土地及生態系統。

本研究已提出一套污染土地可持續性綠色整治架構流程，並利用三合法控管作業原則，建立一套流程及層次性整治策略；為能盡速與國際接軌，本研究已將 ASTM 準則導入此系統，且草擬出可持續性綠色指標來因應污染案場之整治規劃；在兼顧環境、經濟及社會相輔相成之下，發展所需考量之各項因素，並區分各項因素之正向指標及負向指標。使用 SEFA 評估工具導入可持續性綠色指標，在推動土地整治之方案時，需同時考量相關因素，降低其負向指標並提高整體效益，協助我國綠色整治策略朝向定量模式發展。

本研究以某供油中心大型生物復育場作為研究案場，且導入評估軟體，共分為能源、空氣、水資源、原料耗材與廢棄物、土地與生態系等五大範疇要素。其中土地及生態部分目前以定性方式呈現，但本計畫嘗試將此範疇定量，因此針對油污染土壤健康整治進行土壤及生態指標，其評估項目依序有以下幾項(1) 土壤肥力指標 (2) 成長狀況 (3) 收成狀況 (4) 蔬果成品品質狀況。研究結果發現，如欲導入並落實綠色可持續性整治，能源管理與現行各類相關環境申報機制若納入整治計畫／控制計畫，並予審查、稽核追蹤與要求落實，不僅可促使國內案場落實綠色可持續性整治，亦可活絡甚至衍生其他相關綠色經濟，有助污染土地社會經濟環保各面向更均衡之永續發展。

英文摘要

In order to construct the mainframe of green and sustainable remediation policy, a systematic evaluation mechanism was developed. Such evaluation tool was established according to the requirement of Taiwan Soil and Groundwater Remediation Act, and was referring from sustainable remediation case examples of USEPA and other US governmental agencies, and the American Society of Testing Materials (ASTM). The established Chinese version of Green and Sustainable Remediation Evaluation Tool has considered energy consumptions and environmental footprints in five aspects include: energy, air, water, materials and solid wastes, as well as land and ecological aspects. To test the comprehensiveness of the GSR Evaluation Tool, a field scale of TPH contaminated soils bio-remediation case was applied and found successful. To the administrative concerns, it is suggested that energy consumptions and the related environmental footprint data should be estimated and reported in the site remediation plan or the site control plan. Then the administrators should follow up the implementation plan via auditing program to enforce the completeness of the plan. Enforcing green and sustainable remediation policy, not only can cultivate green remediation business opportunities, but also can harmonize and balance society, economic, and environment groups; thus, a sustainable future can be expected.

目次

一、	前言	1
二、	研究目的	3
三、	文獻探討	4
3.1	國際綠色及可持續性整治發展情形.....	5
3.1.1	美國聯邦.....	5
3.1.2	美國聯邦環保署.....	6
3.1.3	美國國防部.....	9
3.1.4	美國州際技術及法規委員會.....	11
3.1.5	美國試驗與材料協會.....	12
3.1.6	美國永續整治論壇.....	14
3.1.7	英國.....	16
3.1.8	歐盟.....	18
3.1.9	澳洲.....	19
3.2	我國綠色及可持續性整治發展情形.....	19
3.2.1	台灣土壤及地下水環境保護協會.....	20
3.2.2	工業污染防治期刊.....	20
3.2.3	行政院環境保護署.....	23
3.2.4	工程科技資訊.....	26
3.3	綠色及可持續性整治評估及評鑑工具集.....	32
3.4	油污染土壤概況介紹.....	37
3.5	加油站污染整治技術之選擇.....	39
四、	研究方法與過程	40
4.1	執行流程.....	40
4.2	執行方法.....	41
4.2.1	法規.....	41
4.2.2	環境足跡評估方法.....	43

4.2.3 定量評估.....	47
4.2.4 最佳管理實務 Best Management Practices (BMPs)	49
4.2.5 減少環境足跡方法.....	50
4.2.6 既有規範軟體工具.....	50
4.2.7 研究案場.....	54
4.3 工作進度甘特圖.....	56
五、 結果與討論.....	57
5.1 結果與討論.....	57
5.1.1 建立本土化之系統架構.....	57
5.1.2 可持續性綠色指標.....	63
5.1.3 可持續性綠色整治定量計算方法.....	68
5.1.4 研究案場油污染土壤整治.....	71
5.1.5 案場結果之建議與對策.....	77
5.2 結論與建議.....	78
5.2.1 結論.....	78
5.2.2 建議.....	79
六、 參考文獻	82
七、 附件	86
附件一、廚餘堆肥化整治區收成玉米 SGS 重金屬檢測	87
附件二、廚餘堆肥化整治區收成玉米 SGS 農藥殘留 202 項檢測	89
附件三、廚餘堆肥化整治區收成蕃茄 SGS 檢測	94
附件四、Spreadsheets for Environmental Footprint Analysis (SEFA).....	100

圖次

圖 1-1 綠整治最佳控管實務要素圖.....	1
圖 3.1- 1 美國聯邦整治技術圓桌會議小組整治策略.....	6
圖 3.1.2-1 綠色整治五大要素.....	7
圖 3.1.4-1 ITRC 可持續性綠色整治架構.....	12
圖 3.1.5-1 ASTM 綠色淨化之總覽	13
圖 3.1.6-1 SuRF 可持續整治架構.....	15
圖 3.1.6-2 SURF 永續性整治評估流程	16
圖 3.1.7-1 永續整治架構.....	17
圖 3.1.7-2 永續整治評估流程.....	17
圖 3.1.8-1 永續整治架構.....	18
圖 3.2.2-1 綠整治最佳控管實務運用時機是意圖.....	21
圖 3.2.1.1-1 綠色及永續導向型整治 BMPs 使用時機說明圖	24
圖 3.2.1.2-1 定量評估工具架構.....	26
圖 3.2.4-1 環保署綠色及永續導向型整治架構.....	27
圖 3.4-1 污染場址判定流程圖.....	37
圖 4.2.2-1 綠色整治五類核心要項.....	43
圖 4.2.3-1 定量評估過程.....	48
圖 4.2.4-1 最佳管理措施之流程.....	49
圖 5.1.1-2 案場評估流程.....	62
圖 5.1.3-1 可持續性綠色整治指標評估方法流程圖	68
圖 5.1.3-2 可持續性綠色整治雷達圖.....	70
圖 5.1.4-1 整治後土壤狀.....	74
圖 5.1.4-2 玉米生長趨勢圖.....	74
圖 5.1.4-3 根系生長.....	75

圖 5.1.4-4 生長高度.....	76
圖 5.2.2-1 建議列入整治計畫書之因子.....	81

表次

表 3.1.2-1.綠色整治指標概要.....	8
表 3.1.3- 2 美國三軍綠整治策略.....	10
表 3.1.3-2 美國海軍綠色指標.....	11
表 3.2.2-1 永續性綠色整治評估工具.....	22
表 3.2.1.1-1 綠色及永續導向型整治 BMPs 的評估表單	24
表 3.2.1.1-1 綠色及永續導向型整治 BMPs 的評估表單(續).....	25
表 3.2-1 本計畫與我國行政院環保署計畫之差異性.....	28
表 3.2-2 本計畫與我國行政院環保署計畫之差異性.....	29
表 3.2-3 本計畫與我國行政院環保署計畫之差異性.....	30
表 3.2-4 本計畫與我國行政院環保署計畫之差異性.....	31
表 3.3-1 整治策略及評估工具(續).....	34
表 3.3-1 整治策略及評估工具(續).....	35
表 3.3-1 整治策略及評估工具(續).....	36
表 3.4-1 全國受石油碳氫化合物土壤污染場址統計表.....	38
表 4.2.1-1 國內環境相關法規.....	42
表 4.2.2-1 足跡方法論的概述.....	44
表 4.2.2.1-1 足跡定量分析的目標.....	45
表 4.2.6-1 SEFA 操作流程.....	51
表 4.2.7-1 化學整治.....	55
表 4.2.7-2 生物整治.....	55
表 5.1.2-1 可持續性綠色整治指標.....	67
表 5.1.4-1 土壤肥力	73
表 5.1.4-2 收成狀況.....	76

表 5.1.5-1 案場結果比較及對策建議.....	77

一、前言

因工業發展與經濟並濟興盛後，工業發展殘留在土地上的污染日逾趨長，隨著經濟的富裕，逐漸重視生活與環境，如台灣，目前受列管與整治場址農地為 2295 處、加油站 79 處、工廠 143 間，在這樣狹小的台灣面對身旁的污染早已採取各種行動，近年各國的調查行動、風險控管、監控污染案場技術相當成熟，但在整治污染案場上，對於能耗未有所定量評估，更甚導致產生影響環境其他介質足跡，沒有正視，造成更多的環境問題與成本。為解決此問題，本計畫建立本土化方法學以及定量評估，使對環境更為友善。

如美國環保署(2012)、ASTM(2013)制定可持續性綠色整治(GSR)方法，綠整治之五大要項，包含：能源、空氣、水資源、原料耗材與廢棄物、土地與生態系等五大範疇要素，如圖 1-1，目的為在整治過程中能夠減少與監控五大核心要素用以降低環境危害與衝擊，此外，無論整治受污染土地（簡稱
 鄰地）或荒蕪延宕懸而未決之褐（棕）地（Brownfields），綠整治全程若能盡量落實本整治場址能耗與環境足跡之本土化評估系統以及最佳控管實務作業（best management practices, BMPs），除有助污染整治與淨化環境，對土地活化再甦永續發展亦產生極大的實質效益。以下小項為解釋各項目。



圖 1-1 綠整治最佳控管實務要素圖

資料來源：綠色整治技術之創新性與未來性，社團法人台灣土壤及地下水環境保護協會簡訊

1. 能源：增加使用可替代性再生能源/清淨能源以及減少能源使用總量。
2. 空氣：自整治源頭即應減少空氣污染，並需抑制溫室氣體排放量。
3. 水資源：減少耗用水量且需降低對水資源負面影響。
4. 耗材與廢棄物：加強原料物料耗材管理和致力減少廢棄物質量。
5. 土地生態系：加強土地管理和對生態系統環境保護。

此方法用以來定量材料，廢棄物，水，能源，以及代表活動的環境足跡涉及污染場地淨化空氣指標。該指標的目的是：反映整治辦法專案團隊有一個比較直接的能力改變及促進做法，將導致有利變化的度量值參數。促進這些淨化指標的定量：該方法是一個總體框架。

幫助現場團隊瞭解，整治辦法組件對專案的環境足跡影響最大。定量指標可以作為降低整治辦法足跡的初始步驟。整個過程從另一個角度看可以涉及整治過程分析的整治辦法，並可能產生不確定性的其他方式，可進行並具成效的改善。

提供有關技術方法的建議，以減少（但不能優先引導該足跡減量的結果）整治辦法的足跡更可以擴大利害關係人之間的技術轉移，由美國環保署、ASTM 經驗傳達許多多變的現場整治進行足跡分析及根據任何其他各方提交的淨化程序，進行足跡分析的過程，採用此兩系統評估足跡分析結果，用以達成符合超級綠色整治策略行動“開發一個機制方法論，用於評估一個淨化的環境足跡”。

二、 研究目的

本研究為環境足跡之評估系統研析，冀能藉由本研究嘗試提出一套評估系統並可應用至國內案場，並在推動整治的過程中能盡速推動土地活化再甦，使國土日益嚴重的污染問題，能夠透過污染土地再開發的經濟效益化危為轉機，不僅落實對環境生態更友善之可持續性綠色整治淨化方案之推展亦能促進國土資源永續發展之目標，以下列所示：

1. 資料蒐集以及分析彙整。
2. 整合國內外方法與指引。
3. 分析既有規範軟體工具。
4. 建立本土化之系統架構。
5. 建立本土化評估方法學。
6. 嘗試建立可評估能耗與環境足跡之定量評估試算軟體工具。

三、 文獻探討

工業發展在國家的社會及經濟發展上皆扮演重要角色，不僅改善人類的生活環境，亦成為滿足健全經濟成長的要件之一。過去未能重視土地永續性的觀念，導致環境遭受嚴重破壞，而整治污染土地經常耗時多年，且往往費用高昂所費不貲，有時甚至造成整治活動無以為繼，而戟傷案場當地與鄰近社區之活動與經濟發展，使得污染案場業主、污染土地關係人、周遭社區及/或政府機關等利害關係人相關社群付出極大經濟以及社會成本。

因此，世界各國不斷致力於追求滿足當代需求，且在不影響後代發展的觀念下建立永續發展原則；永續發展泛指環境、經濟與社會三個面向能相互補、共同發展且達均衡的狀態。

然而在各項資源有限的限制條件下，整治所使用技術，對於節省能耗、減少碳排放、減少影響空氣、減少影響水體、減少產生廢棄物、影響土地以及生態等經濟與環境議題在傳統整治方案之選用上甚少著墨。如何免除二次污染減少環境整體負荷，在世界環保先進國家已更加重視。

國際間對於土地污染整治，環保先進國家對其土地污染，近年正全面導入並且極力推動對環境更為友善之綠色整治，近年對於污染土地如何兼顧環境保護、經濟發展以及社會均衡，推廣綠色及永續整治亦有方興未艾之勢。對於綠色及永續整治，國際間目前主要區分為下列三類：

第一類：為美國環保署（U.S., Environmental Protection Agency, USEPA）所提出之綠色整治 (Green Remediation) 或「深綠整治」(Deep Green Remediation)。

第二類：為英國永續整治論壇(Sustainable Remediation Forum, SURF-UK)等單位提出之永續整治(Sustainable Remediation)。

第三類：為美國州際技術與法規會(The Interstate Technology and Regulatory Council, ITRC)及美國國防部(Department of Defense, DoD)所提出之綠色及永續整治(Green and Sustainable Remediation)。

地球公民世界強權環保先進國家之美國，將土地活化再甦視為極具挑戰且相當棘手之議題，因為人口郊區化的影響，許多鋼鐵起家的工業城鎮面臨產業外移，導致都市核心內衰頹與廢棄地產生之問題。這些工業廢棄地，不

僅造成不動產上經濟的損失，更造成都市環境景觀破壞。基此，美國於 1980 年發展出「環境因應及賠償責任法」(Comprehensive Environmental Response, Compensation and Liability Act, CERCLA) 處理這一類工業廢棄地的問題，並創立專責「超級基金」(Superfund) (U.S. EPA, 2008)，來處理工業區內疑似有污染的廢棄地的整治經費。以下整理相關國內外文獻對於污染土地處理與活化之策略，可做為本計畫污染整治環境足跡系統評估之參考。

3.1 國際綠色及可持續性整治發展情形

3.1.1 美國聯邦

美國聯邦對於土地資源的妥善管理，已不再停留在單純的整治與污染改善，而是以土地的永續利用及價值再造為目標；有鑑於此，1990 年成立美國聯邦整治技術圓桌會議小組(Federal Remediation Technologies Roundtable, 簡稱 FRTR)，由美國國防部、陸海空三軍、美國環保署與聯邦政府所共同組成，建立一個聯邦機構間合作的橋梁，不但匯集整治清理管理人員，亦於近年來積極推動綠色整治作法，提出許多建議及成功案例分享，將理論化為實際，讓更多人知悉綠色整治所帶來的好處。FRTR 發展的焦點是在整治場址的最佳化操作條件與地下水監測系統，近年來美國聯邦整治技術圓桌會議小組發展出一套整治流程，如圖 2.1-1 所示，透過案場監控、三合法導入以及數據管理建立完整詳實的概念模型，FRTR 認為整治過程最佳化操作，是利用一個系統性的監控和評估方法，進行案場識別和針對不同案場的性質，直視案場真正的需求，整治方法及操作因不同案場而有所不同，透過嚴謹的整治策略降低環境的二次污染，控制成本及時間，並提高整治之可行性。

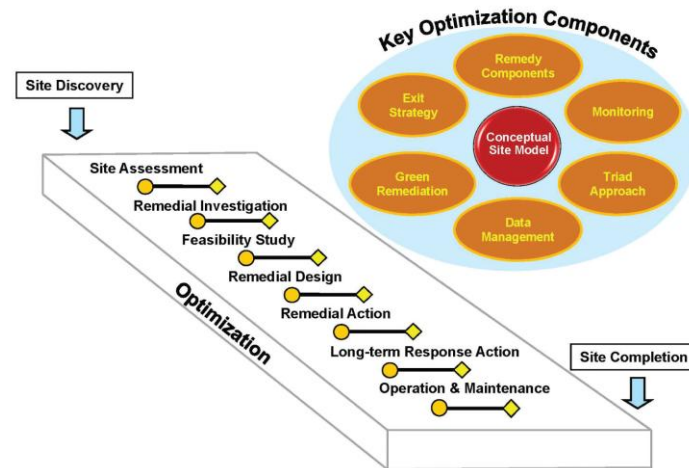


圖 3.1- 1 美國聯邦整治技術圓桌會議小組整治策略

資料來源: FEDERAL REMEDIATION TECHNOLOGIES ROUNDTABLE ANNUAL SUMMARY OF ACTIVITIES: August 2012

3.1.2 美國聯邦環保署

美國環保署近來配合氣候變遷議題及環境永續保護前提下，在整治策略中納入減少溫室氣體排放的要求，減低其他對環境造成的負面影響，推出超級基金綠色整治策略（Superfund Green Remediation Strategy）(U.S. EPA，2010)，美國環保署超級基金整治辦公室，不但管理著超級基金場址之長期整治，亦致力於保護人類健康和環境，為提高超級基金綠色整治策略之整治行動，2009 年 8 月發行了綠色整治原則，其核心關鍵在綠色整治五大要素，如圖 3.1.2-1 所示，包含能源、空氣、水體、土地與生態系、原料耗材與廢棄物等五大範疇要素，提倡整治實務宜更重視「增佳品質與減少耗量」。施行的方式需符合法規和管理規則，且需有明確的整治目標與行動、考量社區的利益、合理的整治時間表等，整治則是需考量環境足跡、場址的可持續性，考驗的不單只是環境，還包含了場址使用人及當地社區所關注的社會面和經濟面。

於 2011 年 1 月之前，陸續完成「現地熱處理」、「場址整治清理承包機制」、「封閉式掩埋場」，甚至是「場址整治清理環境相關干擾環境因素之足跡分析(footprint)方法」。「環境足跡的方法論」適用時機包含：場址污染評估（environmental site assessment）、案場調查（investigation）、風險評估（risk assessment）、緊急應變（emergency response）、整治清理（remediation clean-up）、系統操作（system operation）、營運管理（manage,

operation & maintain)、品質監控 (quality monitoring & control)、復育 (restoration) 及關場 (site closure) 等污染清除與整治過程。此外亦適用於土地再甦活化各階段，例如於：受污染場地設施除役與設備拆卸分解和清除處理，土地清理整治和廢棄物管理，土地活化規劃設計營建與再利用，土地永續利用和中長期管理等階段，最佳管理實務皆可得到高度運用與充分發揮。

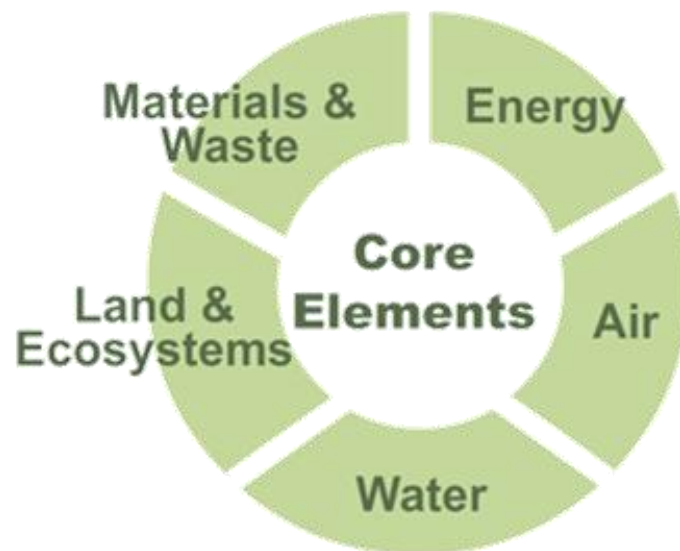


圖 3.1.2-1 綠色整治五大要素

資料來源: Methodology for Understanding and Reducing a Project' s Environmental Footprint ,2012

於 2012 年更進一步提出「降低環境足跡的方法論」(Methodology for Understanding and Reducing a Project 's Environmental Footprint)，提出綠色整治指標，作為減少環境足跡的定量參考依據，讓使用者在污染場址整治過程中，可以用定量的方式計算整治各階段的环境足跡，幫助使用者進行最佳管理措施的決策，達到減少環境足跡的目標。綠色整治評估矩陣的使用流程，大概可分為 7 個主要的步驟：

- (一) 設定分析的目標及範疇
- (二) 收集並整理整治策略的資訊
- (三) 定量原物料及廢棄物指標
- (四) 定量水指標

(五) 定量能源與空氣指標

(六) 定性描述生態系影響的情況

(七) 結果

表 3.1.2-1.綠色整治指標概要

核心 元素	材料	測量單位
能源	E-1：總能源使用	MMBtu
	E-2：自願從可再生資源的總能源	
	E-2A：現場發電或採用和生質柴油的使用	MMBtu
	E-2B：自願購買可再生能源電力	MWh
	E-2C：自願購買的地區經濟共同體	MWh
空氣	A-1：現場氮氧化物，硫氧化物，懸浮粒子排放量	英鎊
	A-2：現場有害空氣污染物排放量	英鎊
	A-3：總氮氧化物，硫氧化物，可吸入懸浮粒子和排放量	英鎊
	A-4：總有害空氣污染物排放量	英鎊
	A-5：總溫室氣體排放量	噸，二氧化碳當量
水資源	現場用水（按來源劃分）	
	W-1：來源、使用、最終命運的組合 #1	百萬加侖
	W-2：來源、使用、最終命運的組合 #2	百萬加侖
	W-3：來源、使用、最終命運的組合 #3	百萬加侖
	W-4：來源、使用、最終命運的組合 #4	百萬加侖
原物料與	M&W-1：現場所使用的成品	噸

廢棄物	M&W-2：回收或廢棄物的百分比	百分比
	M&W-3：現場所使用的原物料	噸
	M&W-4：使用原物料中來自回收或廢棄物百分比	百分比
	M&W-5：現場產生的有害廢棄物	噸
	M&W-6：現場產生的無害廢棄物	噸
	M&W-7：現場潛在可回收或再利用之總廢棄物百分比	百分比
土地與生態系	定性描述	

資料來源：Methodology for Understanding and Reducing a Project's Environmental Footprint, 2012

3.1.3 美國國防部

根據聯邦行政法公佈第 13541 號行政命令(U.S. EPA, 2009)—聯邦在環境、能源及經濟績效領導，使用第 13423 號行政命令之架構，希冀建置一個朝向永續發展的聯邦政府策略，強制規定所有聯邦機構進行環境、交通、能源及各項活動，對於環境、經濟及社會之各項指標進行綜合性評估，透過可持續發展的方式，期望創建一個“環境、能源及經濟表現之領導政策”。美國三軍依據行政命令積極推動綠色整治策略，如表 3.1.3- 1 所示，且也實際應用於受污染之土地，已有為數不少成功案例。

表 3.1.3- 2 美國三軍綠整治策略

美國空軍綠色整治 發展重點	美國空軍的環境復育計畫，著重在成本控制、降低風險、遵循法律以及其他測量標準，在保護人體健康及環境之際，減少成本支出、縮短整治期程，同時強調與大自然合作，目前發展的工具具有 Sustainable Remediation Tool (SRT) 及 Performance Tracking Tool (PTT)
美國陸軍綠色整治 發展重點	陸軍以環境可持續發展的精神解決環境污染的問題，並與其他機構合作發展最佳管理作業，整治過程重視利益相關者的參與，目前發展的工具為 Sustainable Remediation Tool (SRT) 及 Sustainable Environmental Restoration (SER)
美國海軍綠色整治 發展重點	確保環境保護和保存遵循環境法律和法規，並維持所需資源取得公眾支持，在保護人體健康及環境之際考慮後續操作，同時強調與大自然共存，並思考生命週期設計(LCD)，達到產品生命週期之延續，減少廢棄物之產生，目前發展的工具 Site Wise™與生命週期評估(Life Cycle Assessment, LCA)。

雖然目前美國三軍皆積極推動綠色整治發展策略，但就屬美國海軍發展最為完整，美國海軍設施工程部門(Naval Facilities Engineering Command)於2012年4月出版了一本「Department of The NAVY Guidance on Green And Remediation」海軍綠色整治指引，該指引提供了一個明確的整治策略與方法，將綠色整治和可持續性綠色整治詳盡考慮於場址整治過程中。海軍的環境整治行動選項，包括主動式、被動式或主被動複合式之整合性組合，含括移除、圍堵與處理等技術；自然衰減；消除暴露途徑；工程控制；行政禁制。這些補救措施的目的不但是為了消除對人類健康和環境的不可接受風險，亦可整治或管理環境介質中的污染，背後的理念是通過滿足現有的需求，同時最大限度地降低潛在的負面影響。指引內容包括海軍所發展的綠色整治指標如表3.1.3-2所示，且整治場址必須將此指標詳盡列入考量，並透過 Site Wise™及 SRT™ 量化或定性各項指標，透過此定性及定量工具，有助於案場選取對環境更為友善之整治方法，建立一個可持續性綠色整治策略，有效降低整治造成的環境足跡，並提供最大的整治效益。

表 3.1.3-2 美國海軍綠色指標

美國海軍 綠色指標	環境	• 空氣的排放 • 水資源利用 • 資源消耗 • 對生態的影響 • 廢棄物的產生
	經濟	• 生命週期評估成本 • 獲利的空間 • 創造就業機會/失去工作
	社會	• 工人事故風險 • 整治對社區造成的影響 • 環境正義 • 未來土地使用的限制 • 整治對當地社區的文化損失 • 利益相關者的參與和接受度 • 公共補救活動

3.1.4 美國州際技術及法規委員會

由美國 35 個州於 1995 年聯合成立美國州際技術及法規委員會(The Interstate Technology and Regulatory Council, 簡稱 ITRC)，ITRC 的主要工作是出版環境技術指導綱要與提供人員教育訓練，並持續發展最佳管理實務(BMPs)，可以大為減低各州獨立研擬環保標準與尋找相關技術資訊之工作(ITRC,2011)。

ITRC 的可持續性綠色整治評估架構包括可持續性綠色整治規劃及可持續性綠色整治實施程序二部份(如圖 3.1.4-1)。可持續性綠色整治規劃是整合可持續性綠色整治的原則與作法使之成為計畫的起始點，可在準備建議書、合同、計畫範圍界定时使用，同時亦可應用於執行期間的評估、最佳化過程或計畫完成的參考。可持續性綠色整治規劃內容包括評估或更新場址概念模式、設定可持續性綠色整治目標、利益相關者的參與、選擇指標與可持續性綠色整治評估階層和範圍、整治成效文件記錄五個工作項目。

可持續性綠色整治實施的流程依序為確認可持續性綠色整治選項、執行可持續性綠色整治評估、實施可持續性綠色整治方法及監測、追蹤及文件建檔，整個實施過程都必須符合可持續性綠色整治規劃程序的五個階段目標，而場址整治執行期間必須執行的措施工作包括：調查研究、整治評估與篩選、整治規劃設計、整治系統建置、操作維護及監測、整治系統最佳化、整治收尾工程。



圖 3.1.4-1 ITRC 可持續性綠色整治架構

參考出處：The Interstate Technology & Regulatory Council Green and Sustainable Remediation Team, “Green and Sustainable Remediation: A Practical Framework”, November 2011.

3.1.5 美國試驗與材料協會

美國試驗與材料協會（American Society of Testing & Material, International, 簡稱 ASTM），已提出一系列綠色整治概念構想與實務通報，並亟欲制定「案場評估與綠整治清除之永續發展新指引 (ASTM WK23495 - New Guide for Incorporating Sustainable Objectives Into Cleanup)」。草案指引綱要架構提供一套準則，在整個案場整治清理過程，透過全面性的綜合考量環境，經濟和社會因素，並指出如何選擇與決定最佳控管實務與可持續性發展的指標，且識別各種利害關係人所關注之利益，促使在保護人類健康之同時，協助整治場址達到同時兼顧環保與節省經濟成本，達到最終污染土地(褐地)再利用之目標。

於 2013 年提出「綠色淨化之標準指南(ASTM E2893 - 13e1 - Standard Guide for Greener Cleanups)」其指南提供了評估實施、記錄和行動報告的過程，以減少由以下五大核心元素所定義之淨化環境足跡。

1. 減少能源總使用並提昇可再生能源最大限度地利用
2. 減少空氣污染物和溫室氣體排放
3. 減少水資源的使用和影響
4. 減量、再利用和再循環原物料和廢棄物
5. 保護土地和生態系統

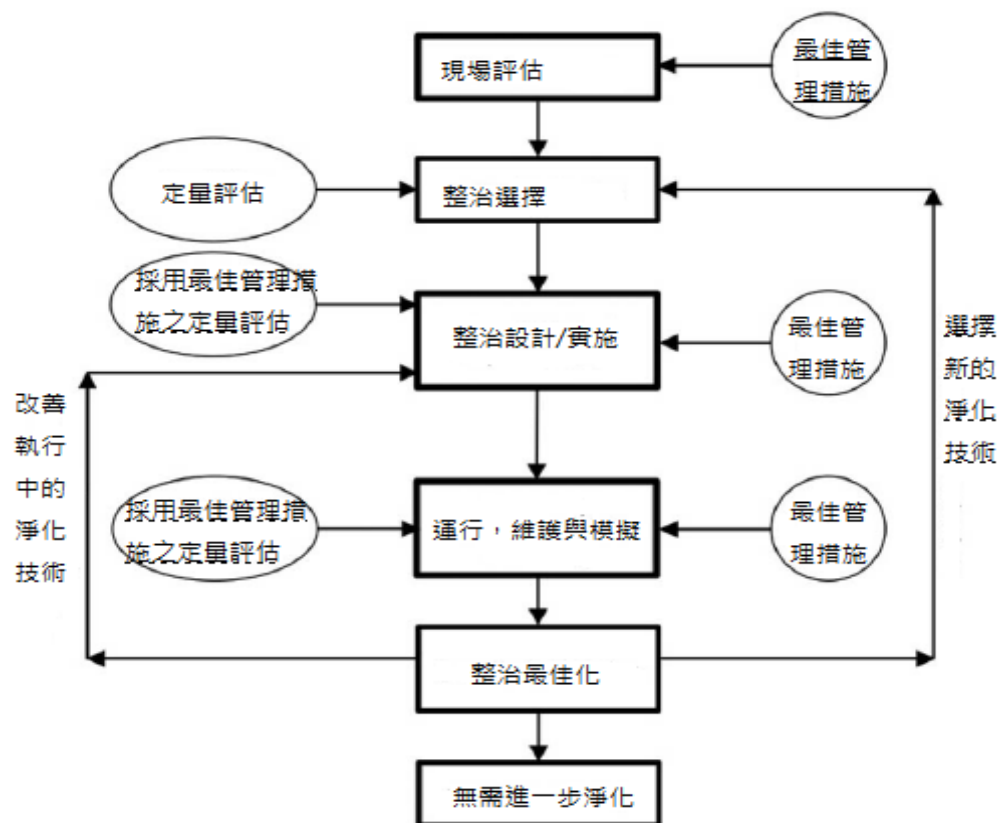


圖 3.1.5-1 ASTM 綠色淨化之總覽

參考出處：ASTM E2893 - 13e1 - Standard Guide for Greener Cleanups

3.1.6 美國永續整治論壇

美國永續整治論壇(Sustainable Remediation Forum, SURF)，美國永續整治論壇(Sustainable Remediation Forum, SURF) 為美國民間主要推動永續整治工作的組織，最早於 2006 年由一群整治工作的專家組成，爾後組織持續擴大，成員來自工業界、政府單位、環保團體、顧問機構及學術機構，推廣永續整治的觀念。2009 年 SURF 於 Remediation Journal 國際期刊發表「SURF 永續整治白皮書」(Sustainable Remediation White Paper-Integrating Sustainable Principles, Practice, and Metrics Into Remediation Projects)，透過生命週期評估的方式，定性或定量的評估場址過程每個階段可能帶來的環境足跡，並依據環境、經濟、社會三個主題，彙整國際間可持續整治的發展現況，提出需要擬訂可將可持續參數併入整治決策程序的永續整治架構。

2011 年更進一步於 Remediation Journal 中發表「如何將可持續整治架構納入整治計畫」(Framework for Integrating Sustainability into Remediation Projects)，此可持續整治架構，提供一系統化、程序化、完整的方法，且說明如何在場址整治過程中考慮、使用或紀錄可持續參數，架構包含下列四項

1. 階層式的可持續性評估
2. 依據可持續性評估的結果來建立/更新概念式模型(Conceptual Site Model)
3. 找到並進行影響可持續之監測/量測
4. 決策過程，取得可持續性及其他考慮因素的平衡點，來達到可持續整治的目的(SURF, 2011)。

同年，SURF 亦發表「可持續整治評估矩陣」(Metrics for Integrating Sustainability Evaluations into Remediation Projects)及「在整治工業中進行環境足跡分析與生命週期分析指引」(Guidance for Performing Footprint Analyses and LCAs for the Remediation Industry)兩份指引文件，供企業界、工業界、政府部門、顧問公司參考。

圖 3.1.6-1 為 SuRF 可持續整治架構概念圖，與傳統整治工法選擇

上，以線性的方式依序進行調查、整治工法選擇、整治策略設計及設置、操作與維護及完成整治的概念不同，在 SuRF 永續整治架構中，永續性參數除了在每個階段中被完整考慮外，也同時也考量不同階段之間相互影響。

各利害關係人或整治過程的參與者，都可以隨時回顧前一階段中的可持續參數及其影響，並對場址下個階段，甚至未來的整治執行進行更具可持續性的規劃。(SuRF, 2011)。

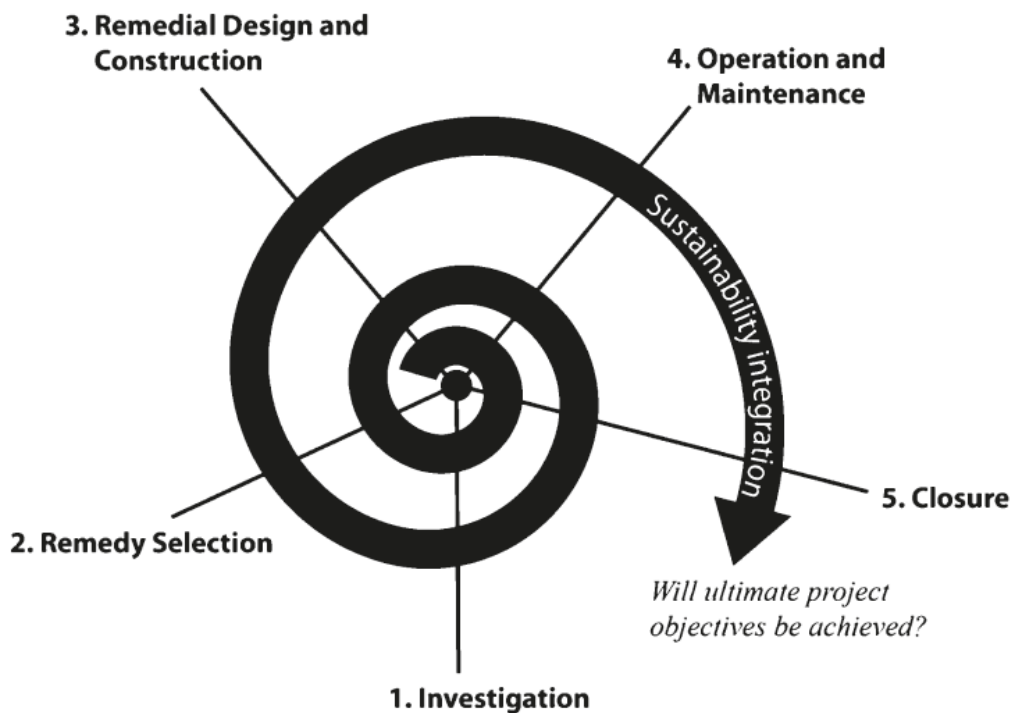


圖 3.1.6-1 SuRF 可持續整治架構

參考出處：Holland, Karin S., et al. "Framework for integrating sustainability into remediation projects." Remediation Journal 21.3 (2011): 7-38.

執行永續整治的過程，需要完整地評估永續性，因此 SURF 建議採行與英國永續整治論壇(Sustainable Remediation Forum United Kingdom, SuRF-UK)相似的階層式永續評估方式進行，如圖 3.1.6-2。區分為 3 個階層，依據整治計畫需評估的條件來決定進行那一個階層的評估，如計畫目標、範疇、複雜程度、經費、資源或利害相關者等(SURF, 2011)，第一層次主要採以較標準化的、無關計畫特性之定性評估，而第二層次則以半定量方式同時評估無關計畫特性及計畫特性

的參數。第三層次則將需要細膩的分析計畫特定的參數，並取得定量的結果。

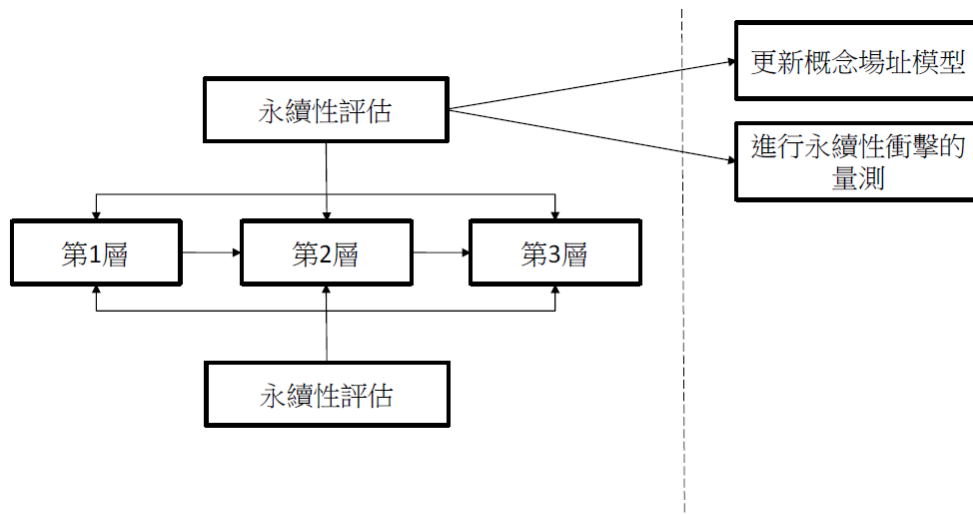


圖 3.1.6-2 SURF 永續性整治評估流程

資料來源：污染場址綠色及永續整治策略研擬計畫, 2013

3.1.7 英國

2007 年英國環保局鼓勵土地開發商採用永續的技術來處理污染場址，並對污染土方採以適當的整治及再利用。近期最有名的案例為倫敦奧運場地開發工程，採以永續發展的觀點，將東倫敦大量的污染場址及褐地進行整治及開發工作。而在民間團體部份，英國 CL:AIRE (Contaminated Land: Applications in Real Environments, CL:AIRE) 為英國民間相當活躍的非營利組織，致力於提升英國政府及社會對污染場址整治的意識，並組成專家小組，一方面協助英國政府發展污染場址土地管理政策，另一方面則開發永續的污染整治技術。

CL:AIRE 成立英國永續整治論壇 (Sustainable Remediation ForumUK, SuRF-UK)，在 CRL-11 的基礎架構下，於 2010 年發展「永續性土壤及地下水整治評估架構」(A Framework for Assessing the Sustainability of Soil and Groundwater Remediation)，其永續整治架構 (圖 3.1.7-1)，可簡單區分為(一)計畫與設計階段(A 階段)及(二)整治執行階段(B 階段) (CL:AIRE, 2010)，無論是任何規模的場址(都市區域規劃、工業大型場址或小型場址)或計畫(褐地再開發、運作中場址整治)均可適用。但整體而言，SuRF-UK 認為在 A 階段的計畫初期，便可

將永續的觀點納入考量，可以得到更永續的整治結果。在實際執行永續整治架構的過程，需要進行永續整治評估，SuRF-UK 亦以類似生命週期評估的邏輯，提出階層式的永續整治評估流程如 3.1.7-2 所示，這個階層式的永續整治評估流程，透過反覆審視永續整治評估流程中，依據計畫目標、利害相關者意見、邊界條件、永續指標、整治策略選項、技術、敏感度分析、任何其他適當的議題，達到永續整治的目標。

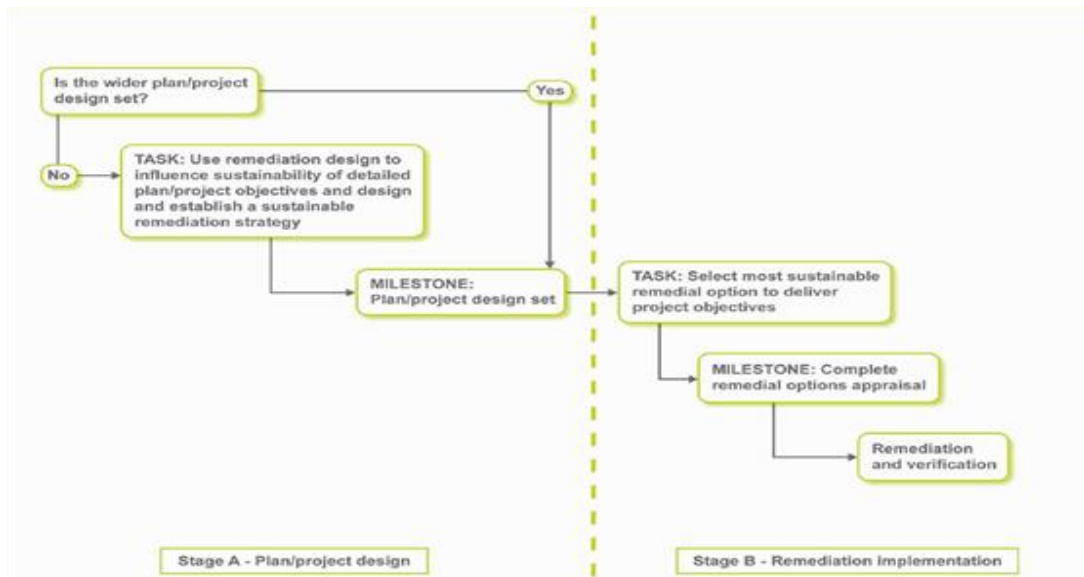


圖 3.1.7-1 永續整治架構

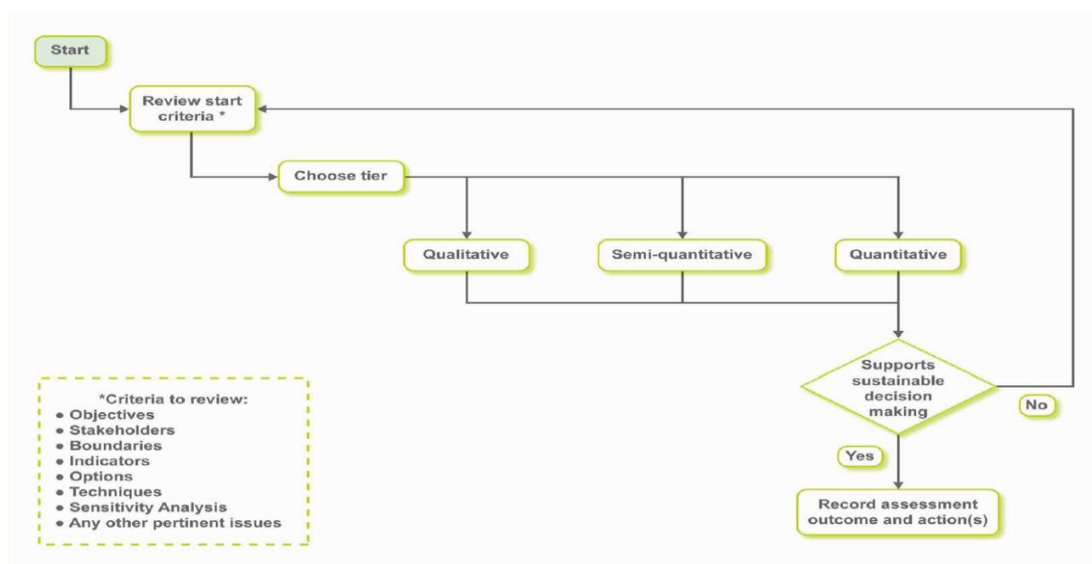


圖 3.1.7-2 永續整治評估流程

參考出處：A Framework for Assessing the Sustainability of Soil and Groundwater Remediation, 2010

3.1.8 歐盟

EURODEMO+於 2007 年 12 月提出「永續場址整治及管理架構」(Framework for Sustainable Land Remediation and Management)，為歐洲地區之綠色及永續整治奠定基礎，這個架構的主要架構於生命週期評估的觀念，評估整治技術的生態效益(Eco-efficiency)，並轉換成投資經費做為評估的指標。

EURODEMO+於 2007 年發表「永續場址整治及管理架構」，期望歐洲國家來有效掌握污染場址整治情況，並找出最佳的整治執行策略，採行環境友善的整治技術。EURODEMO+的永續整治架構如圖 3.1.8-1 所示，區分為 3 個層級，包含(一)技術表現層級、(二)場址層級及(三)區域特定層級，並設定不同的指標參數，這些指標參數均需要符合當前歐盟環境政策及環境指標規範，或從一般的永續指標去設定及推導。此外，通常單一的指標參數並無法完全反應如此複雜且動態的場址整治工作，因此常須要透過生態效益指標(Eco-Efficiency Indicators)的建立，來反應及評估整治工程隨時間及空間的變化(EURODEMO+, 2007)。

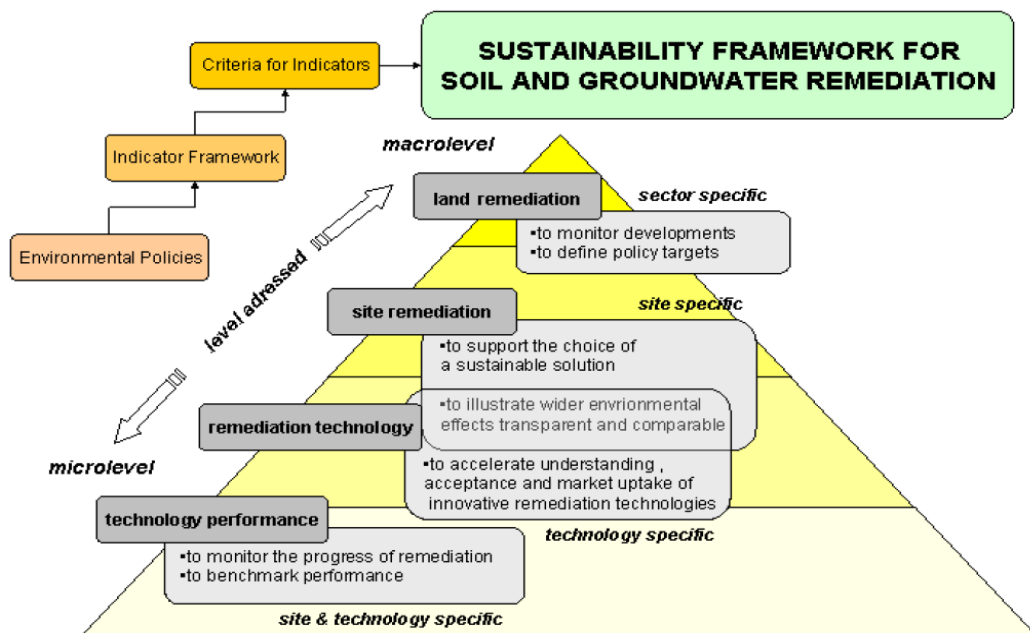


圖 3.1.8-1 永續整治架構

資料來源:European Platform for Demonstration of Efficient Soil and Groundwater Remediation, 2008

3.1.9 澳洲

澳洲政府在 2002 年以「環境永續的澳洲」(An Environmentally Sustainable Australia) 為施政目標，進行澳洲整體環境之管理。

澳洲永續整治論壇(Sustainable Remediation Forum Australia, SuRF-ANZ)成立於 2009 年，主要宗旨在推動及鼓勵澳洲污染場址整治過程，納入永續原則，目前由澳洲土水協會(Australasian Land and Groundwater Association, ALGA) 的成員為主要的支持者。2011 年 4 月提出「永續性的土壤及地下水整治評估架構草案」(A Framework for Assessing the Sustainability of Soil and Groundwater Remediation (Draft))，其主要架構內容與 SuRF-UK 提出之架構相似，區分為 2 階段進行評估。

3.2 我國綠色及可持續性整治整治發展情形

目前我國正在推動綠色及可持續性整治，如圖 3.2-1 為台灣綠色及可持續性整治之發展。

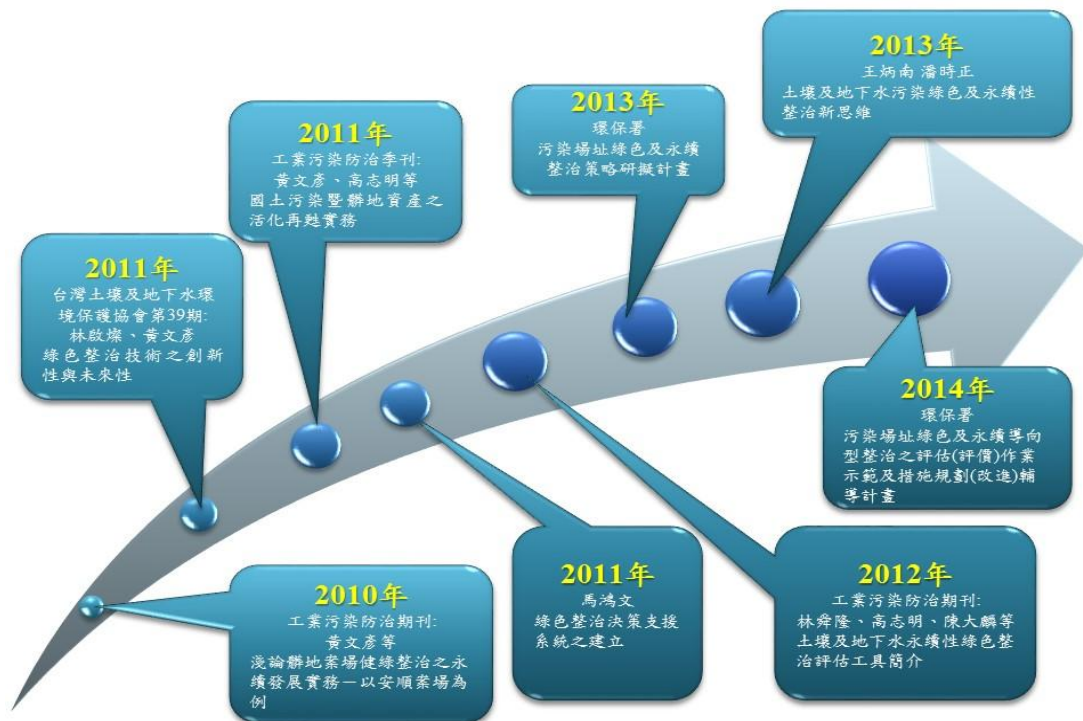


圖 3.2-1 台灣綠色及可持續性整治之發展

3.2.1 台灣土壤及地下水環境保護協會

2011 年林啟燦、黃文彥發表「綠色整治技術之創新性與未來性」，主要提出落實綠色整治技術之創新性與未來性，結合其相關最佳控管實務，且介紹綠色整治之目標、五大要項、最佳控管實務、直接或間接效益，期能將綠色整治技術之創新性與未來性概念構想，提供國內業界參考，始能邁入更為環保時代。

根據 ASTM 該指引初稿內容顯示，ASTM 不僅將環境因素納入考量以符合綠色整治為依歸，同時亦揭櫫必須兼顧社會和經濟兩大層面，此精神稱為「三重底線 (triple bottom line)」，或者「永續性之三項支柱 (three legs of sustainability)」，即污染整治必須考量環保、社會和經濟三者皆能獲得均衡發展。

執行綠色整治落實最佳控管實務，國內仍有極大進步空間，更需政府政策工具引導。政府若欲要求民間貫徹執行，自當身先表率未雨綢繆，建立完整政策與相關配套誘因機制等法規條例。藉立意良善政策工具，協助業者加速落實節能減碳綠色整治。

此外，對於髒地或褐地之污染整治，除必須符合工安與環保等現行法規標準，亦應採用最佳控管實務作業，將符合綠色整治項目之整治清理復育技術及設備，全程納入規劃、設計、施工、控管與營運等各階段之採購發包管理體系。對於杜絕二次污染、落實節能減碳之任何干擾環境因素相關不利足跡，亦應釐清不確定性，並予定量評估，以控管綠色會計環境成本潛在風險。

3.2.2 工業污染防治期刊

2010 年「淺論髒地案場落實綠整治之永續發展實務—以安順案場為例」，敘述綠整治五大要項：(1)減少能源使用總量和增加使用可替代再生能源，(2)自整治源頭即減少空氣污染和溫室氣體排放量，(3)減少水的使用（量）且降低對水資源負面影響，(4)加強物料耗材管理和致力減少廢棄物質與量，(5)加強土地管理和對生態系統保護。此外，無

論整治受污染土地或荒蕪延宕懸而未決之褐地 (Brownfields)，綠整治全程若能盡量落實最佳控管實務作業 (best management practices, BMPs)，如圖 3.2.2-1 所示，綠整治最佳控管實務不僅可使用於污染案場整治全程，更可適用於土地活化再甦在開發永續發展等用途，有助污染整治與淨化環境，對土地活化再甦永續發展亦產生極大的實質效益。

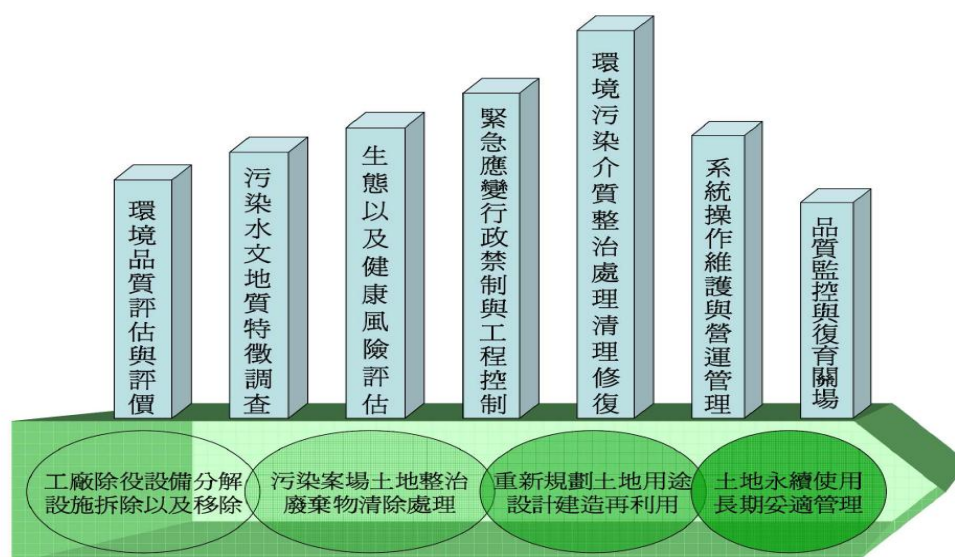


圖 3.2.2-1 綠整治最佳控管實務運用時機示意圖

資料來源：淺論鄰地案場落實綠整治之永續發展實務—以安順案場為例

2012 年「土壤及地下水永續性綠色整治評估工具簡介」，目前許多污染責任者或企業對於污染整治成效不彰，而無法徹底完成整治，且為迅速達到法規標準所使用的整治方法，過程往往需相對消耗大量的能源與資源，對整體的自然環境造成衝擊以及二次污染，使得污染整治所發揮的經濟效益相對降低。

因此，為了在整治過程中減少對自然環境資源的需求與破壞，降低整治過程所產生的環境足跡(footprint)，減少對環境的危害，不致於因整治工作而造成整體環境品質的惡化，所以發展綠色整治之最佳實務措施及永續性綠色整治評估工具(如表 3.2.2-1)，使得污染整治工作的進行將更加環保，且符合保護自然資源的目標。

表 3.2.2-1 永續性綠色整治評估工具

工具名稱或標題	開發或贊助者	工具形式			標的		評估項目					
		網頁計算	決策軟體	決策矩陣	政策或產業工具	特定場址	能源效率	可再生能源	水資源	空氣污染排放	土地及生態	使用材料及廢棄物
Green Remediation Evaluation Matrix (GREM)	California Department of Toxic Substances Control (CA DTSC)			⊙		⊙	⊙		⊙	⊙	⊙	⊙
Greener Cleanups Matrix	Illinois Environmental Protection Agency			⊙		⊙	⊙	⊙	⊙	⊙	⊙	⊙
Leaking UST Footprint Calculator (BETA release)	U.S. EPA, California State Water Resources Control Board	⊙				⊙				⊙		
SiteWise™	U.S. Navy, U.S. Army, U.S. Army Corps of Engineers, Battelle					⊙	⊙		⊙	⊙		⊙
Spreadsheets for Environmental Footprint Analysis (SEFA)	U.S. EPA Office of Superfund Remediation and Technology Innovation		⊙			⊙	⊙	⊙	⊙	⊙		⊙
Sustainable Remediation Tool™ (SRT)	Air Force Center for Engineering and Environment		⊙			⊙	⊙			⊙	⊙	

3.2.3 行政院環境保護署

環保署在 2013 年「污染場址綠色及永續整治策略研擬計畫」及 2014 年「污染場址綠色及永續導向型整治之評估(評價)作業示範及措施規劃(改進)輔導計畫」中，蒐集國際「綠色及永續整治」之推動策略、評量指標、管理機制、所遇困境及案例，並整體評估國內法規制度、污染場址管理及現況，分析綠色及永續整治概念推動之優劣得失後，擬定我國「綠色及永續導向型整治」之推動策略及可行的架構。

提出我國綠色及永續導向型整治之定義、架構、執行方式，且發展出結合最佳管理措施及環境足跡計算的評估工具與評量指標，用以推動綠色及永續導向型整治，並撰寫綠色及永續導向型整治技術參考指引。檢討我國草擬之污染場址綠色及永續導向型整治之推動策略、評量指標、評估方法論與工具集等，並選擇場址進行場址管理階段與場址特性規劃 GSR 輔導，包含利害關係人確定與溝通協調、環境足跡分析、健康風險評估、整治方案經濟影響分析與最佳管理措施擬定等。

另為加速落實綠色及永續導向型整治的場址管理思維，本計畫進行綠色及永續導向型整治認證制度可行性評估與架構訂定，已初步完成認證對象、認證方法、認證內容、認證標準及審查程序的雛型。

3.2.1.1 最佳管理措施

以綠色與永續導向型整治而言，整治活動的 BMPs 即為任何可達成綠色整治之五大核心項目的方法、技術、措施或管理策略。整治單位可依據特定場址的污染特性、污染範圍、整治技術或工法、整治經費與未來土地使用規劃等，擬定場址可採行的 BMPs，使得整治工作達成整治目標的前提下，將整治過程對環境、社會與經濟的負面影響最小化，並積極創造整治產生的效益。

圖 3.2.1.1-1 為我國綠色及永續導向型整治 BMPs 使用時機說明圖，分為場址調查、整治工法選擇與設計、整治策略執行(包含設備建置、操作與維護及監測)三個階段，最後之目標即為將污染濃度降於管制標準之下，解除場址之列管。BMPs 可以定量工具輔助，計算污染場址整治任一活動/階段的環境足跡、社會影響與經濟影響。因此，定

量工具與定性 BMPs 為一反饋循環之關係，藉由定量工具，可了解影響程度較大的活動，並據此選擇對環境、社會與經濟最友善的策略，進而訂定可行之 BMPs；另一方面，若於擬定 BMPs 時並未以定量工具規劃，亦可在實行 BMPs 後，透過定量工具計算，了解採行 BMPs 帶來之效益(如溫室氣體減少量、廢棄物回收比例等)。

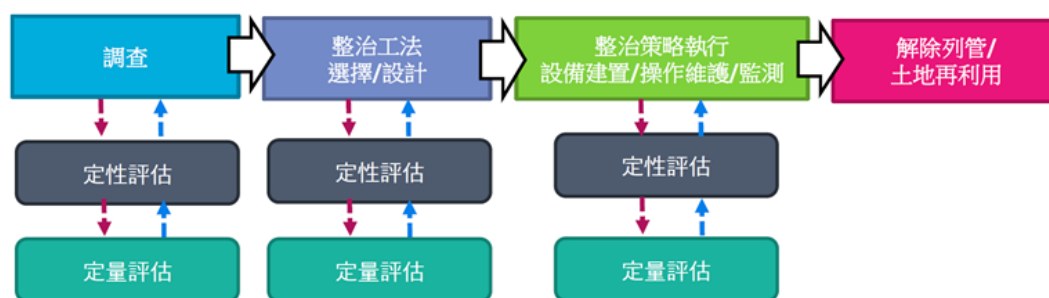


圖 3.2.1.1-1 綠色及永續導向型整治 BMPs 使用時機說明圖

資料來源:污染場址綠色及永續整治策略研擬計畫

表 3.2.1.1-1 為綠色及永續導向型整治 BMPs 的評估表單，並分為環境面、社會面與經濟面表單，整治單位應就綠色及永續導向型整治的核心項目與原則，依其污染場址特性，擬定可採行之 BMPs。

表 3.2.1.1-1 綠色及永續導向型整治 BMPs 的評估表單

面向	核心項目	原則	具體作法	調查	整治工法設計	整治策略執行			紀錄文件
						設備建置	操作維護	長期監測	
環境面	減少能耗	提高能源使用效率							
		使用再生能源							
		採行節能措施							
	降低大氣排放	減少空氣污染物排放 (NOx, SOx, PM ₁₀)							
		降低溫室氣體排放							
		防止關切污染物大氣排放或逸散							
	最小化水資源使用影響	減少水資源消耗與廢水							
		廢水回收再利用							
		防止對地表及地下水體造成衝擊							
	土壤及生態系影響	選擇對土壤及生態環境衝擊較小的工法							
		保存生物多樣性							
		減少污染物的生態風險							
	資材與廢棄物減量	減少資材或原料消耗							
		減少廢棄物產生							
		盡可能廢棄物回收再利用							

表 3.2.1.1-1 綠色及永續導向型整治 BMPs 的評估表單(續)

面向	核心項目	原則	具體作法	調查	整治工法設計	整治策略執行			紀錄文件
						設備建置	操作維護	長期監測	
社會面	人體健康及安全	整治前後與整治過程的人體健康風險							
		避免產生二次污染							
		阻絕曝露途徑·避免污染物向場址外擴散							
	社會公義	利害關係人參與決策							
		資訊公開							
		保護並保留文化資產 考慮整治工法對附近居民的影響							
經濟面	直接經濟影響	成本投入							
		創造工作機會							
		增加稅收							
		整治工作人員之醫療成本							
		採用當地材料產生之經濟效益							
		土地價值變動							
	間接經濟影響	因整治降低之醫療成本							
		環境改善之整體效益(如地下水水質改善、觀光效益等)							
		整治完成後土地利用產生之整體效益(如:農作效益、土地與住宅價值減少素地開發、)							

3.2.1.2 環境足跡計算的評估工具與評量指標

定量評估工具架構(如圖 3.2.1.2-1)主要依據污染介質(土壤或地下水污染)設計,除了所選用工法不同,其中工程參數亦有差異。土壤污染整治工法,工具中所設定的工法包括開挖法與土壤氣體抽除,開挖法的後續土方處理方式再區分為土壤清洗、土耕法與熱處理法,開過程中包括土方外運與回填等工作,根據不同處理方式搭配開挖過程工程項目,個別計算各階段工項,統計併用複合工法之環境足跡。地下水污染整治方案區分為現地與離地不同方式處理,現地工法包括現地化學氧化、促進式生物整治與自然衰減法,離地工作包括地下水抽出處理法。

參考國外工具(SRT 與 Site Wise)進行估算環境指標，進而設計環境足跡計算方法。本工具建置於 excel 上，據現況調整工法的選項，且可以再擴充不同工法，以非單一種工法施行方式為基礎，且同時採行多種工法合併計算環境足跡。

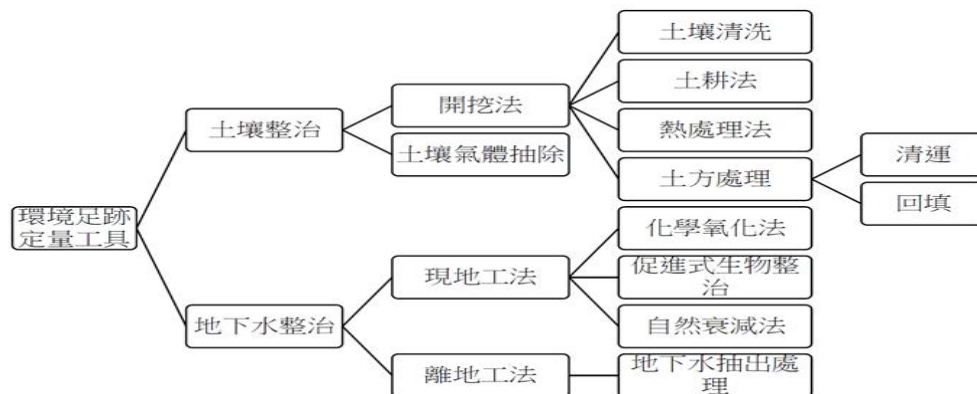


圖 3.2.1.2-1 定量評估工具架構

資料來源：污染場址綠色及永續導向型整治之評估(評價)作業示範及措施規劃(改進)輔導計畫

3.2.4 工程科技資訊

2013 年王炳南、潘時正發表「土壤及地下水污染綠色及永續性整治新思維」，提出在解決污染的同時，應該開始從土地目前及未來的利用方式進行考量，以永續經營的角度來思考土壤及地下水污染整治工作，包含整治過程每個環節產生的環境足跡、社會及經濟影響，尋找最適合這塊土地污染改善方式。

圖 3.2.4-1 為環保署所建立之綠色及永續導向型整治架構圖，簡言之，綠色及永續導向型整治非單指一種整治技術，而是在整治工作的執行過程，均思考環境、社會及經濟三方面之影響，並選擇最適合該場址之整治策略，達到整治目標，並在環境面減少整治工作所帶來的環境足跡與環境衝擊，在社會面則應透過利害關係人參與機制，取得符合社會共同利益的決策，而在經濟面則需評估整治工作所造成之經濟衝擊與效益，採行經濟衝擊最低、效益最大的整治方案。

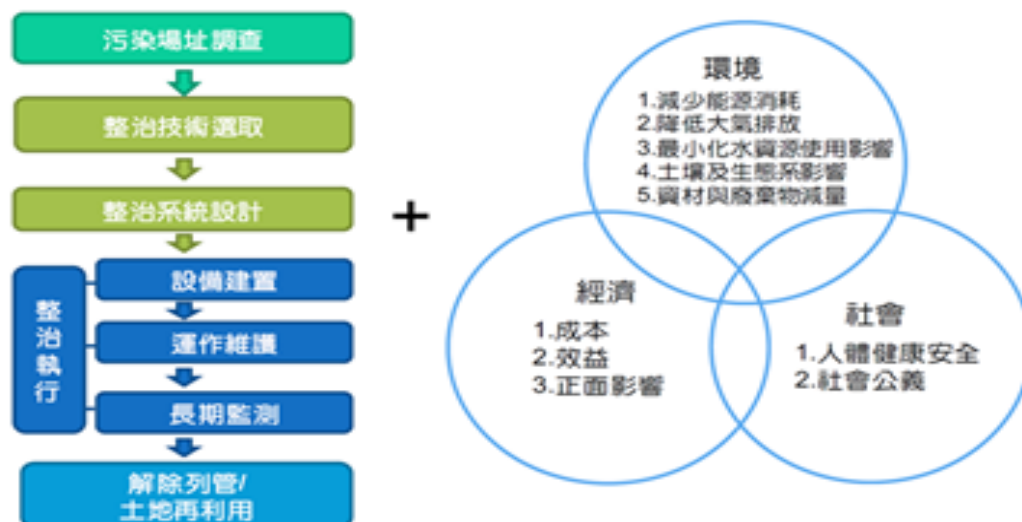


圖 3.2.4-1 環保署綠色及永續導向型整治架構

資料來源:土壤及地下水污染綠色及永續性整治新思維, 2013

本計畫針對環保署污染場址綠色及永續整治策略研擬計畫以及綠色整治決策支援系統建立進行比對，如表 3.2-1 所示。

表 3.2-1 本計畫與我國行政院環保署計畫之差異性

標題	內容					
	完成國外綠色整治相關研究之蒐集與彙整，以為國內推行綠色整治時的參考與依據	建立適用於地下水整治之健康風險評估方法	建立適用於地下水整治之生命週期評估方法	建立決策支援系統之架構，選定評估之準則因子，擬定出環境面向之評估準則。	應用多準則決策方法中之層級分析法，藉由專家問卷調查地下水整治技術評估準則之相對重要性，求得地下水整治技術評估準則權重之分配。	選定一台灣南部污染場址作為實廠案例，完成實廠進行整治工作時所投入之能資源量盤查表，以提供生命週期評估所需參數，並測試本系統的實用性。
綠色整治決策支援系統建立	◎	◎	◎	◎	◎	◎
污染場址綠色及永續整治策略研擬計畫	◎	—	—	◎	—	◎
整治場址能耗與環境足跡之本土化評估系統建立及應用	◎	◎	—	◎	—	—

表 3.2-2 本計畫與我國行政院環保署計畫之差異性

標題	內容					
	提出如何選擇與決定污染場址整治之最佳控管實務，以及可持續性整治/永續發展指標。	務實識別各種利害關係人所關注之利益，求同存異，促進合意共識形成。	在維護生態及保護人類健康之同時，協助整治場址達到同時兼顧環保與節省經濟成本，達到最終污染土地(褐地)再利用之目標。	提供更符合經濟與社群需求之綠色及可持續性整治評鑑系統與技術工具。	提供政府、污染者、整治業者、環保團體、土地開發業者、銀行保險業者、民意代表/意見領袖等利害關係人更科學化系統化流暢化之溝通對話與討論平台。	促進國內既有污染案場之整治意願及流暢度，加速及落實污染土地再開發之進度。
綠色整治決策支援系統建立	—	—	—	—	—	—
污染場址綠色及永續整治策略研擬計畫	◎	—	—	—	◎	◎
整治場址能耗與環境足跡之本土化評估系統建立及應用	◎	◎	◎	◎	◎	◎

表 3.2-3 本計畫與我國行政院環保署計畫之差異性

標題	內容					
	建立本土化評估方法學	可評估能耗與環境足跡之定量化評估試算軟體工具	參考 USEPA, 2012「Methodology for Understanding and Reducing a Project's Environmental Footprint」	參考 ASTM, 2012「Standard Practice Greener Cleanup」	參考 ASTM, 2012「Standard Guide for Integrating Sustainable Objectives into Cleanup」	參考 ASTM, 2013「ASTM E2893-13 Standard Guide for Greener Cleanups」
綠色整治決策支援系統建立	—	—	—	—	—	—
污染場址綠色及永續整治策略研擬計畫	—	—	—	◎	◎	—
整治場址能耗與環境足跡之本土化評估系統建立及應用	◎	◎	◎	—	—	◎

表 3.2-4 本計畫與我國行政院環保署計畫之差異性

標題	內容					
	建立使用者親善的操作軟體界面，作為未來擴充的雛形。	研擬綠色及永續導向型整治推動策略	分析工具集與技術參考指引	研擬我國綠色及永續整治之推動計畫即選定、輔導示範場址之原則	提供評鑑系統/辦法激勵績優地方主管/執行機關、污染業主、整治業者。	建立本土化之系統架構
綠色整治決策支援系統建立	◎	—	—	—	—	—
污染場址綠色及永續整治策略研擬計畫	◎	◎	◎	◎	—	—
整治場址能耗與環境足跡之本土化評估系統建立及應用	◎	—	◎	◎	◎	◎

3.3 綠色及可持續性整治評估及評鑑工具集

定性評估主要目的在於透過一般工程原則進行評估，目的在於提升整體效率及資源使用極小化。但定性工具無法估算環境、社會或經濟之淨衝擊。各國政府、工業、非營利事業機構等全球各界團體分別開發了多種能源或環境評估計算軟體及定量評估工具，評估綠色整治核心元素對環境所帶來之影響。透過輸入場址參數與工程相關參數，推算對環境造成的負擔以及所呈現的環境足跡，協助選擇對環境、社會與經濟具有最大淨效益之執行方式，本計畫整理美國相關定性及定量評估工具於表 3.3-1，可供國內參考各界參考。

表 3.3-1 整治策略及評估工具

美國各州	定性評估工具	評估項目與指標			
美國州際技術及法規委員會 (ITRC)	最佳管理實務 (BMPs)	1. 場址調查(Site investigation) 2. 整治/控制計畫 (Remedial Design)	3. 整治工作(Operations, monitoring and maintenance) 4. 解除列管(Site closure)		
美國各州定量工具 (贊助單位)	工具說明	Tier	三重底線元素		
			環保	社會	經濟
Green Remediation Evaluation Matrix (GREM) (California Department of Toxic Substances Control)	加州毒性物質臨時部門參考其他工具，發展出加州 GSRM 評估矩陣，是免費提供使用的工具， GREM 採以生命週期評估的方式，讓計畫執行者及相關主管機關，在進行場址整治的過程，永續發展的觀點進行整治工作。	1, 2	已開發	發展中	發展中
Greener Cleanups: How to Maximize the Environmental Benefits of Site Remediation (Illinois EPA)	基於綠色清理的方向與原則，伊利諾州環保局開發 Greener Cleanups Matrix（綠色清理矩陣）用於確認各種增進環境整治措施的優勢，並將其效益極大化。政策矩陣區分場址評估、設計規劃與執行清理 3 階段，進行評估時，政策矩陣列出整治過程中不同階段所使用的措施，並對各種措施優勢高低、增減成本與時間、以及技術複雜程度予以評點，同時註記說明其對於空氣、水資源、土地及能源可能造成的潛在影響。	1, 2	已開發	—	—

表 3.3-1 整治策略及評估工具(續)

美國聯邦部會	定性評估工具	評估項目與指標				
美國有害廢棄物暨緊急應變管理處 (OSWER)	最佳管理實務 (BMPs)	1. 挖除與表面回復技術 2. 場址調查技術 3. 抽出處理技術 4. 生物復育技術 5. 土壤蒸氣萃取結合空氣注入法	6. 油品洩漏污染場址整治技術 7. 整合再生能源應用於場址整治技術 8. 地下儲槽洩漏系統處理技術 9. 掩埋場覆蓋系統&能源產生			
美國三軍定量工 (贊助單位)	工具說明		Tier	三重底線元素		
				環保	社會	經濟
Sustainable Remediation Tool (SRT) (Air Force Center for Engineering and the Environment)	雖然 SRT 的目的是為美國空軍整治所使用之評估工具，但是 SRT 是一套公開免費使用的軟體，操作界面類似 Microsoft Excel，的基礎工具，旨在幫助評估場址整治技術實施在基礎的可持續性指標，評估整治方法和的最佳化操作技術。		1, 2, 3	已開發	發展中	發展中
SiteWise™ (Battelle, U.S. Navy, and U.S. Army Corps of Engineers)	SiteWise™是一個公開可免費的評估工具，操作界面類似 Microsoft Excel，旨在幫助整治業者計算常見的的環境足跡。並提供幾個量化的可持續發展指標，包括溫室氣體排放、能源的使用、標準空氣污染物的排放量、水的使用和意外風險。		1, 2, 3	已開發	發展中	—

表 3.3-1 整治策略及評估工具(續)

產業單位	定性評估工具	評估項目與指標				
美國材料試驗協會 (ASTM)	ASTM WK35161 -New Practice for Greener Site Assessment and Cleanup (GSAC)	1. 建物 2. 物料 3. 電力與燃油 4. 專案與團隊管理 5. 殘餘廢棄土方及廢水	6. 採樣與分析 7 整地與土地復耕 8. 地表水與降雨管理 9. 車輛與設備管理 10. 廢水管理			
	ASTM WK23495 -New Guide for Incorporating Sustainable Objectives Into Cleanup	1. 空氣逸散 2. 能源 3. 水資源衝擊 4. 物料與廢棄物 5. 土地與生態系	7. 加強個人環境人權 8. 當地社區活力 9. 社區參與 10. 經濟衝擊與當地社區 11. 效益與節約成本			
產業定量工具 (贊助單位)	工具說明		Tier	三重底線元素		
				環保	社會	經濟
AECOM Holistic Tool (AECOM)	AECOM 的整治工具操作界面類似 Microsoft Excel，一個易於使用的工具，用以估計可持續發展指標及以下的整治技術：開挖、運輸、sediment dredging、組絕法、土地農耕法、板樁牆安裝(sheet pile wall installation)、熱脫附、泥漿牆安裝(slurry wall installation)、現地熱處理、穩定固化、高壓噴射灌漿，並可量化可持續發展指標，包括能源消耗、廢氣排放和風險評估。		1, 2, 3	已開發	發展	—

表 3.3-1 整治策略及評估工具(續)

產業定量工具 (贊助單位)	工具說明	Tier	三重底線元素		
			環保	社會	經濟
BalanceE3™ (ARCADIS)	BalanceE3™是一個定量工具，用於評估不同的整治方法，提供可持續整治方法的選擇和設計，收集 8 種可持續發展指標提供任意組合量測（能源，廢氣排放，對水的衝擊，土地的影響，廢棄物發電和材料消耗，管理(stewardship)，健康和環境，以及生命週期成本）的定量分析統計方法，供不同方案的比較，以改善實際整治方法。	1, 2, 3	已開發	發展	—
Sustainable Remediation Assessment and Methodology (CH2MHILL)	永續發展的評估及理論： 這個理論就是列出所有可能的影響及 102 個會影響這方案推動之因素，評估與可量化評估的小類別，一旦把那些可能的影響列出並將圖表完成，那麼相關人員就可以使用決策工具去決定每一種影響類別的重要性，報告的不確定性和不確定的參數進行 Monte Carlo 的分析方法，使決策者了解他們整體決策中關鍵參數的影響。	1, 2, 3	已開發	發展	發展中
GoldSET-CN-SR (Golder Associates in partnership with Canadian National)	GoldSET-CN-SR 是一個多標準決策分析工具，藉由使用一些單一指示和不同的指示，再把摘要的發展原理植入計劃裡變成圖表，這個工具它提供定性與量化的標準讓你參考，但是你也可以因為地方環境的不同去做變更、增加或刪減，它也可以是個多工的工具，可以讓很多用戶同時工作，並具有能源和溫室氣體計算器。。	1, 2, 3	已開發	發展	發展中

3.4 油污染土壤概況介紹

行政院環保署土水整治基金管理會明定污染場址判定流程由發現場址開始，經查證有未依規定排放、洩漏、灌注或棄置之污染物時，則予以公告並定期監測。圖 3.4-1 為污染場址判定流程，當污染來源明確且超過管制標準時該場址則被列為控制場址，而有危害國民健康及生活環境之虞時，則進一步列為整治場址並提出整治計畫來處理。

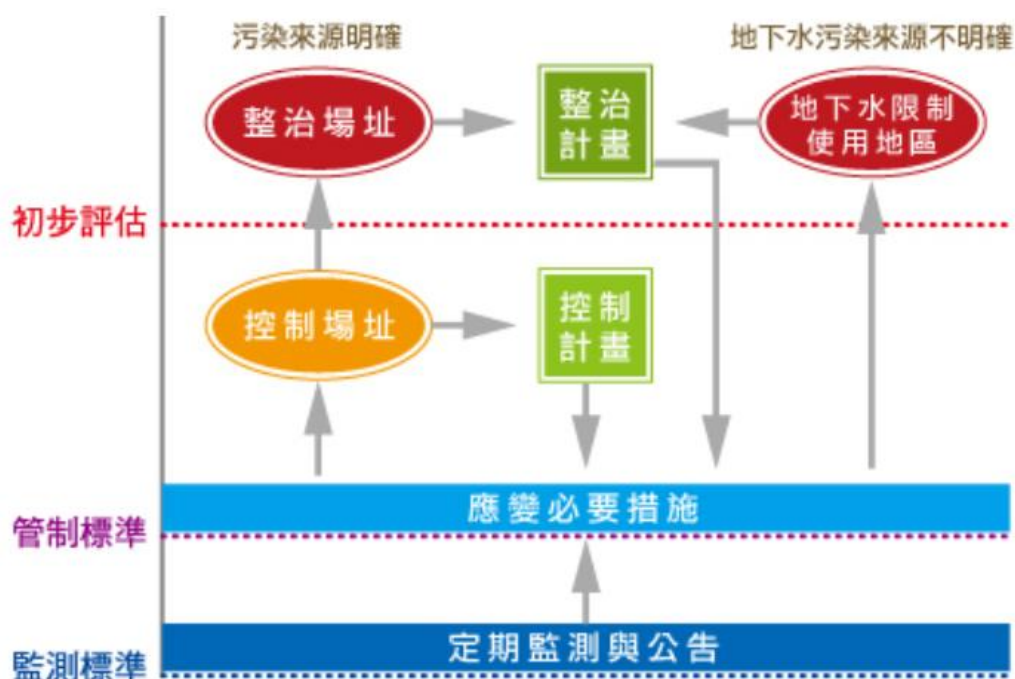


圖 3.4-1 污染場址判定流程圖

參考出處：環保署土壤及地下水污染整治網

土壤及地下水均是重要的環境資源，由於隱藏於地下環境，當發生污染時，往往不易察覺，而任何污染持續與惡化，終將達到危害人類環境與破壞生態的程度。台灣地區人口稠密，各型產業發達，造成的污染問題相當多，又由於土地資源不豐，亦常有缺水情形發生，相當仰賴良好的土壤及地下水品質，故特別需要重視土壤及地下水污染概況。土壤/地下水被燃料油、汽油、柴油及其他油品(petroleum hydrocarbons)所污染是一個愈趨普遍且嚴重的問題。油品污染之主要來源包括地下儲油槽(underground storage tanks, USTs)漏油、油管破裂、及地面油品意外洩漏等。在美國有三百萬以上的儲油槽，據估計有 35%的儲油槽可能在漏油(AFCEE, 1994);在台灣，油品污染亦是主要的土壤及地下水污染來源。

根據能源局的統計至 103 年 3 月底全台尚有 2,504 座加油站，每座加油站依大小而有 4 到 6 個地下儲油槽，所以至少有一萬座的地下儲槽，都是油槽普遍潛在的污染源。根據美國資源部研究，埋設於 10 年以上之儲油槽有 46% 會發生洩漏，15 年以上者，發生洩漏機率高達 71%，所以不得不重視加油站、大型儲槽的污染調查。

根據環保署土污基管會資料統計，總石油碳氫化合物(TPH)之污染為當前占地面積最廣且對人體及環境有立即性危害的污染問題。包括有加油站、儲槽、及工廠污染，以筆數計表 3.4-1 有 95 處列為控制場址、23 處列為整治場址，其中就有 65 處為加油站及儲槽，可見加油站洩漏為一大型洩漏源，且大部分污染場址多集中在南部地區，較著名有高雄煉油廠 P-37 與苓雅儲運。顯示國內土壤受總石油碳氫化合物污染的問題著實嚴重，而總石油碳氫化合物(TPH)內包含有柴油(diesel)、燃料油(fuel oil)、單環芳香族碳氫化合物(monocyclic aromatic hydrocarbons)，如 BTEX (benzene, toluene, ethylbenzene, xylenes)與多環芳香族碳氫化合物 PAH (polycyclic aromatic hydrocarbons)等污染土壤與地下水問題，一經洩漏進入土壤或地下水中發生脫附、蒸發、擴散等作用後，將會對人體造成危害(Baheri et al.,2001；Menzie et al.,1992)。可見污染問題之嚴重，這在地狹人稠的台灣更是迫切需要整治改善。

表 3.4-1 全國受石油碳氫化合物土壤污染場址統計表

全國受石油碳氫化合物土壤污染場址						
類別 列管狀態	農地	加油站	儲槽	工廠	非法棄置場址	其他
公告為控制場址	0	52	1	27	0	15
公告為整治場址	0	12	0	7	0	4
公告地下水受污染限制使用地區及限制事項	0	0	0	0	0	0
解除列管場址	0	29	0	12	0	1

參考資料：環保署土壤及地下水污染整治網

3.5 加油站污染整治技術之選擇

概觀我國加油站污染整治方式，當僅有土壤污染時，主要以土壤氣體抽除法（Soil Vapor Extraction）、生物通氣法（Bioventing）、開挖（Excavation）排土/客土為主；而當存有地下水污染時，則另搭配抽出處理法（Pump and Treat）、空氣注入法（Air Sparging）、現地化學氧化法（In-situ Chemical Oxidation）、釋氧劑（ORC）灌注等；若污染情況更嚴重而有浮油時，則搭配浮油回收（Free-product Recovery）、多相抽除（Multi-phase Extraction）等技術。由於環保機關大多要求業者於一定時間內（如 3 年）完成整治，整治期程較長之生物復育（Bioremediation）、監測式自然衰減法（Monitored Natural Attenuation）等技術目前則較少採用。

依照加油站污染為例，土壤離場處理為目前污染場址經常使用之整治方法，其優點為可於短時間內移除高濃度區，以儘速降低污染物濃度，並可連帶更換儲油設備。加油站主要污染原因區分為動態污染與靜態污染。其中動態污染為卸油溢流與汽機車加油等兩項作業中的洩漏；而靜態污染則包括（一）卸油口及卸油管線（二）油槽（三）輸油管線（四）泵島（或稱為加油島）等任何用於儲存油品的設施。因此若污染是因儲油設備造成洩漏，多數加油站整治時皆需考量開挖已移除/更換洩漏之儲油設備，對於局部區域土壤污染而言，開挖處理法可以直接而有效的移除現地的污染，對於緊急應變處理等目的而言，具有相當的意義且多數整治工法皆以開挖整治工法序列組合方式進行，由過去累積迄今的整治經驗顯示，很少有單一技術可以完全勝任整治工作，絕大多數的情況都將數種整治技術合併使用，以達最佳的效果。例如開挖後之土壤搭配物理焚化法、化學氧化法、生物整治等方式進行。

而基於土地永續性及綠色整治之考量下，整治後之土壤利用價值為環境可否永續發展之一關鍵，舉例而言若採用焚化法後土壤有回填性及能源消耗、尾氣處理等耗能排碳之詬病，而化學氧化法之藥劑可能浪費在與土壤層中其他物質作用而消耗並且影響土壤肥力，且容易有土壤硬化及固結等現象都不利於土壤後續之利用，在國際間綠色整治地蓬勃發展之下國內已逐漸重視，而生物整治被認為最具有整治潛力且可行之技術，費用低廉、對環境衝擊小、整治後之土壤具有可回填利用價值高等優點。

四、 研究方法與過程

4.1 執行流程

圖 4.1-1 為本研究之流程圖，首先需要做足資料蒐集以及分析彙整，接下來本研究將會整合國內外方法與指引，並開始分析既有規範軟體之工具。透過上述資料可使本研究奠定基礎，並能建立本土化之系統架構以及本土化評估方法學，最後將整合評估成「污染場址可持續性整治其影響環境足跡之評估系統」，以提供政府、污染者、整治業者、環保團體、土地開發業者、銀行保險業者、民意代表/意見領袖等利害關係人更科學化系統化流暢化之溝通對話與討論平台。

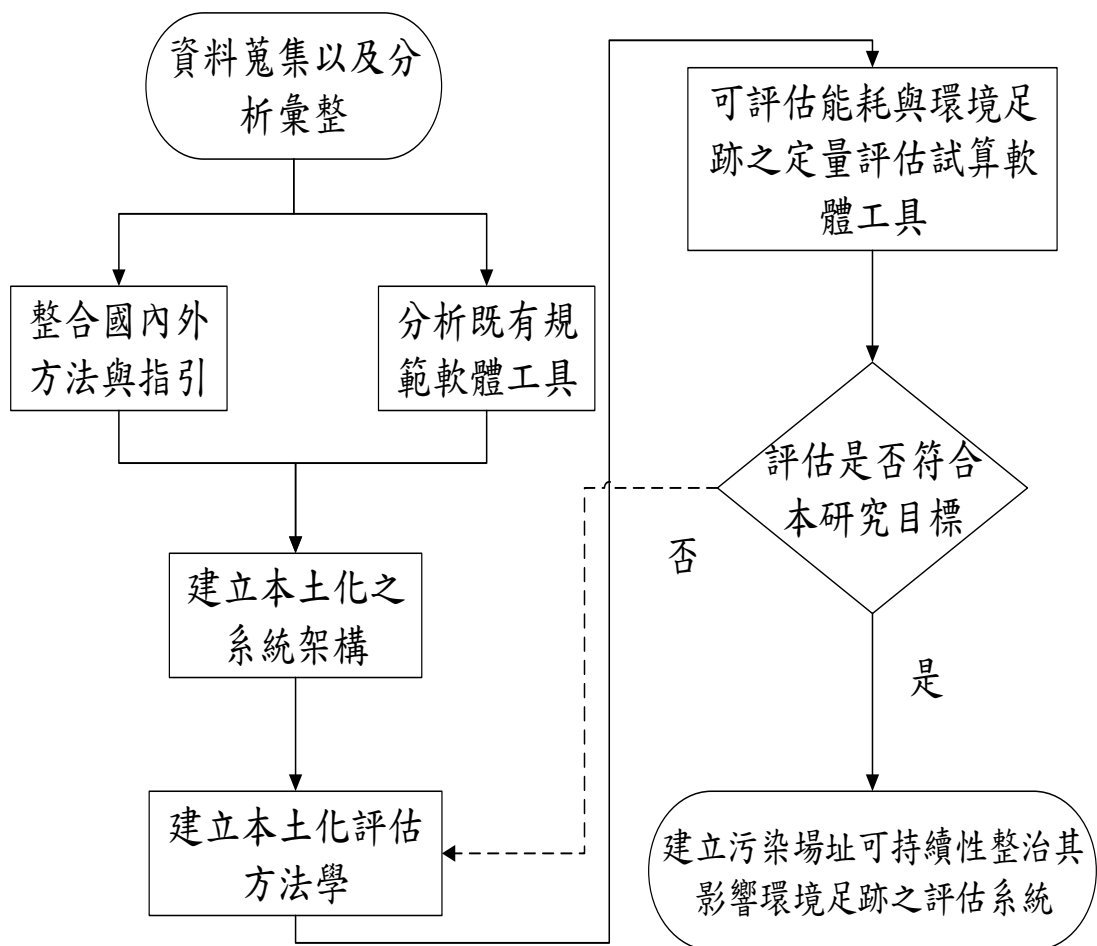


圖 4.1-1 研究流程圖

4.2 執行方法

4.2.1 法規

可持續性綠色整治觀念的傳播與推廣，還需有賴政府與民間共同合作發展，而本研究認為，唯有透過土污法，法規修訂、行政規則修正，從法規面上幫助環保局及利害相關者。故本文將再結論與建議部分，提出幾項淺見，從法規研修的角度以利中央及地方主管機關推行，供各界參考或討論。然而，可持續性綠色整治之推動不單只著重於土污法，亦同時涉及水污、空污、廢棄物、毒性化學物質等等法規，不僅要與現有的法規連結，還必須識別法規草案並且相互整合連結，因此，污染土地所涉及之範圍極廣、資訊豐富、目的不少、項目更多、目標且更多元，所以不是一個平常普通專案（project），更可能是一連串的專案開始，搞不好更會是組合多重專案群組的計畫（program），甚至更是多重計畫群組的極超大型計畫組合（Portfolio），因此，本文整理國內相關法規，如表 4.2.1-1 所示，例如：以「環境綠美化促進法」草案為例，如能將此法自污染土地活化再甦初期便導入此觀念，不僅能解決環境相關污染，還能打破髒亂現象，使國人居住在優美、健康及寧適生活環境，全面提升我國整體寧適美觀之生活環境，且能使整體經濟效益提升。又或整治過程能與「資源循環利用法」草案連結，透過廢棄物減量並注重公害防治以降低環境衝擊，除積極執行現場土方平衡並注重公害防治，提高廢棄物之潛在利用價值，整治如能全方位考量環境、經濟及社會三層面。在社會層面，考量人口結構，社會福祉、老人安泰、健康維護、文化傳承。並持續提昇經濟活力與競爭力，興利防弊並確保自然資源與環境品質，維護國人健康與文化資源，強化社會和諧與福祉，使能符合「永續發展基本法」之原則。

表 4.2.1-1 國內環境相關法規

No.	Act/Regulation	法規名稱
1	Drinking Water Management Act	飲用水管理條例
2	Water Pollution Control Act	水污染防治法
3	Waste Disposal Act	廢棄物清理法
4	Air Pollution Control Act	空氣污染防制法
5	Noise Control Act	噪音管制法
6	Toxic Chemical Substances Control Act	毒性化學物質管理法
7	Public Nuisance Dispute Mediation Act	公害糾紛處理法
8	Environmental Impact Assessment Act	環境影響評估法
9	Environmental Agents Control Act	環境用藥管理法
10	Soil and Groundwater Pollution Remediation Act	土壤及地下水污染整治法
11	Marine Pollution Control Act	海洋污染防治法
12	Resource Recycling Act	資源回收再利用法
13	Basic Environment Act / Constitution Level	環境基本法
14	The Environmental Education Act	環境教育法
15	Indoor Air Quality Act	室內空氣品質法
16	Sustainable Development Basic Act (Draft)	「永續發展基本法」草案
17	Clean Environment Greening Promote & Landscape Aesthetics Act (Draft)	「環境整潔綠美化促進法」草案
18	Resource Recycling Reuse Act (Draft)	「資源循環利用法」草案
19	Greenhouse Gas Reduction Act (Draft)	「溫室氣體減量法」(草案)

4.2.2 環境足跡評估方法

環境足跡的方法適用於國際間各環保先進國家之政府單位、管理機關、學術研究機構、工業（技術顧問）界與污染行為人、場址所有權人，其逐漸意識到污染土地整治過程，兼顧環保、社會、經濟之「永續發展」觀點，進而衍生參考「環境足跡方法」概念，亦即過程必須全面性地考量且在環境、社會及經濟三個面向，並須盡量獲得共識取得平衡。

在整治復育或土地活化再甦開發等過程，全程採取可節能或降低影響環境介質的一切行動項目，以“減少耗用能源以及干擾環境相關因素之足跡”。綠色整治之最佳管理實務作業，是在符合案場污染整治目標之前提下，在調查污染、評估污染潛勢、整治、復育等階段，全程皆極為密切且務實地評估綠色整治五類核心要項，如圖 4.2.2-1 所示，以盡量落實節能減碳尋求對環境較友善方案。

亦即在舊有廠房設施設備除役、設備拆解、場地清理和資源回收再利用、整治案場污染等開始規劃過程，綠色整治概念以及最佳管理實務即須列入規劃、採購、發包要項，加以落實推動。

利害相關者之間的信任及共識，在早期計畫，可採用一些簡單的工具、指標及定量方法，並配合計畫的複雜度進行發展及深入分析。利害相關者越早開始參考環境足跡的方法，就有越多的機會可以得到永續發展的結果。

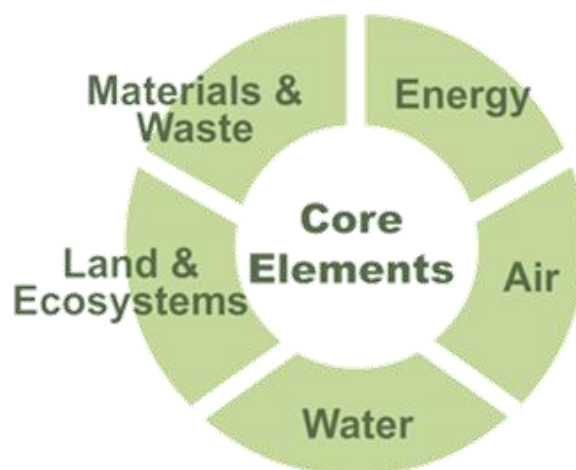


圖 4.2.2-1 綠色整治五類核心要項

資料來源:Methodology for Understanding and Reducing a Project's Environmental Footprint ,2012

如表 4.2.2-1，這種方法是一個七步驟的過程，開始於設定目標和範圍界定的分析，然後收集和整理關於足跡的整治辦法資料。這個資料隨後被用於定量現場材料和廢棄物指標和現場水指標。這些材料，廢物和水，再加上其他整治辦法的資料，用於定量的能源和空氣指標，該指標被計算出來後，在實施整治辦法過程中受影響的生態系統服務功能進行了定性描述。經過該結果表示，可以確定大貢獻的指標和評估足跡減量的機會結果分析。在一般情況下，該方法論利用可公開獲得資訊，並且可以使用標準的電子表格軟件來實現。

表 4.2.2-1 足跡方法論的概述

步驟 1	設定目標和分析範圍
步驟 2	收集整治辦法資料
步驟 3	定量現場耗材和廢棄物指標
步驟 4	定量現場水資源指標
步驟 5	定量能源和空氣指標
步驟 6	定性地描述受影響的生態系統服務
步驟 7	目前結果

4.2.2.1 設定目標和分析範圍

一個足跡分析的第一步是確定分析的目的和範圍。有關這一步驟的其他活動正在建立邊界和功能單元，用於進行分析。該分析的目的通常是不相同的整治階段，及其他現場特定的因子。表 4.2.2.1-1 根據整治階段可能的目標總結了足跡定量分析。

表 4.2.2.1-1 足跡定量分析的目標

整治階段	足跡定量的典型目標
整治方案開發	● 確定大貢獻者足跡組件的各種整治措施替代方
整治設計和最優化整治辦法	● 確定大貢獻者整治措施足跡為整治辦法部份 ● 從不同的角度觀看整治辦法，以確定改進的機會 ● 定義： ○ 在建造或整治辦法操作過程中，設計大貢獻者的足跡部份 ○ 現場模式構想的改進或數據差距，如果解決，可能會有助於減少足跡（例如，提高鑑定該醇化的已知污染源區）
其他	● 定量分析和記錄排放量

4.2.2.2 收集整治辦法資料

包括收集有關整治辦法的設計，建造和運營的資料。這些資料包括設計參數，進行活動，及各類材料使用。該資料的質量取決於當足跡分析進行時的整治階段。該資料在早期設計階段很可能會相對較不明顯，但將因為在設計階段進行，並作為整治措施被實施而確定性增加。在足跡分析中使用的整治辦法資料不確定程度，應記錄為足跡分析所得，隨著不確定性的分析結果可能產生的影響。

資料收集步驟的一般結果為整治資料的項目符號列表，足跡減量方案。雖然該方案提供了實例數據的採集，專業判斷用於一個現場特定的基礎上，確定具體的適當水平，以滿足足跡分析。

一些在此階段和下一階段的足跡分析過程資料收集，一般為現有文件和現場承包人。此外，所需的資訊和索取有關資料的過程類似於資料和使用過程中同時準備設計書，採取整治措施進度報告，或進行整治最佳化評估的資料和過程。因此，強烈建議足跡分析在其中或一個以上的其他活動一致進行。根據可用的資料，一些專門

技術知識整治，可能被要求某些方面整治辦法轉化為有用資料。例如，挖掘污染土壤的一個給定體積所需設備的嘗試、類型及尺寸水平，可估計以提供資料為足跡分析，或粒狀活性碳處理過程水的量，可估計為指定流量和污染物負荷。雖然該方法不能提供需要的所有技術細節，來完成此步驟所有的整治措施。

4.2.2.3 定量現場耗材和廢棄物指標

該方法涉及從那些現場所使用的離場材料，和定量在現場產生的廢棄物。這個定量是顯著材料的核算使用，那些材料的回收成分，生成各種廢棄物，而且廢棄物被回收再利用的部分。

與此步驟相關的主要挑戰包括：1 把不同數量的材料和廢物轉化為常用單位每個標準指標：2 當產生時確認回收、再利用：3 提出了簡潔明了的方式呈列資料。

4.2.2.4 定量現場水資源指標

該方法涉及定量現場用水，注重於減少現場用水和生產使用回流高品質的水，在這個過程中包括：

- 在當地和現場各種水源區別
- 確定來自各各個來源使用水的質量
- 定量的水從每個來源使用量
- 確定從每個來源水的使用
- 區分從每個來源及使用後之間水的不同命運

4.2.2.5 定量能源和空氣指標

能源和空氣指標的計算方法嘗試盡可能解釋材料或活性的整個循環週期。例如，與用電量相關的能源和排放包括資源開採的燃料、使用的燃料、傳輸電和配電損失。此外，汽油和柴油用於現場或運輸，包括提取能源和排放原油和石油精煉進入汽油和柴油內，除了在設備和運輸過程中燃燒的燃料。

在此步驟分為以下三部分，以便組織、呈現和計算出能源和排放的足跡：

Part 1 - 運輸、設備的使用、材料和廢棄物、和離場維護清單整治

辦法。

Part 2 – 用於確定能源使用的整治辦法。

Part 3 – 轉換為能源和空氣指標的清單整治辦法。

4.2.2.6 定性描述受影響的生態系統服務

在其目前的形式，方法論指用定性描述一個整治措施對土地和生態系統服務，如養分吸收和控制水土流失的影響。

4.2.2.7 目前結果

除了透過每個步驟所獲得的資料，在一個足跡分析的文件應提供：

- 篩選過程
- 分析的假設
- 可能的不確定性的領域
- 如何減少足跡的具體意見

4.2.3 定量評估

定量評估是包括排放、資源利用，以及廢棄物相關的淨化工作，如使用足跡分析或生命週期評估預估，而其目的是提供資訊給最具有最顯著貢獻於淨化階段或行動關於核心要素的環境足跡。此外，定量評估可通過估算由特定最佳管理措施所達成的潛在環境足跡之減少量來促進決策。

如圖 4.2.3-1 為定量評估過程，當進行定量評估時，應遵循下列步驟：

步驟 1：目標和範圍定義，使用者應確定進行定量評價的必要性，和記錄定量評估的目標和範圍。這些目標啟動了以定量評估的方式使環境問題得到解答，以及如何使用量化評在決策中。這範圍提供了細節關於如何執行、審查與記錄定量評估（例如：工具、資源）。

步驟 2：邊界定義，使用者應決定行動、地理位置和研究的時間限制。

步驟 3：核心要素和核心要素的促成因素，使用者應審查每個核心要素，確定哪些核心要素都可能是淨化行動中的重要元素，並確定可能

的核心要素的促成因素。

步驟 4：資訊的收集和組織，使用者應編制資訊於淨化組成元件與庫存數據集上，這些有關的淨化行動都要被評估。使用者應該記錄所有收集的訊息，與淨化工作相關的組成元件和庫存數據集。

步驟 5：定量評估的計算，使用者應該使用足跡分析或生命週期分析進行定量評估。

步驟 6：敏感度和不確定性分析，使用者應進行靈敏度和不確定性分析於足跡分析或生命週期分析的結果上，以更佳評估結果的信心和不確定性，並協助將重點致力於可能產生最大的環境足跡減量的行動上。

步驟 7：文檔記錄，使用者介紹並總結定量評估的所有步驟在透明的和有據可查的報告中。該報告應提出並解釋結果，指出關於核心要素最顯著貢獻促成因素，並建議可採取減少淨化工作之環境足跡的行動。

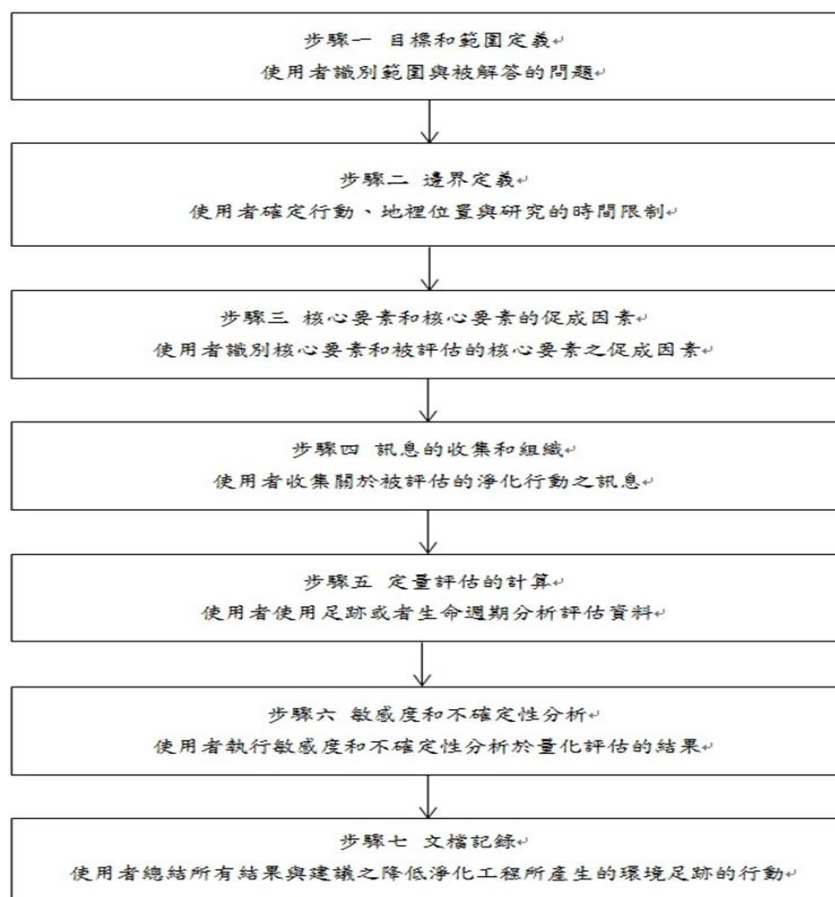


圖 4.2.3-1 定量評估過程

4.2.4 最佳管理實務 Best Management Practices (BMPs)

最佳管理措施過程之目的是讓使用者能夠識別、確定優先次序、選擇、實施，並記錄最佳管理措施的使用，以減少淨化工程對環境的影響，且選擇適用的淨化階段，使用者應該考慮在根據第五項之下收集進行規劃和範圍的訊息，以確定當淨化階段進行最佳管理措施過程中，能進行評估。

最佳管理措施過程，該最佳管理措施過程包括以下五個步驟：第 1 步：最佳管理措施之機會評估；第 2 步：最佳管理措施之優先；步驟 3：最佳管理措施的選擇；第 4 步：最佳管理措施的執行情況；第 5 步：最佳管理措施之文件記錄。使用者應遵循下述之所有步驟，並總結於圖 4.2.4-1 中。

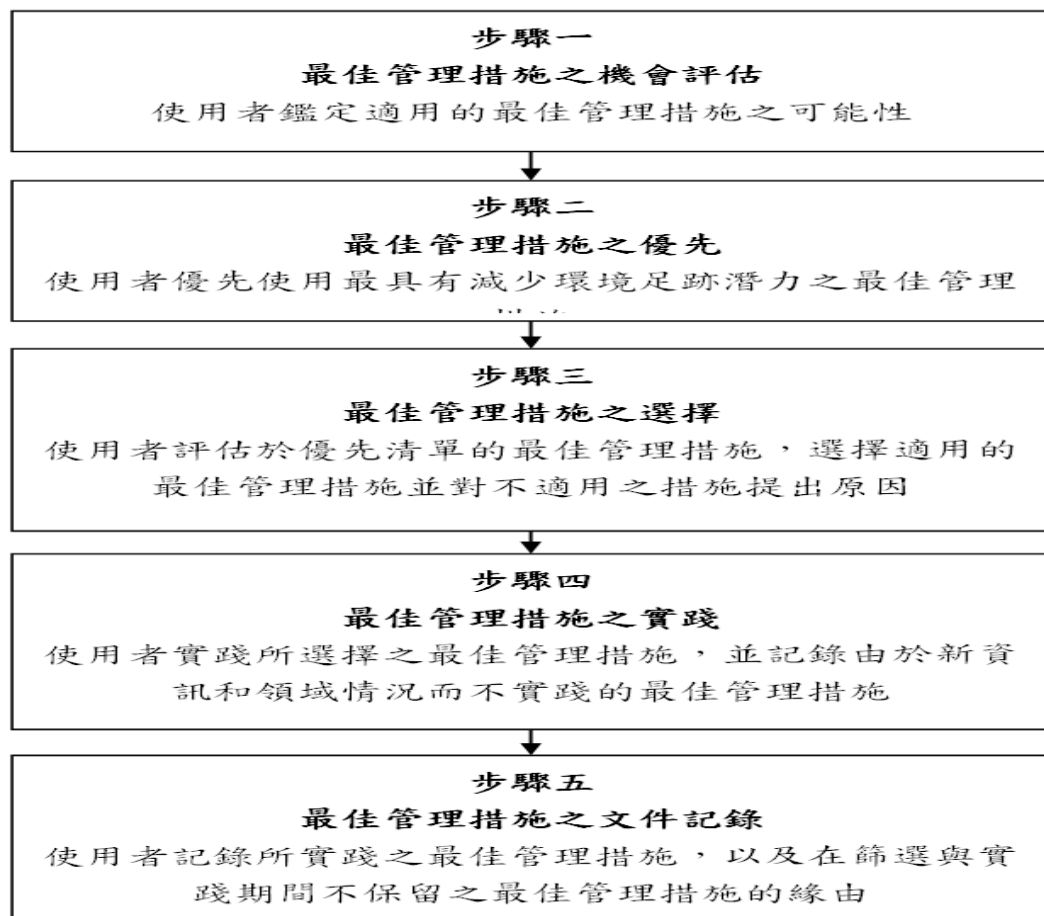


圖 4.2.4-1 最佳管理措施之流程

4.2.5 減少環境足跡方法

進行足跡分析和分析結果的過程，可以幫助專案團隊找出最大的貢獻和發展潛力的方法來減少這些貢獻，實現更環保的清理。任何一個指標最大的足跡減量，通常是從修改某些流程或項目組成的結果。例如，如果用電量是能源足跡最大的貢獻者，最大的足跡減少可能來自減少總用電量使用。在許多情況下，可以通過修改具體整治使用的電力元件，減少用電量。

每種方法應符合站點的獨特條件和一個特定淨化整治的預期運行參數。要度量來自同一個項目的貢獻可能會出現相對於較小其他的貢獻，但相較於其他站點實現可媲美的補救措施很大。例如，用於大泵/抽取-處理整治相關的能源消耗可能相對於在同一地點用電量相關較小的能源消耗。然而，相比在不同現場，泵/抽取-處理整治能源足跡的材料比該站點相關的能源消耗可能較大。

而減少足跡之方法和特定的最佳管理做法，分為三部分：1. 減少材料和廢棄物足跡途徑；2. 減少水資源足跡的辦法；3. 減少能源和空氣足跡的辦法。可以被用來減少各種的整治措施，通常實施現場清理所造成的環境足跡。一個足跡分析結果最佳管理做法是可以幫助利害關係人針對最有效減少佔地面積和跟踪相關的改進項目的環境成果。

4.2.6 既有規範軟體工具

目前國際上正在開發專為整治活動設計之環境足跡分析工具。基本上各組織間並無統一之評估工具，因此由於各工具評估範疇與邊界不同，不同工具間評估結果並不適合互相比較。

Spreadsheets for Environmental Footprint Analysis (SEFA) 是依據美國環保署 2012 年公告之 Methodology for Understanding and Reducing a Project's Environmental Footprint 內容研擬，以類生命週期評估的方式計算整治過程能源、水資源、原物料及廢棄物產生量及回收量等相關參數，另外土地及生態系統則定性描述方式進行。表 4.2.6-1 為 SEFA 操作流程。

表 4.2.6-1 SEFA 操作流程

1. SEFA 主頁：輸入場址及整治措施敘述說明，其中設定之整治措施將決定足跡分析的目標及範疇。

Greener Cleanups: EPA Spreadsheets for Environmental Footprint Analysis - August 2014
Main Workbook

Site Name Green Hills

Remedy Dig & Haul

Identify the site name and remedy name in the spaces above. These names will be populated on all of the worksheets for the project.

Enter the path name (if not saved in same directory) and file name of the "Calculations" workbook for the project.

Path Name: SEFA_Tutorial_calculations_(083114).xlsx

Calculations File Name: SEFA_Tutorial_calculations_(083114).xlsx

Component	Remedy Component Names*
Component 1	Site Investigation
Component 2	Excavation
Component 3	Soil Sent Off-Site
Component 4	Backfill
Component 5	Long-term Monitoring
Component 6	<Component 6>

*Fill in unique names for Remedy Components (optional). These names will be populated on all of the worksheets for the project.

Intro to SEFA **General** Instructions Summary Totals by Scope and Component End

PAGE: 1 OF 1

2. 輸入工作表：每個足跡分析可以輸入多達 14 個項目。而每個表格顏色有助於數據之輸入，例如：紅色為下拉式選單，使用者可以選擇需要之項目；藍色為查詢表或計算結果；黃色則是由使用者輸入之數據。

www.Changes EPA Spreadsheets for Environmental Footprint Analysis - August 2014
Sheet: 100 - Dig & Haul

Input Worksheet for Input Template

Please specify which Remedy Component this input worksheet is part of: Component 1 Site Investigation

General Scope: Example Scope: Eliminated through Increasing Flow

Other Notes and References:

Personnel Transportation

Participant	Number of Personnel (FTE)	Hours to Site	Mode of Transportation	Transport Fuel Type	Total Distance Traveled	Default Fuel Usage Rate	Fuel Usage Rate (Override)	Fuel Used for Personnel Transportation	Activity or Notes

*Explanation: "id" for calculation of equipment and fuel inputs. Multipliers for Fuel Usage Rate: for natural gas, units are hundreds of cubic feet (ft³) for Fuel Used and multipliers for Fuel Usage Rate.

On-Site Equipment Use and Transportation

Equipment Type*	HP	Load Factor (LF)	Efficiency (%)	Electricity (kWh)	Hours Used	Energy Used (kWh)	Notes

*HP and Load Factor must be entered by user in Columns C and D. Please see the "Detailed Notes and Explanations" tab.

On-Site Electricity Use

Equipment Type	HP	Load Factor (LF)	Efficiency (%)	Electricity (kWh)	Hours Used	Energy Used (kWh)	Notes

*HP and Load Factor must be entered by user in Columns C and D. Please see the "Detailed Notes and Explanations" tab.

On-Site Material Use

Equipment Type	Power Rating (kW)	Efficiency (%)	Energy Used (kWh)	Material Used (tons)	Notes

*HP and Load Factor must be entered by user in Columns C and D. Please see the "Detailed Notes and Explanations" tab.

Landfill Gas Collected On-Site for Use

Equipment Type	Gas (ft³)	Landfill Gas	Notes

*Landfill Gas Collected On-Site for Use: This worksheet is used to enter the amount of landfill gas collected on-site for use in the project. The amount of landfill gas collected on-site for use in the project is entered in the "Landfill Gas Collected On-Site for Use" column.

General **Input Instructions** Detailed Notes and Explanations Input Summary Input Template Grid Electricity User Defined Factors Well Material Calculations

CALCULATE

3. 輸入工作表包含人員運輸、現場設備使用和運輸、現場電力使用情況、天然氣和垃圾填埋氣。

www.Changes EPA Spreadsheets for Environmental Footprint Analysis - August 2014
Sheet: 100 - Dig & Haul

Input Worksheet for Input Template

Please specify which Remedy Component this input worksheet is part of: Component 1 Site Investigation

General Scope: Example Scope: Eliminated through Increasing Flow

Other Notes and References:

Personnel Transportation

Participant	Number of Personnel (FTE)	Hours to Site	Mode of Transportation	Transport Fuel Type	Total Distance Traveled	Default Fuel Usage Rate	Fuel Usage Rate (Override)	Fuel Used for Personnel Transportation	Activity or Notes

*Explanation: "id" for calculation of equipment and fuel inputs. Multipliers for Fuel Usage Rate: for natural gas, units are hundreds of cubic feet (ft³) for Fuel Used and multipliers for Fuel Usage Rate.

On-Site Equipment Use and Transportation

Equipment Type*	HP	Load Factor (LF)	Efficiency (%)	Electricity (kWh)	Hours Used	Energy Used (kWh)	Notes

*HP and Load Factor must be entered by user in Columns C and D. Please see the "Detailed Notes and Explanations" tab.

On-Site Electricity Use

Equipment Type	HP	Load Factor (LF)	Efficiency (%)	Electricity (kWh)	Hours Used	Energy Used (kWh)	Notes

*HP and Load Factor must be entered by user in Columns C and D. Please see the "Detailed Notes and Explanations" tab.

On-Site Material Use

Equipment Type	Power Rating (kW)	Efficiency (%)	Energy Used (kWh)	Material Used (tons)	Notes

*HP and Load Factor must be entered by user in Columns C and D. Please see the "Detailed Notes and Explanations" tab.

Landfill Gas Collected On-Site for Use

Equipment Type	Gas (ft³)	Landfill Gas	Notes

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General **Input Instructions** Detailed Notes and Explanations Input Summary Input Template Grid Electricity User Defined Factors Well Material Calculations

CALCULATE

6. 此表為輸入工作總表，匯集使用者輸入前述工作表之數據。分為
- (1) 現地: 能源、空氣排放、電力產生、運輸、運輸燃料使用等。
 - (2) 離地: 建材、整治原物料及化學品、水資源、廢棄物/回收處理、實驗室分析等。
 - (3) 其他, 使用者自行定義原物料及廢棄物之目的。

Greener Cleanups: EPA Spreadsheets for Environmental Footprint Analysis - August 2014									
Green Hill - Dig & Haul									
Remedy Component Number →		Input Summary							
		2	3	4					
		Column headings in Row 1 must match the name of "Input" tabs in this workbook for Columns E - J. In this table to be populated ("P" in Row 4 means "Input" tabs is turned OFF and will not be presented to a user)							
Item	Site Investigation	Excavation	Soil Sent Off-Site	Backfill	Groundwater Monitoring	Total			
On-Site									
<i>On-Site Renewable Energy</i>									
Renewable electricity generated on-site	MWh	0	0	0	0	0	0	0	0
Landfill gas combusted on-site for energy use	csc CH ₄	0	0	0	0	0	0	0	0
On-site biorectal use	gal	0	0	0	0	0	0	0	0
Use-defined on-site renewable energy use #1	TBD	0	0	0	0	0	0	0	0
Use-defined on-site renewable energy use #2	TBD	0	0	0	0	0	0	0	0
<i>On-Site Conventional Energy</i>									
Grid electricity	MWh	0	0.32	0	0	0	0.32		
On-site diesel use	gal	653	3,375	0	2,241	0	6	6,774	
On-site gasoline use	gal	0	0	0	0	0	0	0	0
On-site natural gas use	csc	0	0	0	0	0	0	0	0
Use-defined on-site conventional energy use #1	TBD	0	0	0	0	0	0	0	0
Use-defined on-site conventional energy use #2	TBD	0	0	0	0	0	0	0	0
<i>Other On-site Emissions</i>									
On-site HAP process emissions	Lbs	0	0	0	0	0	0	0	0
On-site GHG emissions	Lbs CO ₂ e	0	0	0	0	0	0	0	0
On-site carbon storage	Lbs CO ₂ e	0	0	0	0	0	0	0	0
GHG avoided by flaring on-site landfill methane	csc CH ₄	0	0	0	0	0	0	0	0
Other on-site NO _x emissions or reductions	Lbs	0	0	0	0	0	0	0	0
Other on-site SO _x emissions or reductions	Lbs	0	0	0	0	0	0	0	0
Other on-site PM emissions or reductions	Lbs	0	0	0	0	0	0	0	0
Electricity Generation									
Grid electricity	MWh	0	0.32	0	0	0	0.32		
Voluntary purchase of renewable electricity	MWh	0	0	0	0	0	0	0	0
Voluntary purchase of RECs	MWh	0	0	0	0	0	0	0	0
Transportation Fuel Use Breakdown									
Biorectal use - Personnel Transport	gal	0	0	0	0	0	0	0	0
Biorectal use - Equipment Transport	gal	0	0	0	0	0	0	0	0
Biorectal use - Material Transport	gal	0	0	0	0	0	0	0	0
Biorectal use - Waste Transport	gal	0	0	0	0	0	0	0	0
Input Instructions Detailed Notes and Explanations Input Summary Site Investigation Excavation Soil Sent Off-Site Backfill Groundwater Monitoring Total									

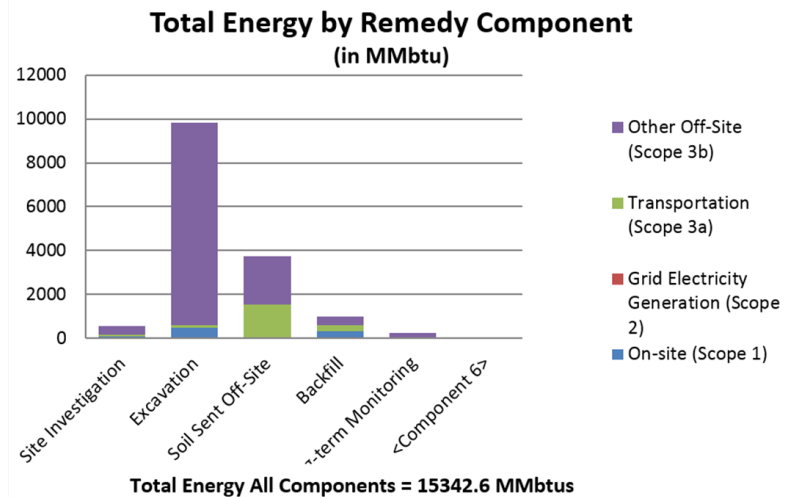
7. 計算工作表:分別為原物料、能源、水資源、廢棄物及離地，並分別輸入單位及使用量即可計算出能源、溫室氣體、NO_x、SO_x、空氣中懸浮微粒及有害空氣污染物之足跡。

Category	Units	Usage	Energy		Greenhouse Gas		NO _x		SO _x		PM		HAPs	
			Cons. Factor	MMBtu	Cons. Factor	Btu CO ₂ e	Cons. Factor	Btu	Cons. Factor	Btu	Cons. Factor	Btu	Cons. Factor	Btu
Construction Materials														
Cement	dry-lbs	0	0.0021	0	0.9	0	0.0018	0	0.00105	0	3.15E-06	0	0.000029	0
Concrete	Btu	0	0.00041	0	0.171	0	0.00035	0	0.00021	0	0.00001	0	0.00001	0
Gravel/sand/clay	Btu	0	0.000028	0	0.00335	0	0.0000185	0	0.000015	0	0.000002	0	2.05E-10	0
HDPE	Btu	20000	0.031	620	1.9	38000	0.0032	64	0.0041	82	0.00004	12.8	0.0000034	0.008
Photovoltaic system (installed)	W	0	0.0336	0	4.47	0	0.015	0	0.032	0	0.00063	0	0.0000029	0
PVC	Btu	0	0.032	0	2.6	0	0.0048	0	0.0076	0	0.0012	0	0.00047	0
Stainless steel	Btu	0	0.0116	0	3.4	0	0.0073	0	0.012	0	0.00044	0	0.000144	0
Steel	Btu	0	0.0044	0	1.1	0	0.0014	0	0.0017	0	0.00016	0	0.000067	0
Other refined construction materials	Btu	0	0.01422	0	1.98	0	0.00374	0	0.00529	0	0.0015066	0	0.0001427	0
Other unrefined construction materials	Btu	0	0.000028	0	0.00335	0	0.0000185	0	0.000015	0	0.000002	0	2.05E-10	0
Notes:														
Treatment Materials & Chemicals														
Cheese whey	Btu	0	0.0025	0	0.031	0	0.000062	0	0.000033	0	0.000002	0	NP	
Emulsified vegetable oil	Btu	0	0.0077	0	2.44	0	0.0066	0	0.0019	0	0.000032	0	NP	
Molasses	Btu	0	0.0044	0	0.48	0	0.0011	0	0.00024	0	0.0000043	0	NP	
Virgin GAC (coal based)	Btu	0	0.015	0	8.5	0	0.014	0	0.034	0	0.0007899	0	0.0012417	0
Other treatment chemicals & materials	Btu	0	0.015	0	1.67	0	0.003	0	0.0065	0	0.00061	0	0.000016	0
Notes:														
Fuel Processing														
Biodiesel produced	gal	0	0.029	0	-16.8	0	0.018	0	0.033	0	0.00082	0	NP	
Diesel produced	gal	20135.925	0.0185	372.1483	2.7	54366.998	0.0064	128.86992	0.011	361.76703	0.00034	6.8463145	0.00012	2.418311
Gasoline produced	gal	300.2	0.021	6.3042	4.4	1320.88	0.008	2.4016	0.019	3.7038	0.00052	0.158104	0.00016	0.048032
Natural gas produced	cf	0	0.0032	0	2.2	0	0.0037	0	0.0046	0	0.000072	0	0.0000061	0
Fuel Processing Subtotals						378.8188		85687.88		131.2715		267.4708		7.002319
														2.464343
Notes:														
Public water														
	gal x 1000	4200	0.0092	38.64	5	21000	0.0097	40.74	0.0019	34.78	0.016	67.2	0.000015	0.063
Notes:														

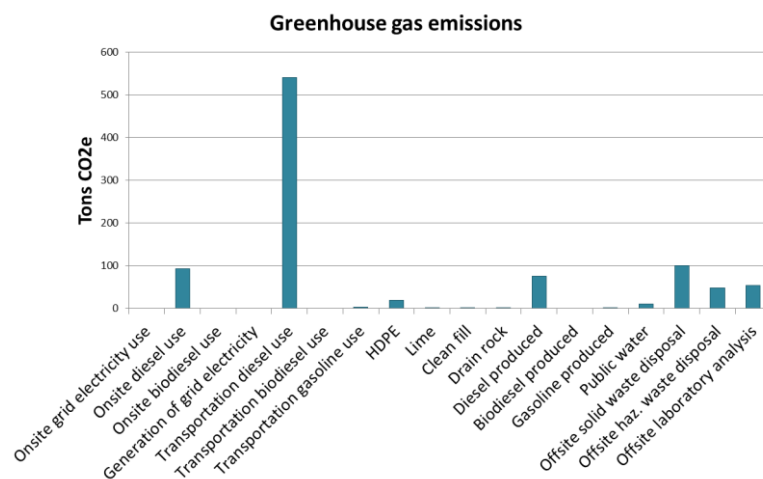
8. 此表為計算環境足跡之總結，工作表上呈現足跡方法對於原物料、廢棄物、水資源、能源以及空氣排放之建議。

Environmental Footprint Summary									
Core Element	Metric	Unit of Measure	Footprint					Long-term Monitoring	Total
			Site Investigation	Excavation	Soil Sent Off-Site	Backfill			
Materials & Waste	Refined materials used on-site	Tons	0	180	0	0	0	180	
	% of refined materials from recycled or reused material	%		0%				0%	
	Unrefined materials used on-site	Tons	0	0	0	7,000	0	7,000	
	% of unrefined materials from recycled or reused material	%				29%		29%	
	On-site hazardous waste disposed of off-site	Tons	10	0	3,512	0	0	3,522	
	On-site non-hazardous waste disposed of off-site	Tons	0	500	7,500	0	0	8,000	
Water (used on-site)	% of total potential waste recycled or reused	%	0	80%	0%			15%	
	Public water use	M/G	0	2.3	0	1.7	0	4.2	
	Groundwater use	M/G	0	0	0	0	0	0	
	Surface water use	M/G	0	0	0	0	0	0	
	Reclaimed water use	M/G	0	0	0	0	0	0	
	Storm water use	M/G	0	0	0	0	0	0	
Energy	Other water resource #1	M/G	0	0	0	0	0	0	
	Other water resource #2	M/G	0	0	0	0	0	0	
	Total energy used (on-site and off-site)	M/G-Btu	557	9,824	3,741	995	226	15,343	
	Energy voluntarily derived from renewable resources								
	On-site renewable energy generation or use + on-site biodiesel use + biodiesel and other renewable resource use for transportation	M/G-Btu	0	0	0	0	0	0	
	Voluntary purchase of renewable electricity	MWh	0	0	0	0	0	0	
Air	Voluntary purchase of RECs	MWh	0	0	0	0	0	0	
	On-site grid electricity use	MWh	0	0.3	0	0	0	0.3	
	On-site NO _x , SO _x , and PM emissions	Pounds	117	603	0	401	1	1,122	
	On-site HAP emissions	Pounds	0	0	0	0	0	0	
	Total NO _x , SO _x , and PM emissions	Pounds	738	7,666	11,203	1,272	305	21,183	
	Total NO _x emissions	Pounds	469	3,164	4,728	951	168	9,480	
	Total SO _x emissions	Pounds	237	3,420	1,773	256	123	5,810	
	Total PM emissions	Pounds	32	1,081	4,701	65	14	5,893	
	Total HAP emissions	Pounds	8	89	41	1	4	144	
	Total greenhouse gas emissions	Tons CO ₂ e*	43	681	328	77	17	1,147	

9. 此圖為總結的結果，有助於了解哪些整治措施具有最大的足跡。



10. 此圖為總結的結果，能使使用者了解整治所造成之足跡、目標區域對於足跡之減量。



4.2.7 研究案場

目前國際間推動污染場址可持續性綠色整治概念的過程中，均將案例發表視為發展的重點，期望透過成功案例宣導，更進一步推廣可持續性綠色整治的概念。目前美國空軍亦已於 Travis AFB, CA、Altus AFB, OK、Massachusetts Military Reservation (MMR)、162nd Fighter Wing, Tucson, AZ 等 4 個空軍基地場址進行綠色及可持續整治工作，做為示範及推廣之用。藉由示範場址成功的經驗，使得污染行為人、政府機關、顧問單位更有意願採行可持續性綠色整治，因此國內政府機關理應由污染行為人不明場址抑或是污染行為人認定仍有爭議，然具有健康危害須政府公權力介入執行整治場址為示範案場優先納入選擇。基於此理念，本研究將以某供油中心大型生物復育場作為研究案場。

此區域為早期加油站污染案例為了盡速解除污染管制，採取開挖污染土壤離場處理之整治方法後，油污染土壤的最終去處，其優點為可於短時間內移除高濃度區，以儘速降低污染物濃度，並可連帶更換儲油設備。而將污染土壤送至油庫再搭配相關整治方法，現行在油污染場址，污染土壤開挖後，技術可行之處理技術包括有：(1)焚化法；(2)低溫熱脫附法；(3)土壤洗滌法；(4)化學氧化法；(5)生物復育法。

但此油庫主要用於儲存油品來源，因此該區域為嚴禁煙火管制區域，因此在整治工法上焚化法、低溫熱脫附法在此場址上較不適用。而本計畫將以化學及生物復育法進行整治，其案場背景表 4.2.7-1 及表 4.2.7-2 所示。而基於土地永續性及綠色整治之考量下，整治後之土壤利用價值為環境可否永續發展之一關鍵，因此將導入本計畫之評估系統，並討論其評估系統之可行性探討。

表 4.2.7-1 化學整治

污 染 物	某供油中心油品污染之土壤				
處 理 量	50 噸				
人 員 交 通	人 數	距 離 (英 里)	交 通 工 具	交 通 工 具 使 用 之 燃 料 類 型	
	10	4	汽 車	汽 油	
現 場 機 具	名 稱	負 載	使 用 時 間 (小 時)	距 離 (英 里)	機 具 使 用 之 燃 料 類 型
	挖土機(175HP)	80%	96	4	柴 油
	運水車(400HP)	65%	96	4	柴 油
	砂石車(400HP)	65%	30	4	柴 油
材 料	名 稱	使 用 量 (噸)			
	過氧化氫(1%)	50			
水 資 源	150.12 噸				

表 4.2.7-2 生物整治

污 染 物	某供油中心油品污染之土壤				
處 理 量	50 噸				
人 員 交 通	人 數	距 離 (英 里)	交 通 工 具	交 通 工 具 使 用 之 燃 料 類 型	
	10	3.6	汽 車	汽 油	
現 場 機 具	名 稱	負 載	使 用 時 間 (小 時)	距 離 (英 里)	機 具 使 用 之 燃 料 類 型
	山 貓 (75HP)	80%	34	4	柴 油
	運 水 車 (400HP)	65%	34	4	柴 油
	砂 石 車 (400HP)	65%	15	4	柴 油
	名 稱	負 載	使 用 時 間 (小 時)	效 率	電 功 率 (kW)
	脫 水 擠 壓 器 (20HP)	65%	8	65%	15
	破 碎 機 (50HP)	65%	8	65%	37
	槽 型 翻 堆 機 (25HP)	70%	#	70%	19
材 料	名 稱	使 用 量 (噸)			
	廚 餘	50			
水 資 源	20.85 噸				

4.3 工作進度甘特圖

年月	1	2	3	4	5	6	7	8	9	10	11	12	備註	
工作項目														
A 資料蒐集以及分析彙整														
B 整合國內外方法與指引														
C 分析既有規範軟體工具							※							
D 建立本土化之系統架構							※							
E 建立本土化評估方法學														
F 初步完成可評估能耗與環境足跡之定量評估試算軟體工具														
工作進度估計百分比（累積數）	7%	20%	33%	41%	47%	55%	60%	73%	78%	85%	90%	100%		
預定查核點	期中		分析既有規範軟體工具、建立本土化之系統架構											
	期末		完成初步可評估能耗與環境足跡之定量評估試算軟體工具											
說明：														
1、工作項目請視專案性質及需要自行訂定。預定進度以粗線表示其起迄日期。														
2、「工作進度百分比」欄係為配合管考作業所需，累積百分比請視工作性質就以下因素擇一估計訂定：（1）工作天數，（2）經費之分配，（3）工作量之比重，（4）擬達成目標之具體數字。														
3、「預定查核點」，請在條形圖上標明※符號，並在「預定查核點」欄具體註明關鍵性工作要項。														

五、 結果與討論

5.1 結果與討論

大眾普遍認為污染案場問題相當複雜棘手且花錢，污染土地再開發不僅涉及土污法，亦同時涉及水污、空污、廢棄物、毒性化學物質等二次污染管控問題，因此，污染業者往往不願與環保單位配合，不僅環保單位因污染整治問題感到痛苦，對於產業界而言，實是深感恐懼更感無奈甚至痛苦之事，環境顧問業也因此承擔高風險，相關社群因污染土地復育與活化再甦遙遙無期，痛苦不堪，連帶致使社會動盪混亂、人民無安全感且經濟活動無法推展等社會問題。綜觀上述問題，整治思維應考量以經濟發展帶動環境保護及環境保護促進經濟發展。意即，挑出最佳的整治工法，使得場址整治可滿足環境、經濟及社會指標，並使得整治的效益比整治帶來的衝擊更高。在整個案場整治清理過程，透過全面性的綜合考量不利因素，並指出如何選擇與決定最佳控管實務與可持續性發展的指標。

5.1.1 建立本土化之系統架構

本研究提出之整治控管策略系統，係以廣義之可持續性綠色整治（Green and Sustainable Remediation）為基礎架構，來因應污染案場之活化再甦，如圖 5.1.1-1 所示，在兼顧環境、經濟、社會之下發展，強調多元利害關係者（multi-stakeholders）之間的對話(dialog)，降低日後整治後整治產稱的紛爭，將整治決策過程區分為案場評估(Assessment Stage)及公證評鑑(Notary evaluation)兩階段。

案場評估階段(Assessment Stage)只要是針對場址(Site)本身的需求及其對環境的影響，一旦發現污染場址，立即進行案場鑑別與登錄(Identification sites Platform login manager)，完整的場址概念模型（Conceptual Site Model），包含污染源源頭、污染物種類、污染介質、污染範圍、傳輸途徑、場址現況、受體以及受體接觸途徑等資訊。幫助場址利害相關人瞭解場址情況，此階段所蒐集之資料相當關鍵，後續之方案設計皆仰賴完整的概念場址模型，仔細嚴謹之調查可降低日後整治之不確定性，減少額外之成本投入，並將人體健康風險(Health Risk Index)及生態風險(Ecology Risk Index)納入評估，以界定範疇(the definition of the subject)。透過前述的調查選定事宜該場址特性的整治工法進行污染整治，並且對於成本提出控制或評估計畫送當地環保局審查，通過後將評估 GSR 指標用以計算此計畫是否符合永續性發展。本研究基於前述考量原則，提出可持續性綠色整治指標（Green and Sustainable Remediation Index, GSRI）。

為達到可持續性綠色整治之目的，需進行永續發展指標的盤查作業，藉由本研究發展之整治控管策略方法，確認可行的整治範疇。公證評鑑階段則經由第三公證查驗機構，再次覆核擬訂之整治策略是否符合永續發展宗旨，同時藉由經濟及社群誘因，配合公部門輔

導改善，提出永續發展之具體對策。建立獎勵評選機制，透過舉辦綠色整治成果展提升企業形象，並協助輔導績效差之企業。

案場評估如圖 5.1.1-2 所示，與國內土污法連結，欲推動一項新的概念，第一個步驟應依本土特性及我國法規現況，提出一清楚簡易使用的系統流程，可避免誤解與誤用，並可獲得各界的信任及提高接受，為使台灣盡速與國際接軌，整治流程將 ASTM 指引納入，ASTM 環境場址評估已經行之有年，且最被廣泛應用。案場評估階段聚焦於場址本身的需求及其對環境的影響並鑑別場址污染情形，提出污染控制計畫或污染整治計畫，以進行場址污染的改善工作，並審慎控制成本，以下分別說明案場評估各步驟之內容：

(1) 加速髒地活化再甦、鑑別案場

目前各國尚無明確之法規或規範，強迫污染場址必須以可持續性綠色整治進行，因此應以鼓勵代替懲罰，以利害相關人之立場(利場)，思考如何可使大眾接受並符合期待，而樂意接受推動案場整治為優先考量，使其污染業主(列管、未列管、無明確污染責任人之場址)看見後續土地活化之利基，因髒地活化再甦是有利可圖而紛紛自願性推動，策略方法可採取 ASTM 場址環境一、二階評估標準實務及可持續棕地重建等指引等，以協助利害相關人選擇最符合經濟效益的場址整治或管理方式。

(2) 調查或查證工作

根據土污法第七條為降低土壤或地下水污染的影響，並避免污染情形擴大，減少對人體或環境立即性危害，環保機關在執行查證工作時發現土壤、底泥或地下水因受污染，而有影響人體健康、農漁業生產或飲水水源的可能時，可以準用第 15 條規定採取應變必要措施，用經採取應變必要措施後，如土壤、地下水之污染情形減輕，且經環保機關查證結果顯示土壤、地下水污染物濃度低於管制標準時，則可以不公告為控制場址。但如土壤、地下水污染物濃度仍有達管制標準情形時，環保機關後續則將進行場址之公告。

(3) 三合控管作業法(The Triad Approach)

美國環保署所提倡之土壤污染調查新概念—三合方法 (Triad Approach)，三合系統 (Triad System) 嚴格來說並不是一種調查技術，而是一種調查策略與方法 (Approach)。三合系統係整合三種要素所組成，包含傳統的系統性規劃 (Systematic Planning)、動態工作計畫 (Dynamic Work Plan) 及現地檢測技術 (on Site Measurement Technologies)。結合此三種要素，由專業的現地調查專家進行現地檢測資料蒐集、分析、研判，據以即時修正工作計畫及進行現地決策，以同時達到縮短調查時程、減少調查經費及降低調查不確定性 (提升調查資料品質) 的共同目標。透過系統性專案規劃 (Systematic Project Planning) 簡化場址的評估流程卻能獲得完整的案場資訊，動態性工作策略 (Dynamic Work Plan Strategies) 面對一個複雜地下環境，就必須要有「彈性調整」去適應多元和易變動的整治需求，及時性檢測工

具(real-time measurement technologies)透過即時性的檢測數據，隨時針對案場進行微調，以最具成本效益的方法來完成現場評估調查，可使利害相關人降低風險。

(4) 場址概念模型 (Conceptual Site Model)

內容應包含污染源源頭、污染物種類、污染介質、污染範圍、傳輸途徑、場址現況、受體以及受體接觸途徑等資訊，幫助場址利害相關人瞭解場址情況，此階段所蒐集之資料相當關鍵，由於場址概念模式是執行範圍與有效實行整個策略的基本，因此在整個清理計畫的執行期間，場址概念模式應該逐步發展成形，當獲得新的資訊或可用的數據時，場址概念模式應該隨著重新評估修正，場址概念模式對於監管機構、承攬商、利益相關者和公眾而言，是一個重要的溝通工具，場址概念模式可呈現出經過考量並具實施可行性的永續性綠色整治，一旦有了場址概念模型，那麼污染源、流經路徑和詳細資訊我們都能掌握，仔細嚴謹之調查，可降低日後整治之不確定性，減少額外之成本投入，可參閱 ASTM E1689-95(2008)。

(5) 活動與土地使用是否受限

致力持續將「活動或使用限制 (Activity and Use Limitations, 簡稱 AULs)」限縮至最小化 (例如：優先將受關切之重度污染設施或設備盡早除污或拆除。回收 (recovery) 或摧毀 (destroy) 熱區 (hot spot) 受關切之高濃/純度化學物質 (chemicals of concern)，整治受影響環境介質以斷絕其傳輸途徑等)，可參閱 ASTM E2091-11 及 ASTM E2435-05(2010)e1。

(6) 健康或生態風險評估

以風險評估為基礎(包括人體健康風險評估及生態風險評估，彙整場址調查結果，反覆的檢視及修正評估方法，用以判定污染場址是否對環境及人體健康造成危害，依風險評估結果，設定整治目標及範疇，並選取適當之整治技術，可參閱 ASTM E1739 - 95(2010)e1 及 ASTM E2020 - 99a(2010)。

(7) 標的邊界設定/範疇界定

根據專案管理架構中，三重限制 (Triple Constraint) 指出，專案必須在「範圍」(Scope)、「時程」(Schedule)、「成本」(Cost) 三個限制之間取得平衡，任何一個限制(範圍、時程、成本)的變動是否能被利害相關者所接受，範疇界定不清容易導致專案失敗，因此再提出整治計畫時必須詳盡考慮各項因素，設定目標與範疇：依據場址大小、複雜程度、整治階段、法規、利害相關者意見、場址未來用途、環境資源的可及性、監測數據需求，考慮各類環境因子，來設定整治的永續目標及範疇來設定整治的永續目標及範疇。

(8) 整治設計及整治行動 (Remedial Design/Remedial Action)

在整治技術選取的過程，可透過環境足跡的計算結果，比較不同整治技術選項間的差異，做為整治技術選取的依據，此階段規劃並執行場址整治計畫和細部事項。清理工作通常多在此階段進行，在此階段需考慮如何儘可能使整治工作配合再利用計畫、與當地政府機關及開發商協調相關事項、考慮可加速土地再利用的相關措施、確定全部或部分場址可以立即進行再利用。視場址的污染狀況，有時候可設計全部場址完成整治前，允許污染整治及部分場址的再利用同時進行。

(9) 成本控制

成本是土地活化再甦和發展不可不談的話題，成本的高低往往直接決定了土地活化再甦與發展，為了解決污染問題，而花費大量金錢，造成經濟龐大的負擔，致使害害相關者不願意提出整治計畫。因此解列關鍵在於成本因素(包含土地再利用)評估，除了考慮污染場址整治所投入的費用外，亦評估對附近居民及整體社會經濟的影響，採用成本效益分析，能夠以最低成本促成最大效益，可參閱 ASTM E2137-06(2011)。

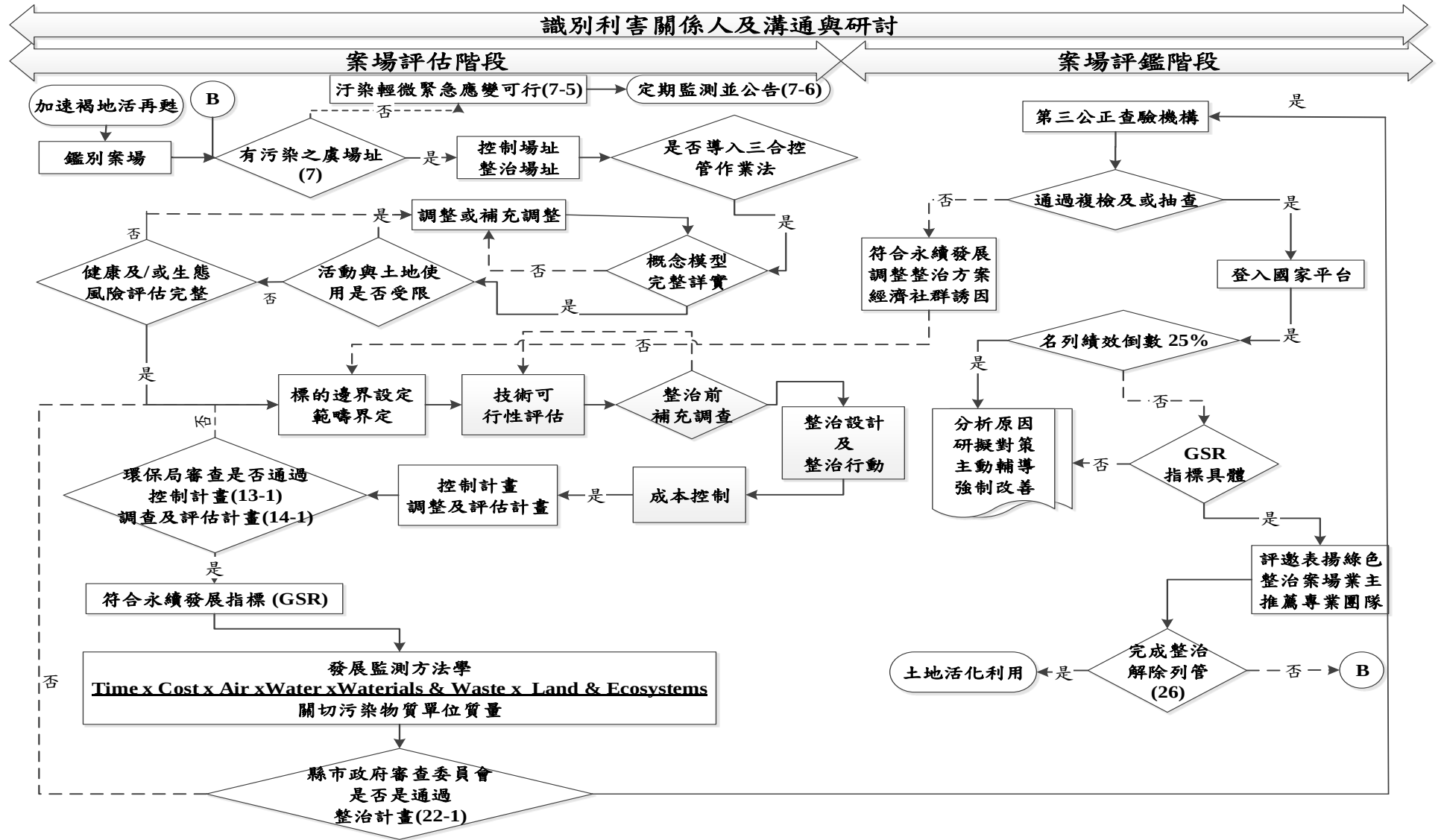


圖5.1.1-1可持續性綠色整治架構

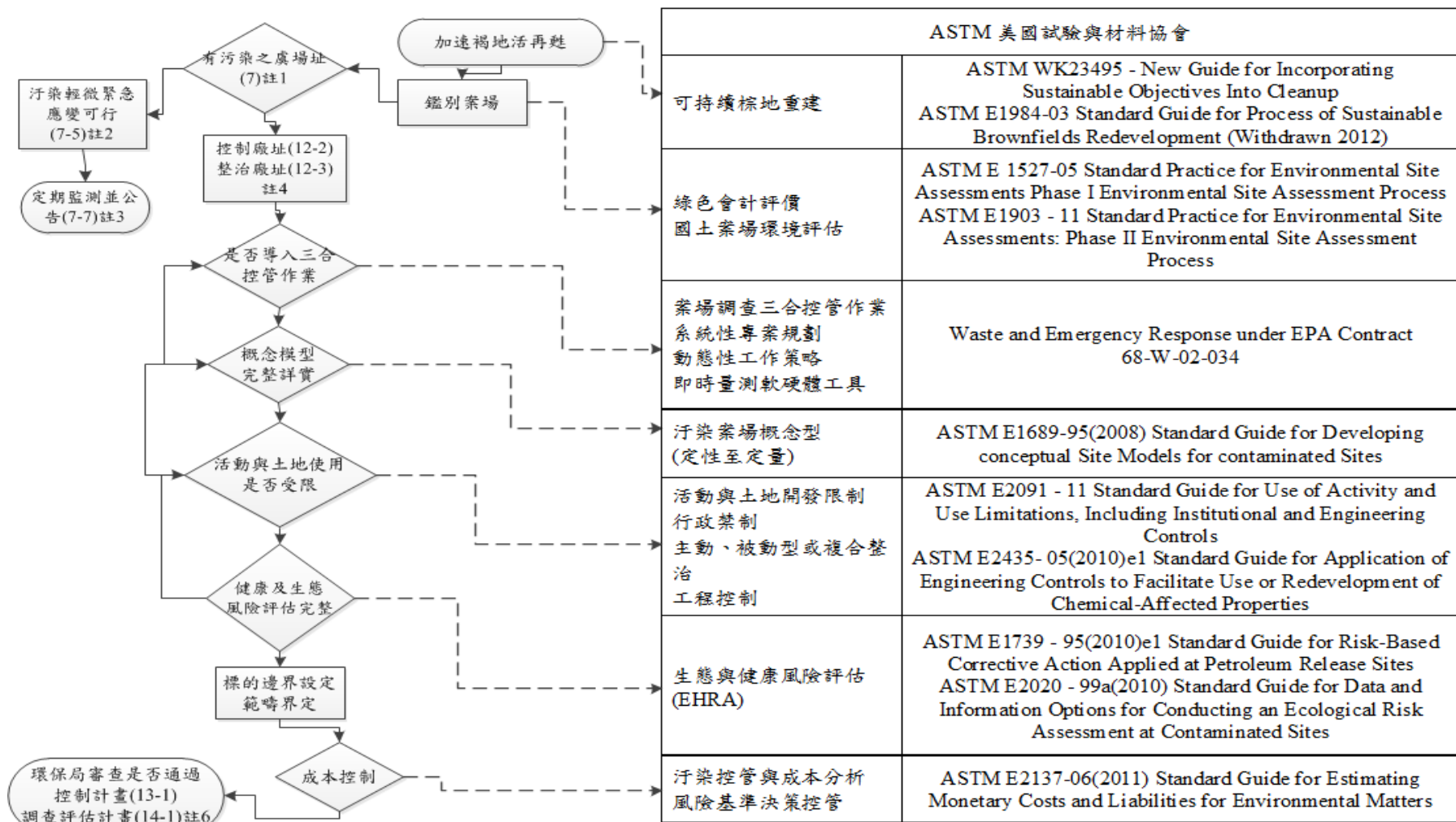


圖 5.1.1-2 案場評估流程

5.1.2 可持續性綠色指標

以目前發展出之永續發展指標來說，世界各級組織及團體已發展了相當數量的指標，其評估的範圍及區域也不盡相同，端視所需評估的目的而定。整體而言，若指標評估的範圍越大，則需要考量的因素就越廣泛。

本研究提出之可持續性綠色整治指標，如表 5.1.2-1 所示，以廣義之可持續性綠色整治為基礎架構，來因應污染案場之活化，在兼顧環境、經濟、社會互惠之下發展所需考量之各項因素，並區分各項因素之正向指標及負向指標。在推動土地活化之方案時，需盡其考量相關因素，降低其負向指標並提高整體效益，例如以經濟指標為例，在確認並了解各項衝擊因素後，選定其相關整治策略，是可壓低成本支出，並能賦予土地更高利用價值，透過研發出更好、更便宜、更安全，也更具永續性的方法來處理工業發展所遺留的環境污染。更重要的是，綠色技術之發展能創造綠色工作機會、不僅提升國人健康和福祉，更能活絡社區經濟，貢獻社會高度正面效益。

(一) 環境指標

環境指標分為能源、空氣、水資源、原物料和廢棄物以及土地生態影響。

1. 能源:減少耗用能源總量，提高能源效率並盡可能致力使用可替代性再生能源。
 - (1) 減少耗用能源總量（如使用節能設備）。
 - (2) 盡量利用案場現場再生能源，以供應整治淨化系統設備之動力來源，減少耗用外購能源。
 - (3) 若自產再生能源不敷使用，考慮避免採購油電，盡可能採購商轉再生能源。
 - (4) 致力使用再生能源與資源，可評估潮汐、水力、風勢或日照光熱等再生能源，以供應整治系統電力需求。

- (5) 所需電力盡可能採用甲烷氣體或二次衍生/半產材料等整治過程之可用再生品。
 - (6) 參與發電或建立購買再生資源能源。若能發展綠能夥伴基礎關係，運用充沛日照、風力、潮汐、水力等案場天然資源，妥善發電或建立購買再生資源能源機制，可產生綠能等諸多直接或間接效益。
2. 空氣:於發生污染與排碳之各單元即盡力減少空氣污染物，並全面控制與降低溫室氣體排放質量。
- (1) 盡量減少溫室氣體產生與排放質量。
 - (2) 整治現場就地直接抑制生成空氣污染物。若採取離地或離場整治，開挖和運輸過程必須盡力抑制揚塵，工程機具盡量選用高效能低排碳者，並減少場內運輸或外運離場之輸出距離。
 - (3) 提高重型工程機具與設備使用效能（例如：實施柴油引擎減碳排放計畫）。
 - (4) 工程機具、整治設備或運輸車輛，盡可能採用配有先進空污抑制與排放控制之高效能系統。
 - (5) 採用可使用清潔燃料之動力機械及輔助設備。
 - (6) 現場封存二氧化碳（例如，現場就地回注地下，使用土壤改良劑或重建綠化美化植被等）。
3. 水資源:致力減少各水體用水量，並盡力保育水資源，且減少對水資源的影響。
- (1) 盡量節約用水，減少消耗外來水資源與自來水，以減少不利環境生態之足跡。
 - (2) 加強收集雨水回收廢/污水，妥適儲存並予再利用（例如，補注回注含水層以涵養水資源，調節灌溉排水補給等）。
 - (3) 盡量減少種植須經常澆灌之植被（例如，避免使用外來種，盡量使用在地本土原生種）。

- (4) 對暴雨預先擬定並採取最佳控管實務（例如：開闢生態溼地滯洪池，評估兼作沉澱、緩衝、蓄洪、排洪或回注地下等多功能可行性）。
 - (5) 善用經回收處理後的水，有利於儲存或灌溉，並涵養含水層。基於節能減碳並珍惜維護水資源，在質量平衡前提下，案場如需用水宜就地取材盡量使用現場天然地面水或地下水進行整治，盡量不外取自來水或其他水資源，且廢水需予回收再利用，並對地面水或地下水進行保育涵養。
 - (6) 盡量減少耗用自來水量，考慮就地取用地面水體或地下水，且提高整治處理過程之廢水回收與循環使用率。例如若採洗土（soil washing）整治，用水即可考慮就地取材，並以再循環利用 100% 全量回收零排放作為目標。
4. 原物料及廢棄物:就近取用所需原料，減少耗材消耗，並予回收重複使用，減少產生廢棄物，落實分類回收與減量。
- (1) 就近使用在地所需原料材料。
 - (2) 致力減少耗材用量，盡量使用再生產品。
 - (3) 致力減少產生廢棄物。
 - (4) 加強廢棄物、土壤和營建拆解碎片鋼筋土石等之前處理分離回收，且予以循環再利用。
5. 土地及生態:優化未來土地利用用途，並且顧及保護生態系統。
- (1) 強化清理與建設幾近同步之策略，整治計畫應與案場土地未來預期用途或再利用計畫預先充分整合（畢其功於一役，避免重工造成資源浪費以及重複擾動環境生態）。
 - (2) 對於土地污染案場，需致力持續將「活動或使用限制（Activity and Use Limitations, 簡稱 AULs）」限縮至最小化（例如：優先將受關切之重度污染設施或設備盡早除污或拆除。優先回收（recovery）或摧毀（destruction）熱區（hot spot）受關切之高濃度/純度化學物質（chemicals of concern），整治對人體健康與生態環境影響較大之環境介

質，以斷絕環境介質之污染傳輸途徑等。)

- (3) 盡量減少對土地和生態棲息地不必要的人為干擾與破壞，妥適保留生態棲地，減少人為營建設施與活動干擾。
- (4) 盡量支持並妥適維護當地本土物種的棲息地。
- (5) 防止對緊鄰案場水體水質優養化造成負荷。盡量不使用人工合成之化學整治藥劑，以保護水質與土壤。可致力開發食品級、環境生態安全之配方，例如：對環境友善生物可分解萃取劑，且盡量回收循環再利用，除可避免水體水質負荷或優養化，且同步維護並復育土壤地力與肥力。

(二) 經濟指標

1. 成本效益

- (1) 成本效益，在選擇整治方法階段，若能以較少的資金投入且能達到整治目標，則該專案相對較有效率。
- (2) 土地活化價值，污染場址達到整治目標且解除列管，健康風險降低、地下水質改善等效益，能使土地價值提升，並能促進當地經濟效益。

2. 經濟影響

經由上述之經濟指標之提升，將污染土地活化再利用，並提升該地之價值，有助於提升當地工作機會，且促進當地經濟，以提高社會之整體福祉。

(三) 社會指標

1. 健康風險及安全

- (1) 健康風險，土壤及地下水污染管制標準已將健康風險納入考量，完成整治時人體健康風險應低於可接受風險。而進行健康風險評估之目的為了解此污染案場的風險現況，進行風險控管措施並與居民溝通。
- (2) 勞工意外風險，整治施工過程之勞工意外風險系指整治設

備操作與交通所可能造成之意外風險。

- (3) 阻絕曝露途徑，將風險較高的途徑設法阻絕此暴露途徑，減少居民與整治工程人員之健康風險。

2. 社會支持度

- (1) 利害關係人參與，發現污染案場、整治過程到完成整治，在這其中不斷了解各利害關係人之意見，已獲得各方皆可接受的方案。
- (2) 考慮整治活動對附近居民影響，整治過程之設備建置、運作可能對鄰近居民造成噪音、光害、震動、異味等不良日常生活干擾，整治業者應檢視整治方案對居民可能造成的影響，並進行改善措施。
- (3) 文化資產，在整治過程中須特別留意場址是否具有化保存價值之建物或自然地景。

表 5.1.2-1 可持續性綠色整治指標

衝擊 種類	正向指標	負向指標
環境	1.資源再利用率 2.淨土產出 3.能源效率 4.綠色能源使用量 5.廢棄資源回收率 6.土地肥力 7.綠化量 8 自然資源 9 綠色採購比率 10 生物多樣性 11 綠色材料使用量	1.碳足跡 2.溫室氣體 3.懸浮微粒 4.資源消耗 5.土壤污染 6.生態風險評估 7.土壤流失率 8. 石化燃料使用 9.廢棄物產量 10.毒性物質 11.噪音 12.交通 13.振動 14.惡臭
經濟	1.土地利用 2.活化價值 3.成本效益 4.工作機會 5.淨土售價 6.新興產業	1.整治成本 2.營運成本 3.調查成本 4.評估成本 5.偶發成本 6.監測成本 7.醫療成本 8.拆除成本

社會	1..人體健康 2 公共健康 3.社會支持度 3.工作機會 4 活化價值 5.醫療服務 6.地域性材料使用量 7.都市發展 8 生活品質 9.生活機能	1.居民意見 2.日常生活干擾 3.時間 4.健康風險評估 5.文化資產

5.1.3 可持續性綠色整治定量計算方法

為發展可持續性綠色整治控管策略，經濟決策過程中除考慮成本、時間與效能外，更應考慮環境體系之影響，包括全程所需之能源供應種類、質量需求、對空氣、水體、土壤、底泥等自然環境之衝擊、與社會人文之平衡，任何的整治活動均會造成環境體系的變遷，是必須具備的認知條件。

如圖 5.1.3-1 為可持續性綠色整治指標評估方法流程圖，首先界定 GSR 之目標與範疇，接著依技術、成本可行性篩選後，篩選多個整治方案。利用可持續性綠色整治指標，評估各指標之衝擊或效益，最後計算出各整治方案在各個評估指標之永續性得分。

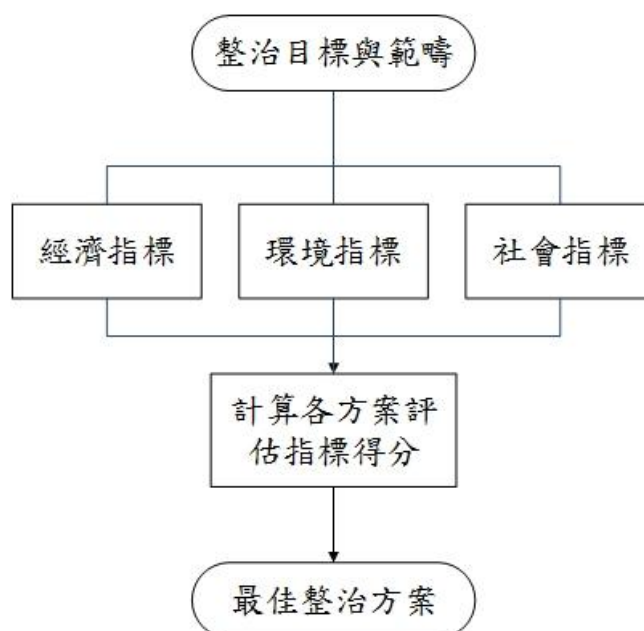


圖 5.1.3-1 可持續性綠色整治指標評估方法流程圖

由於各指標對於整治案場之影響方向不同，有些指標之數值愈大代表該狀態之發展有利於整治案場的發展（稱其為正向指標），以經濟指標為例，如：土地利用、活化價值、成本效益等。反之，有些指標之數值愈小顯示該狀態愈有利於整治案場的發展（稱其為負向指標），如：整治成本、營運成本、調查成本、評估成本、空氣污染的數量等。茲將指數計算方式如公式下：

環境指標公式(1)

正向指標 = f (資源再利用率*淨土產出*能源效率*綠色能源*回收率*土地肥力*綠化量*自然資源*綠色採購比率*生物多樣性*地域性材料*綠色材料使用量)

負向指標 = f (碳足跡*溫室氣體*懸浮微粒資源消耗*石化燃料使用*生態風險評估*土壤流失率*土壤污染*廢棄物產量*毒性物質噪音*交通*振動*惡臭)

環境指標 = f (正項指標+負項指標)

$$0 \leq \text{環境指標} \leq 100$$

經濟指標公式(2)

正向指標 = f (土地利用*活化價值*成本效益*工作機會*淨土售價*新興產業)

負向指標 = f (整治成本*營運成本*調查成本*評估成本*偶發成本*監測成本*醫療成本*拆除成本)

經濟指標 = f (正項指標+負項指標)

$$0 \leq \text{經濟指標} \leq 100$$

社會指標公式(3)

正向指標 = f (人體健康*公共健康*社會支持度*工作機會*活化價值*醫療服務民間參與*地域性材料使用量*都市發展*生活品質*生活機能)

負向指標 = f (居民意見*日常生活干擾*時間*健康風險評估*文化資產)

社群指標 f (正項指標+負項指標)

$$0 \leq \text{社會指標} \leq 100$$

本研究以雷達圖來綜合呈現各項目中所定代表性指標之變化情形，如圖 5.1.3-2 所示，指標以雷達圖呈現具有下列兩項優點，其一因雷達圖之核心顯示為可持續發展整治安場，而往外擴散則顯示該發展方向不利於整治安場的發展，可清楚看出各指標項目之方向性。

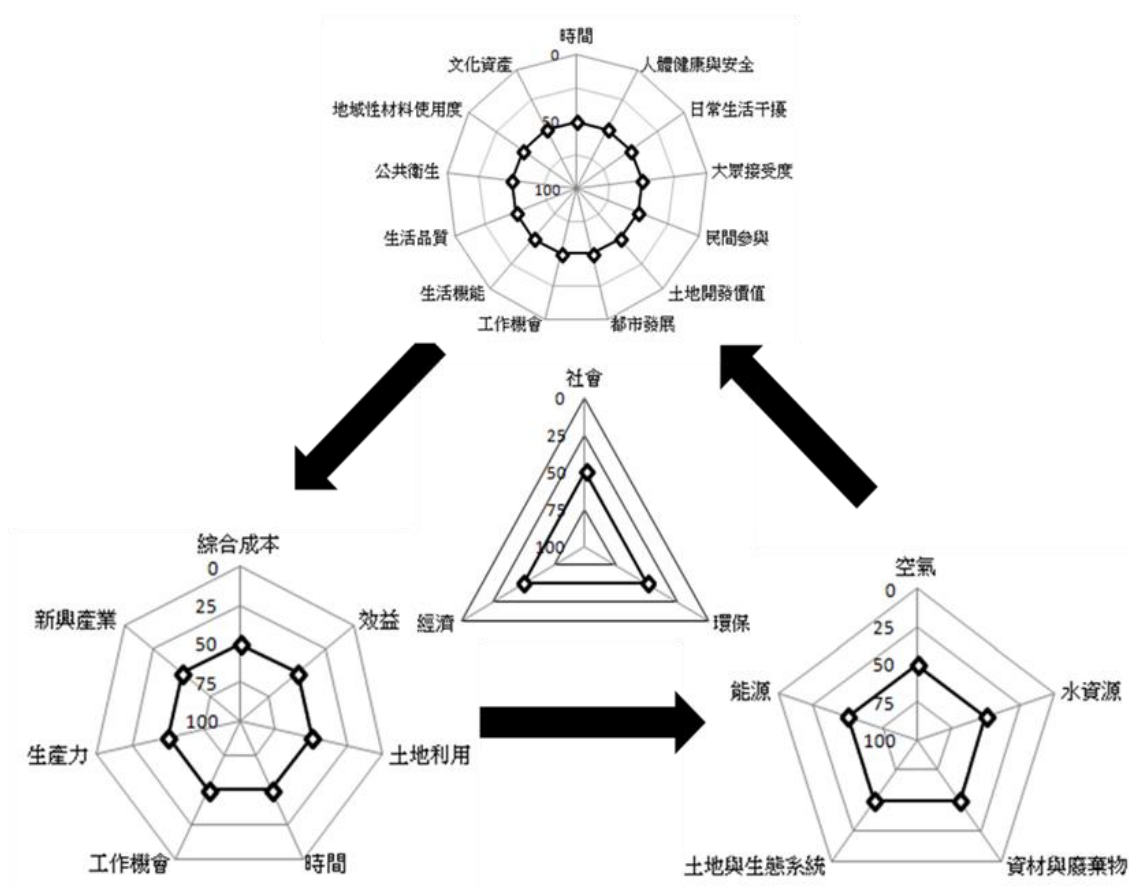


圖 5.1.3-2 可持續性綠色整治雷達圖

5.1.4 研究案場油污染土壤整治

本計畫將受油污染之案場導入評估軟體，下列共分為能源、空氣、水資源、原料耗材與廢棄物、土地與生態系等五大範疇要素之結果。

1. 能源

Core Element		Unit of Measure						
			Excavation	H2O2	Total	Excavation	Bioremediation	Total
Energy	Total energy used (on-site and off-Site)	MMBtu	59.810	1,864.781	1,924.590	59.810	126.812	186.621
	Energy voluntarily derived from renewable resources							
	On-site renewable energy generation or use + on-site biodiesel use + biodiesel and other renewable resource use for transportation	MMBtu	0.000	0.000	0.000	0.000	0.000	0.000
	Voluntary purchase of renewable electricity	MWh	0.000	0.000	0.000	0.000	0.000	0.000
	Voluntary purchase of RECs	MWh	0.000	0.000	0.000	0.000	0.000	0.000
	On-site grid electricity use	MWh	0.000	0.000	0.000	0.000	0.716	0.716

2. 空氣

Core Element		Unit of Measure						
			Excavation	H2O2	Total	Excavation	Bioremediation	Total
Air	On-site NOx, SOx, and PM emissions	Pounds	62.222	413.028	475.250	62.222	132.133	194.356
	On-site HAP emissions	Pounds	0.002	0.012	0.014	0.002	0.004	0.006
	Total NOx, SOx, and PM emissions	Pounds	85.363	1,471.484	1,556.847	85.363	158.120	243.483
	Total NOx emissions	Pounds	66.649	708.457	775.106	66.649	133.826	200.475
	Total SOx emissions	Pounds	9.405	692.801	702.206	9.405	21.373	30.778
	Total PM emissions	Pounds	9.309	70.226	79.535	9.309	2.921	12.230
	Total HAP emissions	Pounds	0.051	1.890	1.942	0.051	0.297	0.348
	Total greenhouse gas emissions	Tons CO2e*	5.667	112.747	118.414	5.667	9.973	15.640

3. 水資源

Core Element		Unit of Measure						
			Excavation	H2O2	Total	Excavation	Bioremediation	Total
Water (used on-site)	Public water use	MG	0.500	0.036	0.536	0.500	0.005	0.505
	Groundwater use	MG	0.000	0.000	0.000	0.000	0.000	0.000
	Surface water use	MG	0.000	0.000	0.000	0.000	0.000	0.000
	Reclaimed water use	MG	0.000	0.000	0.000	0.000	0.000	0.000
	Storm water use	MG	0.000	0.000	0.000	0.000	0.000	0.000
	Other water resource #1	MG	0.000	0.000	0.000	0.000	0.000	0.000
	Other water resource #2	MG	0.000	0.000	0.000	0.000	0.000	0.000

4. 原料與廢棄物

Core Element		Unit of Measure						
			Excavation	H2O2	Total	Excavation	Bioremediation	Total
Materials & Waste	Refined materials used on-site	Tons	0.000	0.000	0.000	0.000	0.000	0.000
	% of refined materials from recycled or reused material	%						
	Unrefined materials used on-site	Tons	0.000	50.000	50.000	0.000	50.000	50.000
	% of unrefined materials from recycled or reused material	%		0.000	0.000		100%	100%
	On-site hazardous waste disposed of off-site	Tons	0.000	0.000	0.000	0.000	0.000	0.000
	On-site non-hazardous waste disposed of off-site	Tons	0.000	50.000	50.000	0.000	80.000	80.000
	% of total potential waste recycled or reused	%		25%	25%		100%	100%

5. 土地與生態

(1) 土壤肥力指標

污染土地整治後之土壤可能因整治造成破壞土壤構造、降低土壤團粒穩定度、微生物活性降低、有機質減少與微量元素含量偏低等現象，因此土壤污染整治完成後必須正視其土壤肥力，俾利後續農地種植作物之需求。土壤基本性質分析包含土壤特性與肥力分析，其項目包括：pH 值、EC 值、灰分、碳、氮、磷、種子發芽率、保水力、有機質等。從碳、氮、磷的比值中可發現廚餘堆肥化整治後之土壤有較佳的數據呈現，且在玉米種植發芽率試驗為 95%。

另可從土壤生物觀察土壤狀況，一般來說，土壤中除了有微生物存活外，還有各種動物在其中活動，這些小動物生於斯、長於斯，因此它們的活動相對地也就會影響到土壤的性質。例如蚯蚓就是最常見的一種，當有較多蚯蚓生存的土壤，代表土壤的物理、化學、生物性都適宜動植物生長，所以土壤活性相對較高。圖 5.1.4-1 整治後土壤可以很明顯看出，土壤中有蚯蚓的存在，研判為廚餘堆肥後之土壤載 pH、有機質較有利蚯蚓生存。

表 5.1.4-1 土壤肥力

項目	一般化學整治技術	廚餘堆肥化整治技術	理想土壤肥力	參考文獻
pH值	8.7	7.6	5.5~7.5	農委會台中區農業改良場
EC值	0.2	0.8	0.5~1.2 mS/m	農委會台中區農業改良場
灰分(%)	90	79	-	-
碳氮比	19	17	20以下	雜項堆肥標準
種子發芽率	70	95	80%以上	雜項堆肥標準



化學整治後土壤

廚餘堆肥化法整治後土壤

圖 5.1.4-1 整治後土壤狀

(2)成長狀況

玉米種植成長狀況由圖 5.1.4-2 中趨勢得知，玉米種於廚餘堆肥化之土壤成長至第 3 週平均為 36 公分；試驗直至第 9 週廚餘堆肥化土壤之玉米生長高度平均 191 公分，藉由此成長狀況之量測可看出廚餘堆肥化之土壤不但有助於玉米生長，亦證明透過友善技術處理油污染土壤較不影響土壤肥力。植物生長情形與根系健康息息相關，因此從根系生長圖 5.1.4-3 所示，可看出種植於廚餘堆肥化整治土壤中之根系茂盛。

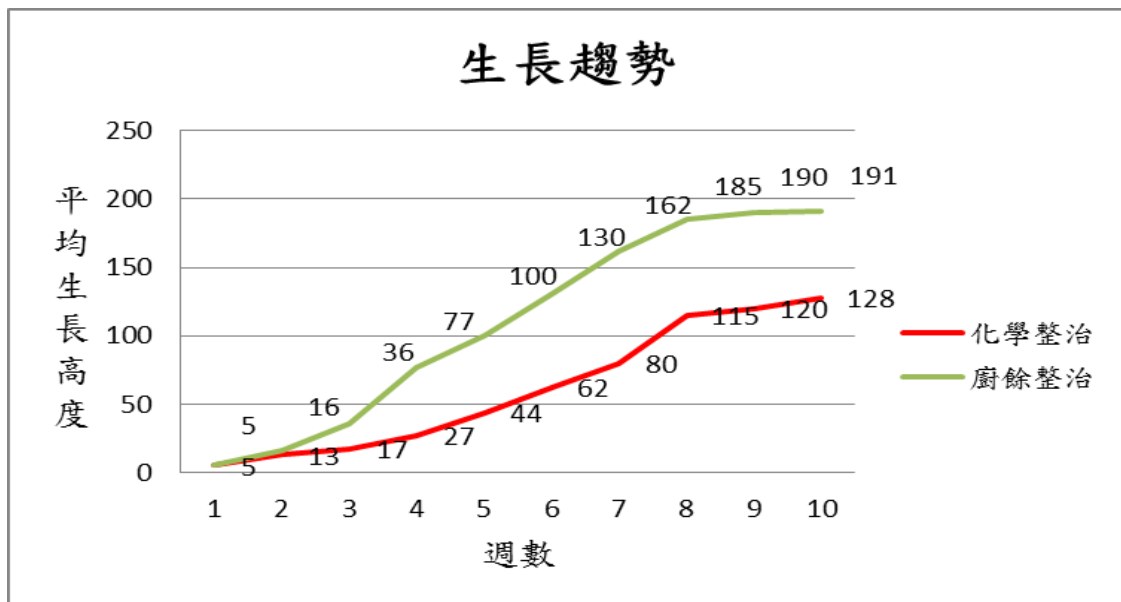


圖 5.1.4-2 玉米生長趨勢圖



圖 5.1.4-3 根系生長

(3)收成狀況

玉米成熟後採收 30 穗成熟玉米帶回實驗室進行長度、寬度、重量測量，由圖 5.1.4-4 可看出於廚餘堆肥化整治區採收之玉米未進行處理所測之平均長度（23.4 公分）、寬度（5.4 公分）、重量（222.7 公克）。由表 5.1.4-2 亦可看出經處理後之玉米內部再平均長度、寬度、重量仍是如此情況，此結果證明利用廚餘堆肥化整治土壤種植蔬果可提升其收穫產能。

表 5.1.4-2 收成狀況

	一般化學整治 (H_2O_2)		廚餘堆肥化整治	
				
測量數 (穗)	30		30	
平均長度 (公分)	20.1	12.6	23.4	16.0
平均寬度 (公分)	4.4	3.9	5.4	4.9
平均重量 (公克)	114.4	92.6	222.7	189.5

圖 5.1.4-4 生長高度



(4) 蔬果成品品質狀況

為了確認玉米成果品質是否有因使用淨化後之油污染土壤的種植產生有毒物質的殘留，因此；將玉米送至認證實驗室 SGS 進行蔬果檢測。

檢測重金屬 (Heavy Metal) (Cu、Zn、As、Cd、Pb、Ni、Cr、Hg) 及農藥殘留 202 項 (pesticide residue 202 items)，其中包含有機氯農藥、有機磷農藥、LC 87 項農藥定量分析。蔬果合格標準則參照農業署食品法 (食字第 1001301183 號令) 之規定。分析結果 (如附錄一所示) 雖有部分微量元素，但微量的重金屬元素是有助植物生長。依據我國食品法有機蔬果規範玉米屬蔬果植物類重金屬限量標準鎘：0.05 ppm 以下，鉛：0.1 ppm 以下，檢測後玉米中之鎘、鉛含量皆為 ND，完全符合我國食品法規之標準。另一檢測之農藥殘留 202 項化合物皆呈現出均未檢出之結果 (如附錄二所示)，因此：經由數據佐證可確性廚餘堆肥處理後之土壤用於蔬果種植，並不會使蔬果有重金屬累積之影響，甚至有助於蔬果生長、提升蔬果產值。

5.1.5 案場結果之建議與對策

本研究案場導入評估軟體後，如表 5.1.5-1 為得知化學整治及生物整治之環境足跡，並加以討論整治方法之建議。

表 5.1.5-1 案場結果比較及對策建議

五大核心要素	化學整治	生物整治	對策建議
能源	高耗能	低耗能	本案例所使用之化學整治工期比生物整治較長，在人、機、材使用上時間相對也較長，故能源耗用部分甚高。
空氣	較高污染/ 二次污染	較低污染/ 二次污染	機具類型及人員進出案場會隨整治時間長短而有所影響。例如：化學整治使用之挖土機為(175HP)，而生物整治使用山貓(75HP)，且在挖土機使用時間較長，所產生的空氣污染相對較高；另外，因人員進出所搭乘之交通工具也列入計算，若整治時間長，人員進出案場之頻率相對較高，故會影

			響空氣之足跡。
水資源	耗水量多	耗水量少	因廚餘本身具有滲出水，本案例將滲出水再利用；而化學整治所使用之過氧化氫需大量稀釋，相對於生物整治所需之水資源較多。
原物料	有	無	生物整治所使用之廚餘為廢棄物，而在化學整治所使用之藥劑為過氧化氫，故在原物料部分化學整治有原物料產生。
廢棄物	廢棄物回收達 25%	廢棄物回收達 100%	廚餘本身為廢棄物，在生物整治將廚餘 100%回收再利用，對於環境也較為友善；另外在化學整治部分，所使用過氧化氫需製造及調配，故廢棄物回收率較低。
土地及生態	差	佳	整治後達標之土壤回填案場，化學整治使土壤面臨貧瘠問題，且過氧化氫會破壞原本土壤性質及肥力，不利於土地及生態之發展；餘堆肥化整治使土壤肥力提升，在過程中能看到生物指標-蚯蚓，且種植蔬果之生長趨勢及收成比化學整治佳。

5.2 結論與建議

5.2.1 結論

國內土壤與地下水環境污染的管理隨民國 89 年『土壤與地下水污染整治法』的公佈施行邁入新的一頁。歷經十年以上的施行時間，透過多元的調查工作，對於國內的污染場址已有相當程度的掌握，然面對數量龐大的控制場址與整治場址，除了持續作積極的管理與污染改善之外，亦需考量如何提供污染場址合宜的出口。

美國永續整治論壇(SURF)2013 年之工作即為發展一套可持續性綠色整治評鑑架構，我國應持續追蹤國際最新發展之趨勢，建議可持續性綠色整治初期宜先推動可持續性綠色整治執行架構、最佳管理措施為優

先，並以示範場址試用定性與定量評估方法，累積不同類型場址之經驗。並經由本研究發展之公證評鑑階段藉由公證第三單位，再次覆核擬訂之整治策略是否符合永續發展宗旨，同時藉由經濟及社群誘因，配合公部門輔導改善，提出永續發展之具體對策。建立獎勵評選機制，透過舉辦綠色整治成果展提升企業形象，並協助輔導績效差之企業。

因應國土污染整治復育，可持續性綠色整治是目前的潮流與趨勢，是一個正確發展之趨勢所在。本研究提出一套可持續性綠色整治之系統化架構流程，促使綠色整治策略朝向定量模式發展。以可持續性綠色整治為基礎架構，草擬出可持續性綠色指標，來因應污染案場之活化，在兼顧環境、經濟、社會互惠之下發展所需考量之各項因素，並區分各項因素之正向指標及負向指標。在推動土地活化之方案時，需盡其考量相關因素，降低其負向指標並提高整體效益。

目前，國際間正開發環境足跡分析工具，且無統一之評估工具，因此由於各工具評估範疇與邊界不同，不同工具間評估結果並不適合互相比較，而本研究分析美國環保署提出之環境足跡分析試算表(Spreadsheets for Environmental Footprint Analysis, SEFA)，其評估工具是用以計算整治過程之環境足跡等相關參數，以及定性描述土地及生態系統。使用 SEFA 評估工具導入可持續性綠色指標，協助我國綠色整治策略朝向定量模式發展。

5.2.2 建議

1. 有許多參數國內尚無相關法規制度，以至於在整治案場中有許多參數未定量，使得評估案場時無法順利進行，建議將能源、空氣污染、溫室氣體、水污染、原料耗材與廢棄物、土地與生態系等環境申報機制(如圖 5.2.2-1)，若納入整治計畫／控制計畫，並予審查、稽核追蹤與要求落實，不僅可促使國內案場落實可持續性綠色整治，亦可活絡甚至衍生其他相關綠色經濟，有助整治場址能耗與環境足跡之本土化評估系統實務應用。
2. 促進國內既有污染案場之整治意願及流暢度，加速及落實污染土地再開發之進度及提供更符合經濟與社群需求之綠色及可持續性整治評鑑系統與技術工具，且識別各種利害關係人，並促進合意共識形

成。

3. 國內環保署正在研擬各類行政管理措施、獎勵方案、標章規範等措施，以鼓勵利害關係人採行可持續性綠色整治，但在政府及環保署尚未訂定明確獎勵機制前，應從現有研發獎助計畫找出可供各類利害關係人具體獎勵誘因。
4. 可持續性綠色整治推動初期，除了觀念的建立與推廣之外，更重要的是儘速提出示範場址，冀能將污染場址可持續性整治其影響環境足跡之評估系統導入國營或民營之企業，使評估系統能本土化、案場化及實用化。

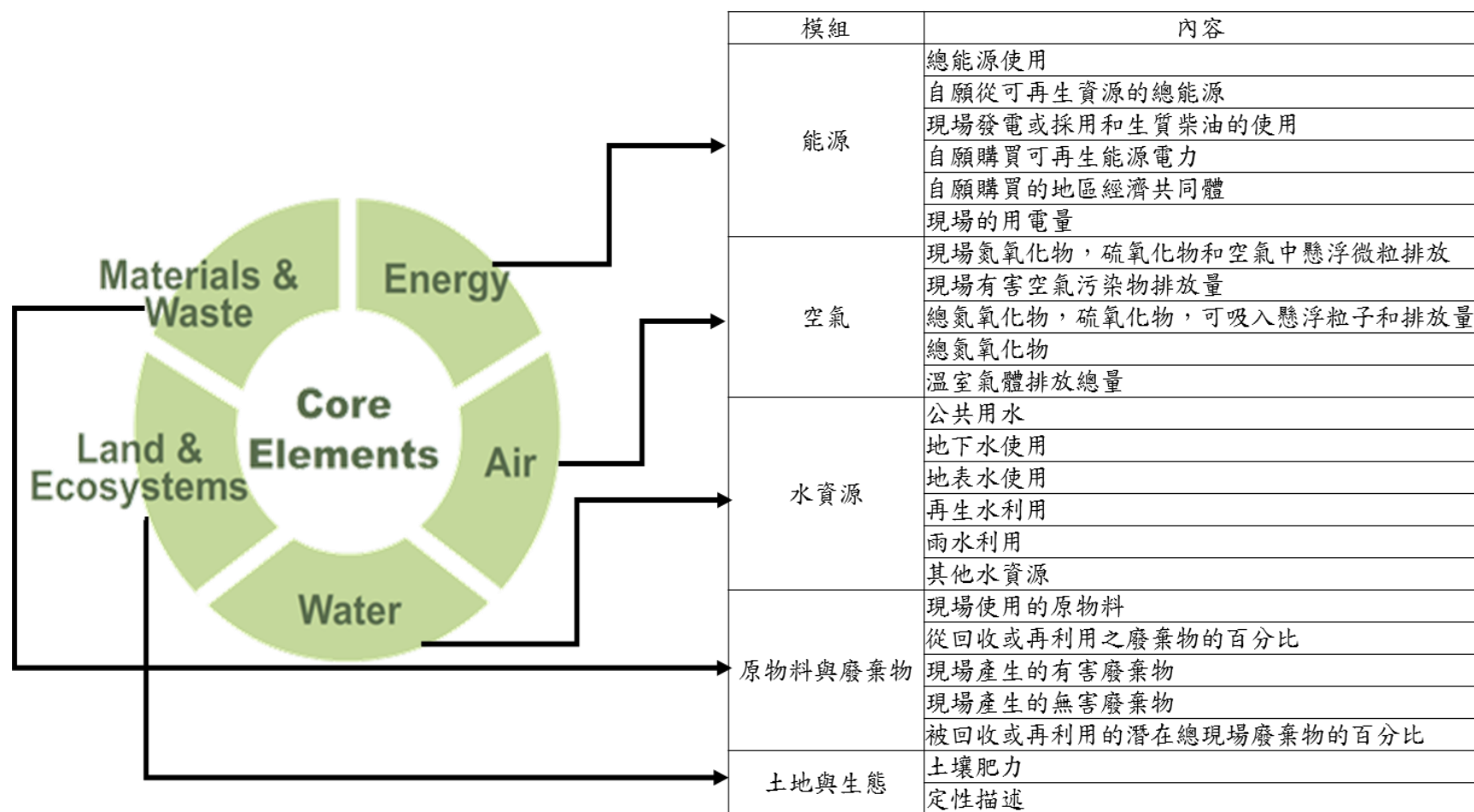


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台灣電力公司 <http://www.taipower.com.tw/>

七、 附件

附件一、廚餘堆肥化整治區收成玉米 SGS 重金屬檢測



試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 1 of 1

報告編號 : VA/2011/C0741A-01

日期 : 2011年12月27日



國立高雄海洋科技大學林啓燦老師實驗室

高雄市楠梓區海事路142號林啓燦老師實驗室

以下測試之樣品係由供應廠商所提供及確認:

產品名稱: 玉米
申請廠商: 國立高雄海洋科技大學林啓燦老師實驗室
送樣日期: 2011年12月16日
測試日期: 2011年12月19日
測試結果:

測試項目	CAS NO.	測試方法	測試結果	檢測極限	單位
銅 (Cu)	007440-50-8	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	0.901	0.010	ppm(mg/kg)
砷 (As)	007440-38-2	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
鉛 (Pb)	007439-92-1	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
鎘 (Cd)	007440-43-9	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
汞 (Hg)	007439-97-6	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
鋅 (Zn)	007440-66-6	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	4.18	0.010	ppm(mg/kg)
鉻 (Cr)	007440-47-3	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	0.0227	0.010	ppm(mg/kg)
鎳 (Ni)	007440-02-0	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	0.0143	0.010	ppm(mg/kg)

備註: 1. 本報告不得分離, 分離使用無效。

2. 低於方法偵測極限之測定值以 "N.D." 表示。

- END -

Jerome Huang, M.R./Supervisor
Signed for and on behalf of
SGS TAIWAN Ltd.

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TWA 6790794

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附件二、廚餘堆肥化整治區收成玉米 SGS 農藥殘留 202 項檢測



試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 1 of 4

國立高雄海洋科技大學林啓燦老師實驗室
高雄市楠梓區海事路142號林啓燦老師實驗室

報告編號 : VA/2011/C0741

報告日期 : 2011年12月23日



以下測試之樣品係由供應廠商所提供及確認:

產品名稱: 玉米
申請廠商: 國立高雄海洋科技大學林啓燦老師實驗室
送樣日期: 2011年12月16日
測試日期: 2011年12月17日

委託測試項目: 有機氯農藥、有機磷農藥及 LC 87項農藥定量分析

測試方法: 本測試參考中華民國國家標準 CNS 13570-2 方法—食品中殘留農藥檢驗方法: 多重殘留分析方法 (II)(88/08/04 公告); 衛生署公告食品中殘留農藥—多重殘留分析方法(三)(公告字號: 署授食字第 0991904819 號公告)及衛生署公告食品中殘留農藥—多重殘留分析方法(四)(公告字號: 署授食字第 0991900925 號公告)。以氣相層析串聯離子阱質譜儀(GC/MS/MS)及液相層析串聯質譜儀(LC/MS/MS)檢測。

測試結果: 此份樣品共檢測202項農藥(詳附錄), 均未檢出。

備註: 1. 本報告不得分離, 分離使用無效。

2. 檢測結果若大於方法偵測極限則匯整上表中, 本次檢測項目及方法偵測極限分別詳列於附錄中。

- END -


Jerome Huang, M.R./Supervisor
Signed for and on behalf of
SGS TAIWAN Ltd.

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TWA 6790790



試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 2 of 4

附 錄

報告編號 : VA/2011/C0741

報告日期 : 2011年12月23日



測試項目及MDL匯整表 : 單位:ppm(mg/kg)

序號	測試項目		CAS NO.	方法偵測極限	序號	測試項目		CAS NO.	方法偵測極限
1.	2,4-地	2,4-D	94-75-7	0.02	41.	克凡派	Chlorfenapyr	122453-73-0	0.01
2.	3-keto加保扶代謝物	3-keto Carbofuran	16709-30-1	0.01	42.	克福隆	Chlorfluazuron	71422-67-8	0.03
3.	3-OH加保扶代謝物	3-OH carbofuran	16655-82-6	0.01	43.	克氯瑞	Chloropropylate	5836-10-2	0.05
4.	毆殺松	Acephate	30560-19-1	0.05	44.	四氯異苯晴	Chlorothalonil	1897-45-6	0.01
5.	亞滅培	Acetamidrid	135410-20-7	0.01	45.	陶斯松	Chlorpyrifos	2921-88-2	0.01
6.	拉草	Alachlor	15972-60-8	0.01	46.	甲基陶斯松	Chlorpyrifos-methyl	5598-13-0	0.03
7.	得滅克	Aldicarb	116-06-3	0.01	47.	克氯得	Chlozolate	84332-86-5	0.01
8.	得滅克代謝物II	Aldicarb sulfone	1646-88-4	0.01	48.	可尼丁	Clothianidin	210880-92-5	0.01
9.	得滅克代謝物I	Aldicarb sulfoxide	1646-87-3	0.01	49.	施力松	Cyanofenphos	13067-93-1	0.02
10.	阿特靈	Aldrin	309-00-2	0.01	50.	賽座滅	Cyazofamid	120116-88-3	0.01
11.	亞烈寧	Allethrin	584-79-2	0.01	51.	賽扶寧	Cyfluthrin	68359-37-5	0.05
12.	亞滅寧	alpha-Cypermethrin	67375-30-8	0.05	52.	賽洛寧	Cyhalothrin	91465-08-6	0.01
13.	谷速松	Azinphos-methyl	86-50-0	0.05	53.	賽滅寧	Cypermethrin	52315-07-8	0.05
14.	亞托敏	Azoxystrobin	131860-33-8	0.01	54.	環克座	Cyproconazole	94361-06-5	0.01
15.	免敵克	Bendiocarb	22781-23-3	0.01	55.	4,4-DDE	p,p'-DDE	72-55-9	0.01
16.	倍尼芬	Benfluralin	1861-40-1	0.01	56.	4,4-DDT	p,p'-DDT	50-29-3	0.01
17.	免扶克	Benfuracarb	82560-54-1	0.01	57.	第滅寧	Deltamethrin	52918-63-5	0.01
18.	本達隆	Bentazone	25057-89-0	0.01	58.	滅賜松	Demeton-S-methyl	919-86-8	0.03
19.	a-蟲必死	α-BHC	319-84-6	0.01	59.	大利松	Diazinon	333-41-5	0.02
20.	b-蟲必死	β-BHC	319-85-7	0.01	60.	益發靈	Dichlofluanid	1085-98-9	0.01
21.	必芬諾	Bifenox	42576-02-3	0.01	61.	二氯松	Dichlorvos	62-73-7	0.01
22.	畢芬寧	Bifenthrin	82657-04-3	0.03	62.	大克爛	Dicloran	99-30-9	0.01
23.	比多農	Bitertanol	55179-31-2	0.05	63.	大克瑞	Dicofol	115-32-2	0.02
24.	乙基溴磷松	Bromophos-ethyl	4824-78-6	0.03	64.	雙特松	Dicrotophos	141-66-2	0.01
25.	甲基溴磷松	Bromophos-methyl	2104-96-3	0.03	65.	地特靈	Dieldrin	60-57-1	0.01
26.	新殺瑞	Bromopropylate	18181-80-1	0.02	66.	待克利	Difenoconazole	119446-68-3	0.05
27.	布瑞莫	Bupirimate	41483-43-6	0.03	67.	二福隆	Diflubenzuron	35367-38-5	0.01
28.	丁基拉草	Butachlor	23184-66-9	0.01	68.	大滅松	Dimethoate	60-51-5	0.01
29.	佈嘉信	Butocarboxim	34681-10-2	0.01	69.	達滅芬	Dimethomorph	110488-70-5	0.01
30.	比達寧	Butralin	33629-47-9	0.05	70.	達克利	Diniconazole	83657-24-3	0.03
31.	四氯丹	Captafol	2425-06-1	0.05	71.	達乃安	Dinitramine	29091-05-2	0.01
32.	蓋普丹	Captan	133-06-2	0.01	72.	大芬滅	Diphenamid	957-51-7	0.01
33.	加保利	Carbaryl	63-25-2	0.01	73.	二硫松	Disulfoton	298-04-4	0.01
34.	貝芬替	Carbendazim	10605-21-7	0.01	74.	普得松	Ditalimfos	5131-24-8	0.03
35.	加保扶	Carbofuran	1563-66-2	0.01	75.	護粒松	Edifenphos	17109-49-8	0.01
36.	加芬松	Carbophenothion	786-19-6	0.02	76.	安殺番I	Endosulfan (alpha)	959-98-8	0.005
37.	丁基加保扶	Carbosulfan	55285-14-8	0.01	77.	安殺番II	Endosulfan (beta)	33213-65-9	0.005
38.	瑞離丹	Chinomethionat	2439-01-2	0.01	78.	安特靈	Endrin	72-20-8	0.01
39.	α-可氯丹	α-Chlordane	5103-71-9	0.01	79.	一品松	EPN	2104-64-5	0.01
40.	β-可氯丹	β-Chlordane	5103-74-2	0.01	80.	益化利	Esfenvalerate	66230-04-4	0.02

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試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 3 of 4

附 錄

報告編號 : VA/2011/C0741

報告日期 : 2011年12月23日



測試項目及MDL匯整表(續) : 單位:ppm(mg/kg)

序號	測試項目		CAS NO.	方法偵測極限	序號	測試項目		CAS NO.	方法偵測極限
81.	愛殺松	Ethion	563-12-2	0.01	121.	加福松	Isoxathion	18854-01-8	0.02
82.	普伏松	Ethoprophos	13194-48-4	0.01	122.	克收欣	Kresoxim-methyl	143390-89-0	0.01
83.	益多松	Etrimfos	38260-54-7	0.05	123.	靈丹	Lindane	58-89-9	0.01
84.	芬滅松	Fenamiphos	22224-92-6	0.01	124.	祿芬隆	Lufenuron	103055-07-8	0.01
85.	芬瑞莫	Fenarimol	60168-88-9	0.02	125.	馬拉松	Malathion	121-75-5	0.01
86.	芬殺瑞	Fenazaquin	120928-09-8	0.01	126.	滅芬草	Mefenacet	73250-68-7	0.01
87.	撲滅松	Fenitrothion	122-14-5	0.01	127.	美福松	Mephosfolan	950-10-7	0.02
88.	丁基滅必蟲	Fenobucarb	3766-81-2	0.01	128.	滅普寧	Mepronil	55814-41-0	0.01
89.	芬普寧	Fenpropathrin	39515-41-8	0.08	129.	滅克松	Methacrifos	62610-77-9	0.02
90.	芬普瑞	Fenpyroximate	134098-61-6	0.01	130.	達馬松	Methamidophos	10265-92-6	0.02
91.	繁福松	Fensulfothion	115-90-2	0.05	131.	滅大松	Methidathion	950-37-8	0.02
92.	芬殺松	Fenthion	55-38-9	0.02	132.	滅賜克	Methiocarb	2032-65-7	0.01
93.	芬化利	Fenvalerate	51630-58-1	0.03	133.	納乃得	Methomyl	16752-77-5	0.01
94.	芬普尼	Fipronil	120068-37-3	0.001	134.	莫多草	Metolachlor	51218-45-2	0.01
95.	伏速隆	Flazasulfuron	104040-78-0	0.01	135.	治滅蟲	Metolcarb	1129-41-5	0.01
96.	護賽寧	Flucythrinate	70124-77-5	0.05	136.	滅必淨	Metribuzin	21087-64-9	0.05
97.	氟芬隆	Flufenoxuron	101463-69-8	0.01	137.	美文松	Mevinphos	7786-34-7	0.02
98.	護矽得	Flusilazole	85509-19-9	0.01	138.	滅蟻樂	Mirex	002385-85-5	0.01
99.	福多寧	Flutolanil	66332-96-5	0.01	139.	稻得壯	Molinate	2212-67-1	0.01
100.	護汰芬	Flutriafol	76674-21-0	0.01	140.	亞素靈	Monocrotophos	6923-22-4	0.02
101.	福化利	Fluvalinate	102851-06-9	0.05	141.	邁克尼	Myclobutanil	88671-89-0	0.05
102.	大福松	Fonofos	944-22-9	0.02	142.	滅落脫	Napropamide	15299-99-7	0.01
103.	福木松	Formothion	2540-82-1	0.03	143.	尼瑞莫	Nuarimol	63284-71-9	0.05
104.	甲基合氯氟	Gallant	69806-40-2	0.01	144.	歐滅松	Omethoate	1113-02-6	0.05
105.	合芬寧	Halfenprox	111872-58-3	0.05	145.	樂滅草	Oxadiazon	19666-30-9	0.01
106.	飛佈達	Heptachlor	76-44-8	0.01	146.	歐殺滅	Oxamyl	23135-22-0	0.01
107.	環氧飛佈達	Heptachlor epoxide	1024-57-3	0.01	147.	嘉保信	Oxycarboxine	5259-88-1	0.01
108.	飛達松	Heptenophos	23560-59-0	0.01	148.	巴克素	Paclobutrazol	76738-62-0	0.01
109.	菲克利	Hexaconazole	79983-71-4	0.02	149.	巴拉松	Parathion	56-38-2	0.01
110.	六伏隆	Hexaflumuron	86479-06-3	0.05	150.	甲基巴拉松	Parathion-methyl	298-00-0	0.01
111.	合賽多	Hexythiazox	78587-05-0	0.05	151.	平克座	Penconazole	66246-88-6	0.02
112.	易胺座	Imibenconazole	86598-92-7	0.05	152.	寶克隆	Pencycuron	66063-05-6	0.01
113.	益達胺	Imidacloprid	138261-41-3	0.01	153.	施得圃	Pendimethalin	40487-42-1	0.01
114.	因得克	Indoxacarb	144171-61-9	0.01	154.	百滅寧	Permethrin	52645-53-1	0.1
115.	丙基喜樂松	Iprobenfos	26087-47-8	0.03	155.	賽達松	Phenthoate	2597-03-7	0.02
116.	依普同	Iprodione	36734-19-7	0.05	156.	福瑞松	Phorate	298-02-2	0.01
117.	依殺松	Isazofos	42509-80-8	0.01	157.	裕必松	Phosalone	2310-17-0	0.03
118.	亞芬松	Isofenphos	25311-71-1	0.01	158.	益滅松	Phosmet	732-11-6	0.02
119.	滅必蟲	Isoprocarb	2631-40-5	0.01	159.	福賜米松	Phosphamidon	13171-21-6	0.05
120.	亞賜圃	Isoprothiolane	50512-35-1	0.02	160.	比加普	Pirimicarb	23103-98-2	0.01

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TWA 6790792



試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 4 of 4

附 錄

報告編號 : VA/2011/C0741

報告日期 : 2011年12月23日



測試項目及MDL匯整表(續) : 單位:ppm(mg/kg)

序號	測試項目		CAS NO.	方法偵測極限	序號	測試項目		CAS NO.	方法偵測極限
161.	乙基亞特松	Pirimiphos-ethyl	23505-41-1	0.01	182.	殺力松	Salithion	3811-49-2	0.02
162.	甲基亞特松	Pirimiphos-methyl	29232-93-7	0.01	183.	得克利	Tebuconazole	107534-96-3	0.01
163.	普拉草	Pretilachlor	51218-49-6	0.05	184.	得福隆	Teflubenzuron	83121-18-0	0.01
164.	撲克拉	Prochloraz	67747-09-5	0.03	185.	托福松	Terbufos	13071-79-9	0.01
165.	撲滅寧	Procymidone	32809-16-8	0.05	186.	四克利	Tetraconazole	112281-77-3	0.01
166.	佈飛松	Profenofos	41198-08-7	0.02	187.	得脫瑞	Tetradifon	116-29-0	0.02
167.	普滅克	Promecarb	2631-37-0	0.01	188.	治滅寧	Tetramethrin	7696-12-0	0.01
168.	除草靈	Propanil	709-98-8	0.01	189.	腐絕	Thiabendazole	148-79-8	0.01
169.	加護松	Propaphos	7292-16-2	0.01	190.	賽速安	Thiamethoxam	153719-23-4	0.01
170.	普克利	Propiconazole	60207-90-1	0.03	191.	殺丹	Thiobencarb	28249-77-6	0.01
171.	安丹	Propoxur	114-26-1	0.01	192.	硫敵克	Thiodicarb	59669-26-0	0.01
172.	普硫松	Prothiofos	34643-46-4	0.01	193.	三泰芬	Triadimefon	43121-43-3	0.01
173.	白克松	Pyraclufos	77458-01-6	0.03	194.	三泰隆	Triadimenol	55219-65-3	0.05
174.	白粉松	Pyrazophos	13457-18-6	0.05	195.	三落松	Triazophos	24017-47-8	0.02
175.	畢達本	Pyridaben	96489-71-3	0.05	196.	三氯松	Trichlorfon	52-68-6	0.05
176.	必芬松	Pyridaphenthion	119-12-0	0.1	197.	三氟敏	Trifloxystrobin	141517-21-7	0.01
177.	比芬諾	Pyrifenox	88283-41-4	0.03	198.	賽福座	Triflumizole	99387-89-0	0.02
178.	百利普芬	Pyriproxyfen	95737-68-1	0.01	199.	三福林	Trifluralin	1582-09-8	0.01
179.	百快隆	Pyroquilon	57369-32-1	0.01	200.	繁米松	Vamidotion	2275-23-2	0.05
180.	拜裕松	Quinalphos	13593-03-8	0.02	201.	免克寧	Vinclozolin	50471-44-8	0.01
181.	快伏草	Quinalofop-ethyl	76578-14-8	0.01	202.	滅克蟲	XMC	2655-14-3	0.01



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TWA 6790793

附件三、廚餘堆肥化整治區收成蕃茄 SGS 檢測



試驗報告TEST REPORT
食品實驗室-高雄FOOD LAB-KAOHSIUNG

頁數 : 1 of 4

國立高雄海洋科技大學林啓燦老師實驗室
高雄市楠梓區海事路142號林啓燦老師實驗室

報告編號 : VA/2011/C0742

報告日期 : 2011年12月23日



以下測試之樣品係由供應廠商所提供及確認:

產品名稱: 蕃茄
申請廠商: 國立高雄海洋科技大學林啓燦老師實驗室
送樣日期: 2011年12月16日
測試日期: 2011年12月17日

委託測試項目: 有機氯農藥、有機磷農藥及 LC 87項農藥定量分析

測試方法: 本測試參考中華民國國家標準CNS 13570-2方法—食品中殘留農藥檢驗方法: 多重殘留分析方法(II)(88/08/04公告); 衛生署公告食品中殘留農藥—多重殘留分析方法(三)(公告字號: 署授食字第0991904819號公告)及衛生署公告食品中殘留農藥—多重殘留分析方法(四)(公告字號: 署授食字第0991900925號公告)。以氣相層析串聯離子阱質譜儀(GC/MS/MS)及液相層析串聯質譜儀(LC/MS/MS)檢測。

測試結果: 此份樣品共檢測202項農藥(詳附錄), 均未檢出。

備註: 1.本報告不得分離, 分離使用無效。

2.檢測結果若大於方法偵測極限則匯整上表中, 本次檢測項目及方法偵測極限分別詳列於附錄中。

- END -

Jerome Huang
Jerome Huang, M.R./Supervisor
Signed for and on behalf of
SGS TAIWAN Ltd.
TAIWAN

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試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 2 of 4

附 錄

報告編號 : VA/2011/C0742

報告日期 : 2011年12月23日



測試項目及MDL匯整表 :

單位:ppm(mg/kg)

序號	測試項目		CAS NO.	方法偵測極限	序號	測試項目		CAS NO.	方法偵測極限
1.	2,4-地	2,4-D	94-75-7	0.02	41.	克凡派	Chlorfenapyr	122453-73-0	0.01
2.	3-keto加保扶代謝物	3-keto Carbofuran	16709-30-1	0.01	42.	克福隆	Chlorfluazuron	71422-67-8	0.03
3.	3-OH加保扶代謝物	3-OH carbofuran	16655-82-6	0.01	43.	克氯瑞	Chloropropylate	5836-10-2	0.05
4.	毆殺松	Acephate	30560-19-1	0.05	44.	四氯異苯晴	Chlorothalonil	1897-45-6	0.01
5.	亞滅培	Acetamidrid	135410-20-7	0.01	45.	陶斯松	Chlorpyrifos	2921-88-2	0.01
6.	拉草	Alachlor	15972-60-8	0.01	46.	甲基陶斯松	Chlorpyrifos-methyl	5598-13-0	0.03
7.	得滅克	Aldicarb	116-06-3	0.01	47.	克氯得	Chlozolinate	84332-86-5	0.01
8.	得滅克代謝物II	Aldicarb sulfone	1646-88-4	0.01	48.	可尼丁	Clothianidin	210880-92-5	0.01
9.	得滅克代謝物I	Aldicarb sulfoxide	1646-87-3	0.01	49.	施力松	Cyanofenphos	13067-93-1	0.02
10.	阿特靈	Aldrin	309-00-2	0.01	50.	賽座滅	Cyazofamid	120116-88-3	0.01
11.	亞烈寧	Allethrin	584-79-2	0.01	51.	賽扶寧	Cyfluthrin	68359-37-5	0.05
12.	亞滅寧	alpha-Cypermethrin	67375-30-8	0.05	52.	賽洛寧	Cyhalothrin	91465-08-6	0.01
13.	谷速松	Azinphos-methyl	86-50-0	0.05	53.	賽滅寧	Cypermethrin	52315-07-8	0.05
14.	亞托敏	Azoxystrobin	131860-33-8	0.01	54.	環克座	Cyproconazole	94361-06-5	0.01
15.	免敵克	Bendiocarb	22781-23-3	0.01	55.	4,4-DDE	p,p'-DDE	72-55-9	0.01
16.	倍尼芬	Benfluralin	1861-40-1	0.01	56.	4,4-DDT	p,p'-DDT	50-29-3	0.01
17.	免扶克	Benfuracarb	82560-54-1	0.01	57.	第滅寧	Deltamethrin	52918-63-5	0.01
18.	本達隆	Bentazone	25057-89-0	0.01	58.	滅賜松	Demeton-S-methyl	919-86-8	0.03
19.	a-蟲必死	α-BHC	319-84-6	0.01	59.	大利松	Diazinon	333-41-5	0.02
20.	b-蟲必死	β-BHC	319-85-7	0.01	60.	益發靈	Dichlofluanid	1085-98-9	0.01
21.	必芬諾	Bifenox	42576-02-3	0.01	61.	二氯松	Dichlorvos	62-73-7	0.01
22.	畢芬寧	Bifenthrin	82657-04-3	0.03	62.	大克爛	Dicloran	99-30-9	0.01
23.	比多農	Bitertanol	55179-31-2	0.05	63.	大克瑞	Dicofol	115-32-2	0.02
24.	乙基溴磷松	Bromophos-ethyl	4824-78-6	0.03	64.	雙特松	Dicrotophos	141-66-2	0.01
25.	甲基溴磷松	Bromophos-methyl	2104-96-3	0.03	65.	地特靈	Dieldrin	60-57-1	0.01
26.	新殺瑞	Bromopropylate	18181-80-1	0.02	66.	待克利	Difenoconazole	119446-68-3	0.05
27.	布瑞莫	Bupirimate	41483-43-6	0.03	67.	二福隆	Diffubenzuron	35367-38-5	0.01
28.	丁基拉草	Butachlor	23184-66-9	0.01	68.	大滅松	Dimethoate	60-51-5	0.01
29.	佈嘉信	Butocarboxim	34681-10-2	0.01	69.	達滅芬	Dimethomorph	110488-70-5	0.01
30.	比達寧	Butralin	33629-47-9	0.05	70.	達克利	Diniconazole	83657-24-3	0.03
31.	四氯丹	Captafol	2425-06-1	0.05	71.	達乃安	Dinitramine	29091-05-2	0.01
32.	蓋普丹	Captan	133-06-2	0.01	72.	大芬滅	Diphenamid	957-51-7	0.01
33.	加保利	Carbaryl	63-25-2	0.01	73.	二硫松	Disulfoton	298-04-4	0.01
34.	貝芬替	Carbendazim	10605-21-7	0.01	74.	普得松	Ditalimfos	5131-24-8	0.03
35.	加保扶	Carbofuran	1563-66-2	0.01	75.	護粒松	Edifenphos	17109-49-8	0.01
36.	加芬松	Carbophenothion	786-19-6	0.02	76.	安殺番I	Endosulfan (alpha)	959-98-8	0.005
37.	丁基加保扶	Carbosulfan	55285-14-8	0.01	77.	安殺番II	Endosulfan (beta)	33213-65-9	0.005
38.	瑞離丹	Chinomethionat	2439-01-2	0.01	78.	安特靈	Endrin	72-20-8	0.01
39.	α-可氯丹	α-Chlordane	5103-71-9	0.01	79.	一品松	EPN	2104-64-5	0.01
40.	β-可氯丹	β-Chlordane	5103-74-2	0.01	80.	益化利	Esfenvalerate	66230-04-4	0.02

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試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 3 of 4

附 錄

報告編號 : VA/2011/C0742

報告日期 : 2011年12月23日



測試項目及MDL匯整表(續) :

單位:ppm(mg/kg)

序號	測試項目	CAS NO.	方法偵測極限	序號	測試項目	CAS NO.	方法偵測極限
81.	愛殺松 Ethion	563-12-2	0.01	121.	加福松 Isoxathion	18854-01-8	0.02
82.	普伏松 Ethoprophos	13194-48-4	0.01	122.	克收欣 Kresoxim-methyl	143390-89-0	0.01
83.	益多松 Etrimfos	38260-54-7	0.05	123.	靈丹 Lindane	58-89-9	0.01
84.	芬滅松 Fenamiphos	22224-92-6	0.01	124.	祿芬隆 Lufenuron	103055-07-8	0.01
85.	芬瑞莫 Fenarimol	60168-88-9	0.02	125.	馬拉松 Malathion	121-75-5	0.01
86.	芬殺瑞 Fenazaquin	120928-09-8	0.01	126.	滅芬草 Mefenacet	73250-68-7	0.01
87.	撲滅松 Fenitrothion	122-14-5	0.01	127.	美福松 Mephosfolan	950-10-7	0.02
88.	丁基滅必蟲 Fenobucarb	3766-81-2	0.01	128.	滅普寧 Mepronil	55814-41-0	0.01
89.	芬普寧 Fenpropathrin	39515-41-8	0.08	129.	滅克松 Methacrifos	62610-77-9	0.02
90.	芬普瑞 Fenpyroximate	134098-61-6	0.01	130.	達馬松 Methamidophos	10265-92-6	0.02
91.	繁福松 Fensulfothion	115-90-2	0.05	131.	滅大松 Methidathion	950-37-8	0.02
92.	芬殺松 Fenthion	55-38-9	0.02	132.	滅賜克 Methiocarb	2032-65-7	0.01
93.	芬化利 Fenvalerate	51630-58-1	0.03	133.	納乃得 Methomyl	16752-77-5	0.01
94.	芬普尼 Fipronil	120068-37-3	0.001	134.	莫多草 Metolachlor	51218-45-2	0.01
95.	伏速隆 Flazasulfuron	104040-78-0	0.01	135.	治滅蟲 Metolcarb	1129-41-5	0.01
96.	護賽寧 Flucythrinate	70124-77-5	0.05	136.	滅必淨 Metribuzin	21087-64-9	0.05
97.	氟芬隆 Flufenoxuron	101463-69-8	0.01	137.	美文松 Mevinphos	7786-34-7	0.02
98.	護矽得 Flusilazole	85509-19-9	0.01	138.	滅蟻樂 Mirex	002385-85-5	0.01
99.	福多寧 Flutolanil	66332-96-5	0.01	139.	稻得壯 Molinate	2212-67-1	0.01
100.	護汰芬 Flutiafol	76674-21-0	0.01	140.	亞素靈 Monocrotophos	6923-22-4	0.02
101.	福化利 Fluvalinate	102851-06-9	0.05	141.	邁克尼 Myclobutanil	88671-89-0	0.05
102.	大福松 Fonofos	944-22-9	0.02	142.	滅落脫 Napropamide	15299-99-7	0.01
103.	福木松 Formothion	2540-82-1	0.03	143.	尼瑞莫 Nuarimol	63284-71-9	0.05
104.	甲基合氧氟 Gallant	69806-40-2	0.01	144.	歐滅松 Omethoate	1113-02-6	0.05
105.	合芬寧 Halfenprox	111872-58-3	0.05	145.	樂滅草 Oxadiazon	19666-30-9	0.01
106.	飛佈達 Heptachlor	76-44-8	0.01	146.	歐殺滅 Oxamyl	23135-22-0	0.01
107.	環氧飛佈達 Heptachlor epoxide	1024-57-3	0.01	147.	嘉保信 Oxycarboxine	5259-88-1	0.01
108.	飛達松 Heptenophos	23560-59-0	0.01	148.	巴克素 Paclobutrazol	76738-62-0	0.01
109.	菲克利 Hexaconazole	79983-71-4	0.02	149.	巴拉松 Parathion	56-38-2	0.01
110.	六伏隆 Hexaflumuron	86479-06-3	0.05	150.	甲基巴拉松 Parathion-methyl	298-00-0	0.01
111.	合賽多 Hexythiazox	78587-05-0	0.05	151.	平克座 Penconazole	66246-88-6	0.02
112.	易胺座 Imibenconazole	86598-92-7	0.05	152.	賽克隆 Pencycuron	66063-05-6	0.01
113.	益達胺 Imidacloprid	138261-41-3	0.01	153.	施得圃 Pendimethalin	40487-42-1	0.01
114.	因得克 Indoxacarb	144171-61-9	0.01	154.	百滅寧 Permethrin	52645-53-1	0.1
115.	丙基喜樂松 Iprobenfos	26087-47-8	0.03	155.	賽達松 Phenthoate	2597-03-7	0.02
116.	依普同 Iprodione	36734-19-7	0.05	156.	福瑞松 Phorate	298-02-2	0.01
117.	依殺松 Isazofos	42509-80-8	0.01	157.	裕必松 Phosalone	2310-17-0	0.03
118.	亞芬松 Isafenphos	25311-71-1	0.01	158.	益滅松 Phosmet	732-11-6	0.02
119.	滅必蟲 Isoprocarb	2631-40-5	0.01	159.	福賜米松 Phosphamidon	13171-21-6	0.05
120.	亞賜圃 Isoprothiolane	50512-35-1	0.02	160.	比加普 Pirimicarb	23103-98-2	0.01

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試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 4 of 4

附 錄

報告編號 : VA/2011/C0742

報告日期 : 2011年12月23日



測試項目及MDL匯整表(續) :

單位:ppm(mg/kg)

序號	測試項目		CAS NO.	方法偵測極限	序號	測試項目		CAS NO.	方法偵測極限
161.	乙基亞特松	Pirimiphos-ethyl	23505-41-1	0.01	182.	殺力松	Salithion	3811-49-2	0.02
162.	甲基亞特松	Pirimiphos-methyl	29232-93-7	0.01	183.	得克利	Tebuconazole	107534-96-3	0.01
163.	普拉草	Pretilachlor	51218-49-6	0.05	184.	得福隆	Teflubenzuron	83121-18-0	0.01
164.	撲克拉	Prochloraz	67747-09-5	0.03	185.	托福松	Terbufos	13071-79-9	0.01
165.	撲滅寧	Procymidone	32809-16-8	0.05	186.	四克利	Tetraconazole	112281-77-3	0.01
166.	佈飛松	Profenofos	41198-08-7	0.02	187.	得脫瑞	Tetradifon	116-29-0	0.02
167.	普滅克	Promecarb	2631-37-0	0.01	188.	治滅寧	Tetramethrin	7696-12-0	0.01
168.	除草靈	Propanil	709-98-8	0.01	189.	腐絕	Thiabendazole	148-79-8	0.01
169.	加護松	Propaphos	7292-16-2	0.01	190.	賽速安	Thiamethoxam	153719-23-4	0.01
170.	普克利	Propiconazole	60207-90-1	0.03	191.	殺丹	Thiobencarb	28249-77-6	0.01
171.	安丹	Propoxur	114-26-1	0.01	192.	硫敵克	Thiodicarb	59669-26-0	0.01
172.	普硫松	Prothiofos	34643-46-4	0.01	193.	三泰芬	Triadimefon	43121-43-3	0.01
173.	白克松	Pyraclofos	77458-01-6	0.03	194.	三泰隆	Triadimenol	55219-65-3	0.05
174.	白粉松	Pyrazophos	13457-18-6	0.05	195.	三落松	Triazophos	24017-47-8	0.02
175.	畢達本	Pyridaben	96489-71-3	0.05	196.	三氯松	Trichlorfon	52-68-6	0.05
176.	必芬松	Pyridaphenthion	119-12-0	0.1	197.	三氟敏	Trifloxystrobin	141517-21-7	0.01
177.	比芬諾	Pyrifeno	88283-41-4	0.03	198.	賽福座	Triflumizole	99387-89-0	0.02
178.	百利普芬	Pyriproxyfen	95737-68-1	0.01	199.	三福林	Trifluralin	1582-09-8	0.01
179.	百快隆	Pyroquilon	57369-32-1	0.01	200.	繁米松	Vamidothion	2275-23-2	0.05
180.	拜裕松	Quinalphos	13593-03-8	0.02	201.	免克寧	Vinclozolin	50471-44-8	0.01
181.	快伏草	Quizalofop-ethyl	76578-14-8	0.01	202.	滅克蟲	XMC	2655-14-3	0.01



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試驗報告 TEST REPORT
食品實驗室-高雄 FOOD LAB-KAOHSIUNG

頁數 : 1 of 1

報告編號 : VA/2011/C0742A-01

日期 : 2011年12月27日



國立高雄海洋科技大學林啓燦老師實驗室

高雄市楠梓區海事路142號林啓燦老師實驗室

以下測試之樣品係由供應廠商所提供及確認:

產品名稱: 蕃茄
申請廠商: 國立高雄海洋科技大學林啓燦老師實驗室
送樣日期: 2011年12月16日
測試日期: 2011年12月19日
測試結果:

測試項目	CAS NO.	測試方法	測試結果	檢測極限	單位
銅 (Cu)	007440-50-8	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	0.998	0.010	ppm(mg/kg)
砷 (As)	007440-38-2	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
鉛 (Pb)	007439-92-1	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
鎘 (Cd)	007440-43-9	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
汞 (Hg)	007439-97-6	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	N.D.	0.010	ppm(mg/kg)
鋅 (Zn)	007440-66-6	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	2.35	0.010	ppm(mg/kg)
鉻 (Cr)	007440-47-3	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	0.0174	0.010	ppm(mg/kg)
鎳 (Ni)	007440-02-0	本測試參考USEPA 3051方法, 以感應耦合電漿質譜儀(ICP/MS) 檢測。	0.0160	0.010	ppm(mg/kg)

備註: 1. 本報告不得分離, 分離使用無效。

2. 低於方法偵測極限之測定值以 "N.D." 表示。

- END -

Jerome Huang, M.R./Supervisor
Signed for and on behalf of
SGS TAIWAN Ltd.

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TWA 6791001

附件四、Spreadsheets for Environmental Footprint Analysis (SEFA)

Greener Cleanups



EPA 542-R-12-002

Methodology for Understanding and Reducing a Project's Environmental Footprint

February 2012

U.S. Environmental Protection Agency

Office of Solid Waste and Emergency Response

Office of Superfund Remediation and Technology Innovation

Sponsored by the Technical Support Project

www.cluin.org/greenremediation/methodology

Acknowledgements

The U.S. Environmental Protection Agency (EPA) *Methodology for Understanding and Reducing a Project's Environmental Footprint* was prepared for the Technical Support Project (TSP) administered by the Office of Superfund Remediation and Technology Innovation (OSRTI). The methodology presented in this document was developed under sponsorship of the Engineering Forum (one of three national TSP forums) to address the need for a uniform EPA methodology that helps regional staff and other members of the cleanup community analyze and take steps toward reducing the environmental footprint of cleanups.

OSRTI and the Engineering Forum gratefully acknowledge key contributions from members of the Agency's Greener Cleanups Methodology Workgroup:

- Carlos Pachon, OSRTI
- Stephanie Vaughn, Region 2
- Dale Carpenter, Region 2
- Deb Goldblum, Region 3
- Hilary Thornton, Region 3
- Brad Bradley, Region 5
- Kendra Morrison, Region 8
- Tim Rehder, Region 8
- Michael Gill, Region 9
- Julie Santiago-Ocasio, Region 9
- Karen Scheuermann, Region 9
- Kira Lynch, Region 10.

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For additional information about EPA's footprint assessment methodology or strategies for conducting greener cleanups, interested parties may contact Carlos Pachon (OSRTI) at: 703-603-9904 or pachon.carlos@epa.gov. Other technical assistance in implementing greener cleanups is available from EPA's Engineering Forum Greener Cleanup Subcommittee, which can be contacted through: <http://www.epa.gov/tio/tsp/engforum/gcs>.

An electronic version of this document can be downloaded at:

<http://clu.in.org/greenremediation/methodology> and <http://www.epa.gov/oswer/greenercleanups>.

Disclaimer

This document presents EPA's methodology to reduce negative environmental effects that might occur during hazardous waste site assessment, site remediation, or non-time critical removal actions and to consequently improve the environmental outcome of cleanup projects. It presents technical information based on EPA's current understanding of the link between cleanup activities and their associated environmental footprint. The document contains information designed to be useful for interested stakeholders including governments, the public, and the regulated community. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. This document was subjected to the Agency's administrative and expert review and was approved for release as an EPA document.

This document provides topical introductory information rather than guidance and does not impose legally binding requirements, nor does it confer legal rights, impose legal obligations, implement any statutory or regulatory provisions, or change or substitute for any statutory or regulatory provisions. EPA recommends that users refer to applicable regulations, policies, and guidance documents regarding selection of cleanup remedies and implementation of cleanup actions; selected references and additional resources are provided herein. The Agency notes that this is a living document that may be revised periodically without public notice. EPA welcomes public comments on this document at any time and will consider those comments in any future revisions of this document.

Abbreviations & Acronyms

AS	air sparging
BSFC	brake-specific fuel capacity
BMP	best management practice
Btu	British thermal unit
ccf	hundred cubic feet
CFC	chlorofluorocarbon
cfm	cubic feet per minute
CO ₂ e	carbon dioxide equivalent of global warming potential
cy	cubic yard
eGRID	Emissions & Generation Resource Integrated Database
EPA	U.S. Environmental Protection Agency
Ft	feet
ft ³	cubic foot
GAC	granular activated carbon
GHG	greenhouse gas
gpm	gallons per minute
GWP	global warming potential
HAP	hazardous air pollutant
HCFC	hydrochlorofluorocarbon
HDPE	high-density polyethylene
HFC	hydrofluorocarbon
HP	horsepower
ISCO	<i>in situ</i> chemical oxidation
kW	kilowatts of electric power
kWh	kilowatt-hours of electricity
lbs	pounds
LCA	life cycle assessment
MMBtu	million British thermal units
mpg	miles per gallon
MWh	megawatt-hour
NP	not provided
NO _x	nitrogen oxides
N/A	not applicable
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OSRTI	Office of Superfund Remediation and Technology Innovation
P&T	pump-and-treat
PLF	partial load factor
PM ₁₀	particulate matter 10 microns in diameter or smaller
pmpg	passenger miles per gallon
psi	pounds per square inch
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
REC	renewable energy certificate
RMPA	Colorado-Eastern Wyoming eGRID Subregion and Geographic Descriptor
scfm	standard cubic feet per minute
SO _x	sulfur oxides
SVE	soil vapor extraction
SVOC	semi-volatile organic compound
TBD	to be determined

Ton	short ton (2,000 pounds)
µg/L	micrograms per liter
VFD	variable frequency drive
VOC	volatile organic compound
WRI	World Resources Institute

Contents

1.0 Introduction	1
1.1	B
ackground.....	1
1.2	P
urpose	2
1.3	L
imitations.....	3
1.4	T
he Value of Footprint Analysis.....	3
1.5	L
evel of Effort and Cost	4
2.0 Green Remediation Metrics	5
2.1	M
aterials and Waste Metrics.....	6
2.1.1 Materials Metrics	6
2.1.2 Onsite Waste Metrics	7
2.1.3 Offsite Waste	8
2.2	W
ater Metrics	8
2.2.1 Onsite Water Metrics	8
2.2.2 Site-Specific Consideration for the Onsite Water Footprint	9
2.2.3 Offsite Water Use	10
	5

2.3	Energy Metrics.....	10
2.4	Air Metrics	11
2.4.1	Onsite Air Metrics	12
2.4.2	Total Air Metrics	12
2.4.3	Further Categorization of Air Metrics	13
3.0	Footprint Methodology.....	15
3.1	Step 1: Set Goals and Scope of Analysis.....	15
3.2	Step 2: Gather Remedy Information	17
3.3	Step 3: Quantify Onsite Materials and Waste Metrics	17
3.3.1	Content of a Materials Footprint Analysis	18
3.3.2	Rules of Thumb and General Assistance for Quantifying Materials Use	19
3.3.3	Content of a Waste Footprint Analysis	19
3.3.4	Items Not Included in the Materials and Waste Footprint Analysis	20
3.4	Step 4: Quantify Onsite Water Metrics	20
3.4.1	Content of Onsite Water Footprint Analysis	20
3.5	Step 5: Quantify Energy and Air Metrics	22
3.5.1	Part 1 - Inventory Remedy Transportation, Equipment Use, Materials and Waste, Public Water Use, and Offsite Services	23
3.5.2	Part 2 – Determine Remedy Energy Use	24

3.5.3	Part 3 – Convert the Remedy Inventory into Energy and Air Metrics	26
3.6	Step 6: Qualitatively Describe Affected Ecosystem Services	28
3.7	Step 7: Present Results	28
4.0	Considerations for Interpreting Footprint Results	29
4.1	Data Quality	29
4.2	Tradeoffs between Metrics	30
4.3	Footprint Magnitude	30
5.0	Approaches to Reducing Footprints	33
5.1	Approaches to Reducing Materials and Waste Footprints	34
5.2	Approaches to Reducing Water Footprints	34
5.3	Approaches to Reducing Energy and Air Footprints	35
6.0	References	38

List of Figures

Figure 1.1 Green Remediation Core Elements	1
Figure 3.1 Overview of Footprint Methodology	15

List of Tables

Table 2.1 Summary of Green Remediation Metrics	5
Table 3.1 Goals of Footprint Quantification	16
Table 3.2 Potential Onsite Use of Materials	18

List of Examples

Example 1 Data Quality – Transportation.....	31
Example 2 Data Quality – Electricity Generation	32
Example 3 Footprint Reductions from Optimization and Application of Renewable Energy.....	37

List of Appendices

Appendix A:Exhibits.....	40

Appendix B: Suggested Formats for Presenting the Footprint

Analysis 73

Appendix C: Footprint Reduction Scenarios 87

1.0 Introduction

1.1 Background

The U.S. Environmental Protection Agency (EPA) defines green remediation as the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprint of cleanup actions. Green remediation strategies can include a detailed analysis in which components of a remedy are closely examined and large contributions to the footprint are identified. More effective steps can then be taken to reduce the footprint while meeting regulatory requirements driving the cleanup.

Use of the methodology can provide quantitative information about the footprint reductions gained by applying EPA's green remediation best management practices (BMPs). Through ongoing efforts, the Agency is identifying BMPs that apply to frequently used remedial technologies such as groundwater pump-and-treat (P&T) systems, distinct project phases such as site investigation, or common sources of contamination such as leaking underground storage tanks. Details about the BMPs are available through the green remediation initiative sponsored by EPA's Office of Superfund Remediation and Technology Innovation (as described on the CLU-IN Green Remediation Focus website at www.cluin.org/greenremediation).

Two concepts are central to analyzing the environmental footprint of a cleanup. The first is to establish those parameters (metrics) that are to be quantified, and the second is to establish a straightforward process (methodology) for quantifying those metrics. The term "footprint" refers to the quantification of a specific metric that has been assigned a particular meaning. For example, the "carbon footprint" is the quantification of carbon dioxide (and other greenhouse gases [GHGs]) emitted into the air by a particular activity, facility, or individual. This common footprint measure has been established in the past because emissions of carbon dioxide and other GHGs have been linked to climate change. The term "environmental footprint" as referenced in the methodology comprehensively includes metrics such as energy use and water use as well as air emissions to fully represent the effects a cleanup project may have on the environment.

In context of the methodology, "metric" refers to a project parameter for which a quantitative value may be:

- Derived mathematically
- Estimated through engineering details, or
- Extracted from past project records with actual data

This document presents EPA's metrics and methodology for conducting an environmental footprint analysis of site cleanup activities and describes common approaches to reduce that footprint. The document's structure corresponds to EPA's five core elements of green remediation (Figure 1.1). Topics in the document include:

- The methodology's purpose and limitations, the value of footprint analysis, and the level of effort and cost for footprint analysis
- Definitions of metrics aligning with the core elements of green remediation
- A seven-step process to quantify the metrics
 - Step 1 – Set goals and scope of the analysis
 - Step 2 – Gather and organize remedy information
 - Step 3 – Quantify materials and waste metrics

Figure 1.1. Green Remediation Core Elements



- Step 4 – Quantify water metrics
- Step 5 – Quantify energy and air metrics
- Step 6 – Qualitatively describe affected ecosystem services
- Step 7 – Present results
- Considerations for analyzing and utilizing footprint results
- Illustrative approaches to reduce the environmental footprints.

Appendix A of this document provides exhibits containing supporting technical information, Appendix B provides suggested formats for presenting a quantified footprint, and Appendix C provides illustrative footprint reduction scenarios.

The information needed and the process of obtaining the information for this methodology are the same used to develop remedy alternatives, design a remedy, or optimize a remedy. For this reason, the Agency suggests that a footprint analysis be conducted in concert with one or more of these project phases.

In context of the methodology, “cleanup” or “remedy” generally refers to a remedial project, corrective action, or comparable effort conducted by government or private organizations to address contaminated sites under one or more programs.

1.2 Purpose

EPA recognizes that many factors are involved in quantifying the environmental footprint of a cleanup. The Agency aimed to develop a methodology that is flexible, straightforward, and not overly burdensome to users or the remedial process. The methodology relies on publicly available information and can be implemented through standard spreadsheet software.

The methodology is intended to serve the following purposes:

- Facilitate implementation of EPA’s *Principles for Greener Cleanups* (<http://www.epa.gov/oswer/greenercleanups/principles.html>) by providing a methodology to quantify materials, waste, water, energy, and air metrics that represent the environmental footprint of activities involved with contaminated site cleanup. The metrics are designed to 1) reflect parameters that a remedy project team has a relatively direct ability to change and 2) encourage practices that would result in favorable changes to the metric values.
- Encourage (not require) quantification of these metrics for cleanups. The methodology is a general framework to help site teams understand the remedy components with the greatest influence on the project’s environmental footprint. Quantifying the metrics can serve as an initial step in reducing the remedy footprint. The overall process allows those involved in the remedial process to analyze a remedy from another perspective and potentially yields viable and effective improvements that may not have been identified otherwise.
- Provide technical suggestions on approaches to reduce the footprint of a remedy (but not guidance on prioritizing the footprint reduction efforts).
- Expand technology transfer among stakeholders, by conveying EPA’s lessons learned about footprint analysis conducted at numerous and varied sites undergoing remediation.
- Provide a process for footprint analyses conducted on behalf of EPA and for use by EPA in evaluating footprint analysis results submitted by other parties under any cleanup program.

- Fulfill action 8.2 of the *Superfund Green Remediation Strategy* to “develop an Agency methodology for evaluating the environmental footprint of a cleanup” (<http://www.epa.gov/superfund/greenremediation/sf-gr-strategy.pdf>).

1.3 Limitations

The methodology is not intended to be a detailed life cycle assessment (LCA) nor does it discourage the use of LCA by remediation practitioners. Unlike an LCA, the methodology does not attempt to detail all natural resource inputs and all environmental outputs, nor does it include an “impact assessment” that converts emissions and metrics into environmental effects such as acidification, increased incidence of respiratory illness, human toxicity, or ecotoxicity. The methodology uses a suitable number of green remediation metrics to represent each of the green remediation core elements but limits the number of metrics to streamline the footprint analysis process. As a result, EPA recognizes that these metrics may not capture some environmental effects or footprints associated with a cleanup project.

The methodology is not intended for application to non-remediation projects or for submissions to other organizations or programs with established methodologies for footprint analysis, GHG inventories, or similar efforts. The methodology considers the mandates of Executive Order 13514 *Federal Leadership in Environmental, Energy, and Economic Performance* and EPA guidance on resource conservation and waste minimization. It is intended to be applied in a manner consistent with the Agency’s *Principles for Greener Cleanups* and *Superfund Green Remediation Strategy*.

The methodology does not constitute an EPA requirement. Use of the methodology is intended to support the remedial process and to help improve the environmental outcome of cleanup efforts but not to disrupt, delay, or otherwise reduce protectiveness of a remedy.

1.4 The Value of Footprint Analysis

Greener cleanups can be implemented by applying BMPs without quantifying a remedy footprint or footprint reductions. EPA’s BMPs for green remediation address the most common cleanup activities posing opportunities for footprint reduction (www.cluin.org/greenremediation). Most of the BMPs involve qualitative measures and constitute relatively small modifications to standard operating procedures, such as instituting “no engine idling” policies for vehicles and machinery, substituting potable water with available graywater for onsite needs, and assuring maximum recycling of routine waste. Other BMPs may involve more significant process or equipment changes, such as installing an onsite renewable energy system to meet a portion of, or all of, the energy demand of cleanup equipment.

Footprint analysis brings a number of benefits to a project, including the following:

- Footprint reductions that might be achieved from making project improvements can be quantified.
- Aspects of a cleanup that dominate the footprint can be highlighted, allowing the project team and stakeholders to more specifically target those aspects during remedy design and implementation.
- A cleanup project can be analyzed from a different perspective, which may lead to footprint reduction as well as improvements in remedy effectiveness and efficiency that otherwise may not have been identified by a more traditional evaluation.

A number of other parties recognize these and other benefits of footprint analysis, as evidenced by footprint

analysis tools recently developed by other agencies and organizations. Examples include the Sustainable Remediation Tool (SRT), which was developed by the U.S. Air Force, and SiteWise, which was developed by

Battelle in conjunction with the U.S. Army and U.S. Navy. Analytical tools available from non-government organizations include the “Guidance for Performing Footprint Analyses and Life-Cycle Assessments for the Remediation Industry” which was developed by the Sustainable Remediation Forum.

Determining the footprint of a remedy can be a complex process depending on the level of detail and accuracy sought from the analysis. The decision of whether to conduct a footprint analysis, the structure and detail of the analysis, and the level of effort to conduct the analysis depend on several factors, including:

- **Intended use of the footprint results:** Will the results be used to assist with determining the footprint for an entire organization or a portfolio of sites within the organization? Will the footprint be used to help document or quantify footprint reductions?
- **Complexity of a site cleanup:** Is the cleanup likely to be dominated by one or two aspects such that footprint analysis is not necessary in order to determine the largest footprint contributors? Without undertaking calculations, is it apparent that the cleanup will have a very small footprint relative to other cleanups within an organization’s portfolio? Is the cleanup very complex (with many onsite and offsite components to the footprint) or is it relatively simple?

The methodology does not dictate circumstances in which footprint analysis should be conducted. Users of the methodology are encouraged to practice professional judgment and consult with other environmental professionals to determine the usefulness of footprint analysis in a given set of circumstances.

1.5 Level of Effort and Cost

Application of the methodology is expected to add a negligible amount to the level of effort and cost associated with overall remediation and a fraction of any particular remedial activity, such as a remedy design or an optimization evaluation. For example, footprint analysis is expected to add approximately 10 percent to the level of effort or cost of an optimization evaluation or less than 5 percent to the level of effort or cost of a remedial design. The level of effort and cost will vary depending on the site complexity, experience in conducting footprint analyses, and the level of analytical detail.

The level of effort to conduct a footprint analysis will vary depending on the cleanup project complexity, the availability of information, and prior experience. Most information used in a footprint analysis is generated during typical project phases or activities such as remedy design or remedy optimization and is documented in site reports. Coordinating a footprint analysis with these and other activities can help minimize the level of effort involved in footprint analysis.

The methodology focuses on green remediation metrics and therefore does not include quantification of cleanup cost. The cost of implementing footprint reduction measures is expected to be considered separately by a project team and evaluated on a project-by-project basis. Because cleanup costs often relate to the core elements of greener cleanups (e.g., energy use, materials use, and waste disposal), many footprint reduction strategies can result in cost savings over the life of a cleanup project. The costs and cost savings associated with footprint reductions are project specific; for example, savings attributed to reduced energy use through energy efficiency measures will depend on the unit costs of electricity and fuels, which vary by location and over time.

2.0 Green Remediation Metrics

2.0 Green Remediation Metrics

EPA's green remediation metrics encourage environmentally friendly behaviors that apply to each of the core elements of greener cleanups and emphasize parameters that a remedy project team likely has the ability to change. The metrics identified in this methodology are summarized in Table 2.1 and discussed below. Table 2.1 can be used to present the environmental footprint of a remedy, accompanied by supporting documentation as outlined in this methodology and presented in Appendix B. A more detailed breakdown of the metrics noted in Table 2.1 may be developed based on intermediate calculations in the footprint analysis and may be presented in addition to these metrics.

Table 2.1. Summary of Green Remediation Metrics

Core Element	Metric		Unit of Measure	Metric Value
Materials & Waste	M&W-1	Refined materials used on site	tons	
	M&W-2	Percent of refined materials from recycled or waste material	percent	
	M&W-3	Unrefined materials used on site	tons	
	M&W-4	Percent of unrefined materials from recycled or waste material	percent	
	M&W-5	Onsite hazardous waste generated	tons	
	M&W-6	Onsite non-hazardous waste generated	tons	
	M&W-7	Percent of total potential onsite waste that is recycled or reused	percent	
Water		Onsite water use (by source)		
	W-1	- Source, use, fate combination #1	millions of gals	
	W-2	- Source, use, fate combination #2	millions of gals	
	W-3	- Source, use, fate combination #3	millions of gals	
	W-4	- Source, use, fate combination #4	millions of gals	
Energy	E-1	Total energy use	MMBtu	
	E-2	Total energy voluntarily derived from renewable resources		
	E-2A	- Onsite generation or use and biodiesel use	MMBtu	
	E-2B	- Voluntary purchase of renewable electricity	MWh	
	E-2C	- Voluntary purchase of RECs	MWh	
Air	A-1	Onsite NO _x , SO _x , and PM ₁₀ emissions	lbs	
	A-2	Onsite HAP emissions	lbs	
	A-3	Total NO _x , SO _x , and PM ₁₀ emissions	lbs	
	A-4	Total HAP emissions	lbs	
	A-5	Total GHG emissions	tons CO ₂ e	
Land & Ecosystems	Qualitative description			

RECs = Renewable energy certificates

NO_x = Nitrogen oxides

SO_x = Sulfur oxides

PM₁₀ = Particulate matter smaller than 10 microns in size HAP

= Hazardous air pollutants as defined by the Clean Air Act

MWh = megawatt-hour

MMBtu = million British thermal units

CO₂e = carbon dioxide equivalent of global warming potential

Greener Cleanups: Methodology for Understanding and Reducing a Project's Environmental Footprint
February 2012

2.0 Green Remediation Metrics

2.1 Materials and Waste Metrics

These metrics consider the materials used on site, the recycled content of those materials, the waste generated on site, and the proportion of potential waste generated onsite that is subsequently reused or recycled. Although not included in this footprint methodology, users may wish to add metrics for materials used off site or waste generated off site.

2.1.1 Materials Metrics

The materials metrics consider the total amount of materials used onsite and the percentage of those materials that are produced from recycled material, reused material, or waste material. The following materials metrics are identified for this footprint methodology:

M&W-1. Refined materials used on site – This metric is presented in tons and refers to the mass of manufactured or significantly processed materials that are used onsite and come from offsite sources. Examples include chemicals, nutrients, food grade amendments, metals, plastics, and cement.

Why this Metric?

Raw materials are used in the manufacturing of refined materials. In addition, use of refined material or the manufacturing of the material may result in waste generation. Reducing refined materials use helps conserve raw materials and reduce potential waste generation. This metric and the other materials and waste metrics are consistent with EPA's Reduce, Reuse, Recycle concept. (<http://www.epa.gov/osw/conserve/rrr>).

M&W-2. Percent of refined materials from recycled or waste material – This metric refers to the percentage of the “refined materials” that is produced using recycled or reused materials or is otherwise a waste product of a manufacturing process. Examples include the portion of steel that is from recycled content, off-specification food grade amendments that are otherwise waste and can be used as *in situ* bioremediation reagents, and regenerated (not virgin) granular activated carbon (GAC) or regenerated ion exchange resin.

Why this Metric?

Use of materials from recycled products helps reduce the amount of raw materials consumed and the amount of waste generated. Increasing the percentage of refined materials made from recycled or waste materials helps conserve raw materials and reduce potential waste generation.

M&W-3. Unrefined materials used on site – This metric is presented in tons and refers to the mass of materials that are used on site, come from offsite sources, and generally have not undergone significant processing or refinement. Examples include clean fill, sand and gravel, clay, limestone, bentonite, and the aggregate portion of concrete or asphalt. The term “unrefined materials” does not refer to raw materials that are the feedstock of a “refined material” as identified above.

Why this Metric?

Unrefined materials use is included as a metric for the same reasons that refined materials use is included as a metric. Unrefined materials are distinguished from refined materials for three reasons: 1) unrefined materials (e.g., clean fill) involve less refinement and processing than refined materials; 2) unrefined materials generally consist of common, more plentiful resources than the raw materials used to manufacture refined materials; and 3) unrefined materials are often used in substantial quantities and may overshadow the use of refined materials.

2.0 Green Remediation Metrics

M&W-4. Percent of unrefined materials from recycled or waste material – This metric refers to the percentage of “unrefined materials” obtained from recycled or reused materials or is otherwise a waste product. An example includes crushed concrete that is brought from offsite sources and used as onsite fill.

Why this Metric?

This metric is included for the same reasons as the analogous metric for refined materials. Unrefined materials are distinguished from refined materials for the three reasons described under unrefined materials use.

2.1.2 Onsite Waste Metrics

The waste metrics consider the total amount of waste generated on site and the percentage of total potential onsite waste that is recycled or reused. The following waste metrics are identified for this footprint methodology:

M&W-5. Onsite hazardous waste generated – This metric is presented in tons and refers to the mass of hazardous waste generated on site and disposed of at an offsite hazardous waste facility or in a regulated onsite disposal unit. Examples include excavated soil, treatment plant residuals, and recovered product that are disposed of in this manner.

Why this Metric?

Onsite hazardous waste is generated as a direct result of onsite activities and increases the demand for infrastructure needed to treat, store, or dispose of hazardous waste. Reducing onsite hazardous waste generation by reducing the quantity of waste or the toxicity of waste helps conserve hazardous waste treatment, storage, and disposal capacity.

M&W-6. Onsite non-hazardous waste generated – This metric is presented in tons and refers to the mass of non-hazardous waste that is generated on site and disposed of off site or in a regulated onsite disposal unit. Examples include excavated soil, treatment plant residuals, and recovered product that are disposed of in this manner.

Why this Metric?

Onsite non-hazardous waste is generated as a direct result of onsite activities and increases the demand for disposal options, including landfill space. Reducing onsite waste generation helps conserve disposal capacity.

M&W-7. Percent of total potential onsite waste that is recycled or reused – This metric reflects the total potential waste (hazardous or non-hazardous) generated on site that is recycled or reused on or off site. Examples of wastes that are considered recycled or reused are as follows:

- Treated soil or crushed concrete from the remedy that is used as fill on or off site
- Cleared vegetation that is chipped, shredded, or composted and used on or off site for mulch or compost
- GAC or ion exchange resin that is sent off site for regeneration instead of disposal
- Recovered product from remedial activities that is recycled or reused.

Consistent with *Clarification on Counting Waste-to-Energy in Waste Diversion Goals As per Executive Order 13423 and Implementing Instructions* (January 14, 2008) waste of high heat content that is used for energy recovery is not considered recycled or reused.

2.0 Green Remediation Metrics

Why this Metric?

Reusing and recycling potential waste helps reduce the demand for disposal capacity and conserve raw materials. This metric is included with the other materials and waste metrics to help distinguish between efforts to reduce waste and efforts to recycle and reuse potential waste.

2.1.3 Offsite Waste

A remediation project team may have the ability to reduce waste that is generated as part of onsite activities through BMPs, but does not have much control over the waste generation, reusing, recycling, and disposal practices of material manufacturers or other offsite service providers. As a result, for most project teams, efforts to reduce offsite waste will likely rely on reduced use of materials or reduced use of offsite activities that generate waste. In addition, quantifying waste generated off site and determining the fate of that waste is complex. For these two reasons, an offsite waste metric is not included in this methodology. Although this methodology does not include an offsite waste metric, project teams are not discouraged from evaluating waste that is generated off site in support of a remedy.

2.2 Water Metrics

These metrics consider the water used on site during cleanup and the specific sources and fates of the used water. Although not included in this footprint methodology, users may wish to add metrics for water used off site during supplemental activities.

2.2.1 Onsite Water Metrics

The onsite water metrics consider the source and amount of water used on site, as well as the fate of the water after use. Site-specific factors are discussed further in Section 2.2.2. Onsite water metrics are identified as follows:

W- 1, W-2, W-3, W-4. Onsite water use – Onsite water metrics are presented in millions of gallons of each source of water that is used on site, including brief descriptions of the sources, uses, and fates of the various sources of water used. Water sources considered in this metric include but are not limited to the following:

- Water from the public potable water supply
- Extracted groundwater from each local aquifer
- Surface water
- Reclaimed water
- Collected or diverted stormwater.

The use of the water includes but is not limited to the following:

- Equipment decontamination
- Extraction and treatment
- Injection for plume migration control

- Chemical blending.

Potential fates of the used water include but are not limited to the following:

- Reuse in a public or domestic water supply
- Use as industrial process water

2.0 Green Remediation Metrics

- Discharge to groundwater (specify the aquifer)
- Discharge to fresh surface water
- Irrigation
- Discharges to brackish or saline water
- Discharge to the atmosphere (i.e., as water vapor)
- Discharge to the sanitary sewer.

Why this Metric?

Water is a natural resource that has beneficial uses that depend on the source and quality of the water. The use of water as part of the remedy and the fate of the water after use can affect water quality and its potential for beneficial reuse. Reducing water use, choosing the appropriate water resources, returning water to the environment with equal or improved quality, or reusing the water all contribute to conserving valuable water resources.

2.2.2 Site-Specific Consideration for the Onsite Water Footprint

Water is typically a local or regional resource that may be plentiful or scarce. In addition, there may be several types of local water resources available, and after use, the water may lose its original quality, retain its original quality, or improve in quality. These concepts are discussed further below.

Water is typically a local or regional resource. The same water footprint calculated for two similar sites in two different parts of the country may be interpreted differently by local site stakeholders. For example, groundwater extraction, treatment, and discharge to surface water in one state may be seen as use of a valuable, ~~potentially~~ ^{potentially} drinking water. However, groundwater extraction, treatment, and discharge in another state may not be of concern for water use if the groundwater in that particular location is abundant, if groundwater is of relatively low quality, or surface water is the primary source of drinking water for that location.

Various types of water with varying water quality may be used in association with cleanup activities.

For example, potable water provided by a water supply utility is a refined water resource that likely involves extraction, treatment, and distribution prior to use. Groundwater and surface water, depending on the aquifer or source, may be of drinking water quality without treatment, may be of drinking water quality with some limited treatment, or may not practicably be used for drinking water or other beneficial purposes. Groundwater and surface water may also be used in industrial processes or for irrigation without prior treatment.

The onsite use of water can affect how it is discharged and how it can be reused. Water use can include groundwater extraction and treatment, which typically improves water quality (in addition to removing contamination). Therefore, extracted and treated groundwater may potentially have more uses than other uncontaminated water from the same aquifer. Water used in single-pass heating or cooling systems (e.g., open-loop water source heat pumps) may cause a change in temperature that does not significantly affect its potential use for other purposes. Public water used for blending chemicals that are injected into an aquifer or added to the process stream in a water treatment plant reduces the quality of the used public water because it is blended with other water of lesser quality and can no longer be used directly for public consumption.

Water may be returned to the environment in the same, improved, or reduced quality as a result of cleanup activities. For example, discharge of treated groundwater from a groundwater P&T system to the

subsurface may involve returning that water to its original aquifer and therefore maintain the original groundwater resource. By contrast, the treated groundwater might be discharged to brackish surface water that

2.0 Green Remediation Metrics

is not of suitable quality for drinking, irrigation, or industrial uses, and therefore, the extracted groundwater would no longer be available as a fresh water resource.

2.2.3 Offsite Water Use

Offsite water use refers to the quantity of water that is used off site for activities such as electricity generation at a power plant or manufacturing. Unlike onsite water use, offsite water is used for many purposes and may occur in a variety of geographic locations. Information may not be readily available regarding the source of the water, the specific use of the water, the fate of the used water, and the scarcity/availability of water resources in the areas where it is being used. Due to these sources of uncertainty and the level of effort that would be required to better understand offsite water use, an offsite water metric is not included in this methodology. It is noted, however, that offsite water use will generally decrease when other metrics (e.g., energy use and materials use) decrease. Although this methodology does not include an offsite water metric, project teams are not discouraged from evaluating water that is used off site in support of a remedy.

2.3 Energy Metrics

The energy metrics consider the total amount of energy used by the remedy (including onsite and offsite activities), and energy coming from renewable resources. The following energy metrics are identified for this footprint methodology:

E-1. Total energy use – This metric refers to the total amount of energy used by the remedy for onsite and offsite activities including electricity generation, transportation, materials manufacturing, and other offsite activities that support the remedy.

Why this Metric?

Energy use involves the use of natural energy resources, which puts strain on the existing energy infrastructure, and can result in waste streams. Therefore, reducing total energy use through energy efficiency measures and efficient cleanup helps conserve natural energy resources, decreases demand on the existing energy infrastructure, and decreases associated waste generation. www.epa.gov/energy

E-2. Total energy voluntarily derived from renewable resources – This metric category refers to renewable energy that a project team voluntarily generates or uses in place of energy derived from other resources. The metric category is comprised of three sub-metrics that distinguish between various forms of renewable energy production and use. Each of the three sub-metrics is described below, and additional information regarding renewable energy as it pertains to this methodology is included in Exhibit 2.1 (see Appendix A).

E-2A. Onsite generation or use and biodiesel use – This sub-metric refers to renewable energy that is generated on site and biodiesel used both on site and off site. Examples include the onsite use of landfill gas in place of natural gas and the use of biodiesel in place of diesel for heavy equipment use or transportation. Other examples include the generation of electricity from onsite renewable energy systems (e.g., photovoltaic modules, wind turbines) or generation of heat from onsite solar thermal systems. Systems that are immediately adjacent to the site and provide the renewable energy directly to the site are also included. The value of this metric can be higher than the value of the total energy use metric if renewable energy generated on site exceeds the energy use by the remedy and is exported off site for use by others. To be counted toward this metric, the rights to the renewable energy generated by the systems described here need to be retained by the cleanup project and not transferred to other parties or facilities.

2.0 Green Remediation Metrics

Why this Metric?

Generating and using renewable energy in place of conventional energy helps conserve natural energy resources and reduces waste generation and emissions associated with many conventional sources of energy. In addition, renewable energy generation at the point of use (i.e., on site) helps avoid energy losses due to the transmission of energy from one location to another. Renewable energy in this metric is the most verifiable form of renewable energy production and use for a remedy and therefore is distinguished from the renewable energy in the other sub-metrics.

E-2B. Voluntary purchase of renewable electricity – This sub-metric refers to the voluntary purchase of renewable electricity from an electricity provider in the form of a “green pricing” or “green marketing” product. In regulated electricity markets, renewable electricity may be purchased through the grid from the electric utility by paying a premium for renewable electricity (i.e., buying a “green pricing” product). In competitive electricity markets, the utility distributes the electricity and renewable electricity may be purchased from an electricity generator that offers renewable electricity (i.e., buying a “green marketing” product). This metric does not include the renewable electricity that is purchased by default when purchasing standard grid electricity.

Why this Metric?

Purchasing renewable electricity contributes to the development of large-scale renewable electricity projects that are independent of a remedy. For the purpose of this methodology, this form of purchased renewable electricity is considered more verifiable than purchasing RECs because of the substantial variability in the integrity and environmental attributes of RECs. For this reason, purchased renewable electricity from electricity providers is distinguished from purchasing RECs.

E-2C. Voluntary Purchase of RECs – This sub-metric refers to the direct purchase of RECs. Refer to Exhibits 2.1 and 2.2 for more information on RECs.

Why this Metric?

Purchasing renewable electricity through the purchase of RECs contributes to the development of large-scale renewable electricity projects that are independent of a remedy. Because of the substantial variability in the integrity and environmental attributes of RECs, they are distinguished from the other forms of renewable electricity.

2.4 Air Metrics

The air metrics consider emissions of GHGs, nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter less than 10 microns in size (PM10), and hazardous air pollutants (HAPs). For the purpose of the methodology, NOx, SOx, and PM10 are combined into a single group at the summary stage to streamline footprint presentation. HAPs refer to the original list of toxic air pollutants defined by the Clean Air Act Amendments of 1990 and subsequent modifications. Additional information related to GHGs can be found on EPA’s Climate Change website (www.epa.gov/climatechange). Additional information related to NOx, SOx, and PM10 is available from EPA online at <http://www.epa.gov/air/urbanair> and additional information about HAPs can be found on EPA’s Air Toxics website (<http://www.epa.gov/ttn/atw/pollutants/atwsmod.html>).

Organizations might purchase emissions off-sets or voluntarily purchase renewable electricity from an electricity provider or through the purchase of RECs (see metrics E-2B and E-2C). For the purpose of this methodology, the air metrics reflect project emissions before any potential reductions from these types of purchases in order to put primary emphasis on improvements that directly reduce emissions associated with the remedy. Although emissions reductions associated with these voluntary purchases of off-sets and renewable electricity are not considered in the air metrics, voluntary purchase of these products are still encouraged (see metrics E-2B and E-

2.0 Green Remediation Metrics

2C). Refer to Exhibit 2.2 (see Appendix A) for more information related to emissions reductions associated with voluntary purchases of emissions off-sets, renewable electricity, and RECs.

2.4.1 Onsite Air Metrics

A-1. Onsite NO_x, SO_x, and PM₁₀ emissions – This metric refers to the sum of the onsite emissions for NO_x, SO_x, and PM₁₀ measured in pounds before consideration of potential reductions from voluntary purchases of emissions off-sets, renewable electricity, RECs, or similar products.

Why this Metric?

NO_x, SO_x, and PM₁₀ emissions are all examples of criteria pollutants as defined by the Clean Air Act. NO_x, SO_x, and PM₁₀ each adversely affect local and regional air quality in various ways. Some of the adverse effects are detrimental to the environment (e.g., acid rain caused by NO_x and SO_x), and some adverse effects are directly detrimental to human health (e.g., increase in incidence of respiratory illness caused by NO_x, SO_x, and PM₁₀). Fossil fuel combustion is a source for all three of these pollutants. Other sources also exist for each pollutant, including various industrial processes and PM₁₀ emissions associated with dust generation. Reducing on-site air emissions of these pollutants by reducing fossil fuel use on site, using emissions control technologies on onsite equipment, suppressing onsite dust generation, and employing other practices helps reduce adverse effects on a local scale.

A-2. Onsite HAP emissions – This metric refers to onsite combined HAP emissions (i.e., the sum of all listed HAPs) measured in pounds before consideration of potential reductions from voluntary purchases of emissions off-sets, renewable electricity, RECs, or similar products.

Why this Metric?

HAP emissions adversely affect air quality by increasing toxicity. Reducing onsite air emissions of HAPs by modifying onsite remedial practices and using emissions control technologies for onsite processes helps reduce the adverse effects of these pollutants on a local scale.

2.4.2 Total Air Metrics

The following three total air metrics described in this subsection refer to combined onsite and offsite emissions. Offsite air emissions include emissions associated with electricity generation, materials manufacturing, transportation, and offsite services used during the cleanup.

A-3. Total NO_x, SO_x, and PM₁₀ emissions – This metric refers to the total onsite and offsite NO_x, SO_x, and PM₁₀ emissions measured in pounds before consideration of potential reductions from voluntary purchases of emissions off-sets, renewable electricity, RECs, or similar products.

Why this Metric?

As discussed above, NO_x, SO_x, and PM₁₀ each adversely affect both local and regional air quality in various ways. Therefore, reducing total emissions of these pollutants (i.e., onsite and offsite emissions) can reduce the adverse effects of these pollutants on a regional scale or at the local scale in other regions distant from the cleanup.

A-4. Total HAP emissions – This metric refers to the total onsite and offsite HAP emissions measured in pounds before consideration of potential reductions from voluntary purchases of emissions off-sets, renewable electricity, RECs, or similar products.

2.0 Green Remediation Metrics

Why this Metric?

As discussed above, HAPs adversely affect air quality by increasing toxicity. Therefore, reducing total emissions of these pollutants (i.e., onsite and offsite emissions) can improve air quality on a regional scale, particularly for those HAPs that are persistent in the atmosphere such as mercury.

A-5. GHG emissions – This metric refers to the total onsite and offsite GHG emissions associated with the remedy measured in tons of carbon dioxide equivalent (CO₂e) of global warming potential before consideration of potential reductions from voluntary purchases of emissions off-sets, renewable electricity, RECs, or similar products. Onsite emissions are not presented separately from offsite emissions because the effects of GHGs are independent of the location of the emissions. GHGs, global warming potential, and CO₂e are discussed in more detail in Exhibit 2.3 (Appendix A).

Why this Metric?

Greenhouse gases contribute to climate change, which can adversely affect climate-sensitive systems such as human health, agriculture, natural ecosystems, coastal areas, and heating or cooling needs (www.epa.gov/climatechange). Reducing greenhouse gas emissions can help reduce the potential for significant changes in climate that might adversely affect climate-sensitive systems.

2.4.3 Further Categorization of Air Metrics

In quantifying the onsite and total air metrics presented above and in Table 2.1, this methodology uses a structure based on three "scopes" for air emissions. The scopes are not individual air metrics for this methodology; rather, they are a suggested means of organizing and calculating the emissions metrics to provide insight in the sources of the emissions and to provide a parallel structure to other forms of emissions tracking. This structure is in general agreement with the approach recommended by the World Resources Institute (WRI) Greenhouse Gas Protocol. The approach based on scopes is also reflected by a number of regulatory, non-profit, and other organizations, such as the former EPA Climate Leaders Program, the Climate Registry, the Chicago Climate Exchange, various GHG inventories, and Executive Order 13514. The specific calculations and backup documentation for air emission metrics used in this methodology are described in Section 3.0; these metrics can be calculated without strictly adhering to the suggested organizational approach for emission scopes.

Onsite (Scope 1) – This scope of air emissions occurs from within the site boundaries. This is generally consistent with the WRI Scope 1 emissions. WRI defines Scope 1 emissions as those derived from equipment “owned” by the facility, even if these emissions occur off-property. However, unlike a manufacturing facility or institution that may participate in a GHG inventory, very few remediation projects actually “own” equipment. Therefore, the definition of Scope 1 emissions has been modified for the purpose of this methodology to include only those emissions from onsite activities. Examples of Scope 1 emissions include emissions associated with fuel combusted on site in heavy equipment.

Electricity generation (Scope 2) – This scope of emissions results from offsite generation of electricity used by the project. Consistent with WRI approach, this scope of air emissions does not include air emissions associated with the transmission of electricity from the power station to the site through the electricity grid.

Offsite (Scope 3) – This scope of air emissions results from remedy-related emissions not covered by the “onsite” or “electricity generation” categories. For this methodology, offsite air emissions are further subdivided as follows:

- *Transportation (Scope 3a)* air emissions are those associated with offsite transportation of personnel, equipment, and materials.

2.0 Green Remediation Metrics

- Other offsite (Scope 3b) air emissions are those associated with offsite activities such as materials manufacturing, offsite services (e.g., laboratory analysis), transmission of electricity through the electricity grid, and resource extraction for fuels used in electricity generation.

Because energy and air emissions are closely linked, these categories also apply to calculations and backup documentation for energy use. For example, the electricity used on site (i.e., electricity as measured by the project's utility meter) would be considered “*onsite*” energy use. The waste energy at the offsite electricity power plant would be considered “*electricity generation*” energy use. The energy lost in transmitting the electricity to the site would be considered “*other offsite*” energy use. Similarly, energy use in the form of onsite diesel fuel would be considered “*onsite*” energy use whereas the energy used to produce the diesel would be considered “*other offsite*” energy use.

3.0 Footprint Methodology

As illustrated in Figure 3.1, this methodology is a seven-step process that begins with setting goals and scoping the analysis and then gathering and organizing information about the remedy to be footprinted. This information is then used to quantify the onsite materials and waste metrics and the onsite water metrics. The materials, waste, and water information, plus other remedy information, is then used to quantify the energy and air metrics. After the metrics have been calculated, ecosystem services that are affected during remedy implementation are described qualitatively. The process ends with presenting the results in a manner similar to that illustrated in Table 2.1 and described in Appendix B.

After the results are presented, the results can be analyzed to identify large contributors to the metrics and evaluate opportunities for footprint reduction. In general, the methodology utilizes publicly available information and can be implemented using standard spreadsheet software.

Figure 3.1. Overview of Footprint Methodology



3.1 Step 1: Set Goals and Scope of Analysis

Step 1

The first step of a footprint analysis is to determine the goals and scope of the analysis. Other activities related to this step are establishing the boundaries and functional unit for the analysis.

The goal of the analysis typically varies with the remedial stage and with other site-specific factors. Table 3.1 summarizes likely goals of the footprint quantification based on remedy stage.

3.0 Footprint Methodology

Table 3.1. Goals of Footprint Quantification

Remedy Phase	Typical Goal of Footprint Quantification
Development of remedy alternatives*	Identify components of various remedy alternatives that are large contributors to footprints
Remedial Design and Remedy Optimization	- Identify remedy components that are large contributors to the remedy footprint - View remedy from different perspective to identify opportunities for improvement - Identify: - Design components that are large contributors to footprints during construction or during remedy operation - Refinements or data gaps in the conceptual site model that, if addressed, might help reduce footprints (e.g., improved characterization that refines the known contamination source area) - Potential opportunities for footprint reductions
Other	Quantify and document emissions
* Results of a footprint analysis during the development of remedy alternatives may be subject to substantial uncertainty due to limited remedy-specific information available and the absence of actual data or engineering design estimates.	

The scope of the analysis will depend, in part, on the goals of the analysis. For example, the goals of one analysis may be addressed by including only active components of a remedy (e.g., system operation, chemical injections, or excavation) and omitting one or more components of a monitoring program whereas the goals of another analysis may only be adequately addressed by including in the scope all project components affecting the environment, including the remediation monitoring program. Similarly, the goals of one analysis may be addressed by including only the soil component of a remedy and omitting the groundwater component whereas the goals of another study may only be adequately addressed by considering the site-wide remedy for all affected media. The scope of the analysis significantly influences the data to be gathered in Step 2 of the methodology.

The boundary of study is also established at the outset of a footprint analysis. The study boundary is the conceptual boundary around a system or project that determines the processes that are included and the processes that are excluded. One example of a study boundary is the physical boundary of the cleanup site. For example, a footprint analysis that uses the physical site boundary as the study boundary would only include air emissions from onsite sources and would exclude the emissions associated with generating the electricity obtained through the electrical grid. This methodology generally establishes broad study boundaries that include onsite and offsite processes, resource extraction and processing for fuels, resource extraction and processing of manufactured materials, demolition and disposal of wastes, and project infrastructure. Because the methodology establishes these boundaries, it is not necessary for the user of the methodology to independently establish the boundaries.

Another common concept determined early in a footprint analysis is the functional unit, which is the basic unit of the item undergoing the footprint analysis. In the manufacturing sector, the functional unit may be a single manufactured item. In the remediation community, the functional unit is commonly the life cycle of a remedy from the present to the attainment of remedial action objectives and site closure. Alternative functional units could be a year of system operation for a long-term remedy, a cubic yard of soil to be treated, a gallon of water to be treated, or a cubic yard of aquifer to be restored. Although the methodology generally assumes that the most common functional unit is the life of a remedy from the present to the attainment of remedial action objectives and site closure, the user may decide to use an alternative functional unit as appropriate.

3.2 Step 2: Gather Remedy Information

This step of the footprint methodology involves collecting information about remedy design, construction, and operation. The information includes design parameters, activities conducted, and types of materials used. Exhibit 3.1 (in Appendix A) provides examples of this type of information for several common remedies.

The quality of the information depends on the stage of the remedy when the footprint analysis is conducted. The information will likely be relatively uncertain during the early design stage but will increase in certainty as the design stage proceeds and as the remedy is implemented. The degree of uncertainty in the remedy information used in the footprint analysis should be documented as the footprint analysis proceeds, along with the likely effects of the uncertainty on the results of the analysis.

The typical outcome of the information gathering step is a bulleted list of remedy information. The footprint reduction scenarios presented in Appendix C illustrate the level of detail that is generally expected for this step of the process. Although the scenarios provide examples for data gathering, professional judgment is used on a site-specific basis to determine the appropriate level of detail to meet the objectives of the footprint analysis.

Some of the information to be gathered in this stage and in the next stages of the footprint analysis process is generally available from existing documents and the site contractor. Moreover, the information needed and the process of obtaining the information is similar to the information and process used while preparing design documents, remedial action progress reports, or conducting remedy optimization evaluations. For this reason, it is highly suggested that the footprint analysis be conducted in concert with one or more of these other activities. Depending on the information available, some technical remediation expertise may be required to translate some aspects of the remedy into useable information. For example, the level of effort and type and size of equipment needed to excavate a given volume of contaminated soil may be estimated to provide information for the footprint analysis, or the amount of GAC to treat process water may be estimated for a specified flow rate and contaminant load. Although the methodology cannot provide all technical details needed to complete this step for all remedies, the exhibits in Appendix A of this document convey examples of fundamental information.

The level of detail achieved in the footprint analysis is heavily dependent on the information gathering step because this step will determine the information that is either included in the analysis or excluded from the analysis. A tradeoff arises between the level of detail achieved in the analysis and the level of effort for conducting the analysis. This methodology suggests setting and documenting the following two types of screening limits to select the activities or materials included in the analysis:

- *A screening limit based on a specified percentage of the maximum contributor to a particular metric*
- *A screening limit based on a specified magnitude for a particular metric.*

The limits and the reasoning for selecting them should be clearly documented. Based on professional judgment, an item or activity that is expected to contribute less than either of the limits can be omitted from the analysis with an appropriate level of documentation. Both types of limits should be applied to each of the green remediation metrics or grouping of metrics because an item that is a negligible contributor for one metric (such as GHG emissions) may be a significant contributor for another metric (such as onsite water use). Exhibit 3.2 (Appendix A) presents a screening approach that can be used and an example application of it.

3.3 Step 3: Quantify Onsite Materials and Waste

Metrics

Step 3

The methodology involves quantifying materials from off site that are used on site and quantifying waste that is generated on site. This quantification is an accounting of the significant materials used, the recycled content of those materials, various wastes generated, and the portion of that waste that is recycled or reused. The primary

challenges associated with this step include 1) converting the various quantities of materials and wastes into common units for each of the metrics; 2) recognizing recycling and reuse when it occurs; and 3) presenting information in a clear and concise manner.

3.3.1 Content of a Materials Footprint Analysis

To assist with identifying materials used on site, Table 3.2 provides materials typically involved in various remedy activities. Where a material is comprised of a known combination of refined and unrefined materials, it is appropriate to distinguish between the refined and unrefined portions. For example, concrete is approximately 15 percent refined materials and 79 percent unrefined material, and the remaining 6 percent is water (see Section 3.3.2 for more information). The use of one ton of concrete therefore is considered 0.15 tons of refined material and 0.79 tons of unrefined material.

Materials that exceed the screening limits discussed in Section 3.2 and Exhibit 3.2 would be included in the calculation of the footprint. Materials that fall below these limits would be excluded from the calculation of the footprint. Materials that are excluded should be described with an appropriate level of documentation and can be addressed through qualitative BMPs for green remediation.

Appendix B includes a sample table format for organizing a materials footprint analysis. Examples of completed tables are presented in the footprint reduction scenarios provided in Appendix C.

Table 3.2. Potential Onsite Use of Materials

The materials listed are “refined” as defined by this methodology unless marked with an asterisk (*).

• Wells ○ Grout ○ Well casing (PVC or steel) ○ Sand/gravel/bentonite* • Piping ○ Steel ○ Plastic (PVC, HPDE, other) • Buildings and foundations ○ Concrete** ○ Steel • Cutoff walls ○ Sheet pile (PVC, steel) ○ Slurry (bentonite, grout, fill)** • Geomembranes/liners/caps ○ PVC, HDPE ○ Clay* ○ Asphalt** * <i>Unrefined material</i> PVC = polyvinyl chloride	• Treatment chemicals/materials ○ GAC ○ Oxidants (e.g., hydrogen peroxide) ○ Acids (e.g., sulfuric acid) ○ Bases (e.g., sodium hydroxide) ○ Flocculants (e.g., ferric chloride) ○ Polymer ○ Well rehabilitation chemicals • Injection reagents ○ Oxidants (e.g., permanganate) ○ Acid (e.g., sulfuric acid) ○ Catalysts (e.g., ferrous sulfate) ○ Zero-valent iron ○ Nutrients, electron donors (e.g., vegetable oil) • Other ○ Fertilizers ○ Mulch/compost* ○ Process equipment (PVC, HDPE, steel) **combination of refined and unrefined materials HDPE = high density polyethylene

3.3.2 Rules of Thumb and General Assistance for Quantifying Materials Use

Quantifying materials use in tons can be challenging during any phase of a remedy because many materials are ordered or described in different units, such as feet of pipe, square feet of plastic membrane, or gallons of chemical reagents. Some material use can also be difficult to quantify if many small components are used (e.g., treatment system valves, fittings, and piping). In addition, some commonly used construction materials (e.g., steel) include significant recycled content but the recycled content is not necessarily communicated to the purchaser. For this reason, rules of thumb are useful to simplify the materials inventory process when more site-specific information is not readily available. Exhibits 3.3 through 3.8 (Appendix A) provide general information and rules of thumb for this purpose.

- Exhibit 3.3 provides densities of common materials.
- Exhibit 3.4 provides the approximate materials content of commonly used aqueous chemical solutions.
- Exhibit 3.5 provides estimated materials use for piping and wiring runs.
- Exhibit 3.6 provides estimated materials use for well installation.
- Exhibit 3.7 provides estimated materials use for process equipment and building construction.
- Exhibit 3.8 provides reasonable assumptions for recycled content of steel, concrete, and asphalt, which are construction materials with a significant percentage of recycled content.

3.3.3 Content of a Waste Footprint Analysis

The following waste streams are commonly associated with remediation and may significantly contribute to onsite waste generation:

- Drill cuttings and used drilling mud
- Excavated soil for offsite disposal
- Construction debris
- Treatment plant residue
- Spent GAC.

Many of the above potential waste streams can be reused or recycled. Examples include spent GAC, which often can be regenerated and reused rather than sent to a landfill for disposal.

The following waste streams are also commonly associated with remediation but may be too small to merit inclusion in the waste footprint.

- Used packaging
- Used personal-protective equipment that is disposable.

Waste streams that exceed the screening limits discussed in Section 3.2 and Exhibit 3.2 would be included in the calculation of the footprint. Waste streams that fall below these limits would be excluded from the calculation of the footprint. Waste streams that are excluded should be described with an appropriate level of documentation and can

be addressed through qualitative BMPs for green remediation.

Quantifying waste generation is generally straightforward during remedy design and remedy implementation because significant waste generation typically results in significant costs that need detailed analysis and documentation. For this reason, general information and rules of thumb for waste generation are not provided as has been done for materials use.

Appendix B includes a sample table format for organizing a waste footprint analysis. Examples of completed tables are presented in the footprint reduction scenarios provided in Appendix C.

3.3.4 Items Not Included in the Materials and Waste Footprint Analysis

The methodology does not include in the materials metric the raw materials used in manufacturing processes or materials used in other offsite activities that support the remedy because the project team often does not have direct control over these materials. Similarly, it does not consider waste generation associated with materials manufacturing or other offsite activities that support the remedy. Emphasis instead is placed on reducing onsite materials use, increasing the recycled content in the materials that are used, reducing onsite waste generation, and recycling or reusing materials that have served their purpose.

Although water is a “material” in a broad sense, this methodology considers water a separate core element of green remediation with its own metrics for footprint analysis. Therefore, water used in a cleanup is not included in the materials metric. Similarly, water discharged to an offsite treatment plant is not considered in the waste metric. The production and treatment of water, however, are considered in the energy and air metrics discussed in Section 3.5 because the production and treatment of water involves energy use and air emissions.

Fuels such as gasoline, diesel, and natural gas are also “materials” in a broad sense, but this methodology does not include fuels in the materials metric because the production and use of fuels are considered thoroughly in the energy and air metrics discussed in Section 3.5.

Equipment that is used only temporarily for a remedy is not considered in the materials metric when it is brought on site and is not considered recycled or reused in the waste metric when it is removed from the site. Examples of equipment that are not included in the materials or waste metrics are contractor equipment used at other sites (e.g., heavy equipment, mixing tanks, and hoses) and rental equipment (e.g., portable generators or air compressors for sampling). Equipment that is dedicated to the cleanup remedy, such as well extraction pumps or tanks for treatment of extracted groundwater, should be included in the materials and waste metrics when they are used and decommissioned, depending on the level of detail desired in the footprint analysis.

3.4 Step 4: Quantify Onsite Water Metrics

Step 4

The methodology involves quantifying onsite water use with emphasis on reducing onsite water use and returning water of high quality to productive use. Activities in this step include:

- Distinguishing among various local and onsite water sources
- Identifying the quality of the water used from each source
- Quantifying the amount of water used from each source
- Identifying the use of the water from each source
- Distinguishing among various fates of the water from each source after use.

The following section discusses each of these items in more detail.

3.4.1 Content of Onsite Water Footprint Analysis

Water Resources – Common sources of water that may be used on site in association with a remedy include potable water from a public water supply system, multiple groundwater resources, multiple surface water resources, captured stormwater, and reclaimed water. Multiple groundwater and surface water resources are

3.0 Footprint Methodology

possible because there may be different aquifers from which groundwater can be extracted or multiple locations from which surface water is extracted.

Water Quality – The quality of the water used is an important aspect of the water footprint because the potential beneficial uses of the water by the local community, economy, and environment are directly related to the water quality. Indicating the source of water does not necessarily describe the quality of the water. For example, if water is extracted from a shallow aquifer that is classified as a potential source of drinking water by the state but actually has inadequate water quality for this purpose (perhaps due to high levels of naturally occurring dissolved iron or dissolved solids), then the water quality might be described in the footprint analysis as “potential potable water resource that likely requires treatment before use.” For water that is contaminated by site-related contamination, the description should pertain to the natural quality of that groundwater and should note the site-related contamination.

Volume Used – The amount of water used from the indicated water resource refers to the volume that is used or diverted from that resource over the life cycle of a remedy. For example, the installation and use of impermeable surfaces as part of the remedy may result in diversion of stormwater to surface water rather than allowing it to infiltrate into the subsurface. The stormwater diversion would be considered a “use” of the water. Exhibit 3.9 in Appendix A provides additional information related to stormwater as it pertains to this methodology.

Potential Water Uses – The uses of the water vary from remedy to remedy. Common uses of water resources associated with remediation include the following:

- Extraction for treatment (e.g., in a groundwater P&T system)
- Extraction for testing (e.g., for long-term pumping tests)
- Injection for plume migration control
- Blending and injecting reagents for *in situ* bioremediation
- Blending and injecting reagents for *in situ* chemical oxidation (ISCO)
- Blending of chemicals for treatment plant operation
- Make-up or backwash water from treatment plant operation
- Mixing grout or slurry
- Evapotranspiration from phytoremediation
- Purge water from sampling
- Equipment decontamination
- Dust control and general construction.

Chemical solutions brought to the site from a chemical vendor can contain a significant amount of water. Absent other information, it is appropriate to consider the water content of the solution to be public water that is used on site. Relevant information for many common aqueous solutions used in remediation is available in Exhibit 3.4. This and other uses of public water are also considered in quantifying the energy and air metrics as described in Section 3.5.

Potential Fates of Used Water – The fate of the used water is an important part of the water footprint because the potential beneficial uses of the “used” water by the local community, economy, and environment directly depend on where the water is discharged and the quality of the water once it is discharged. Common fates of water after water use during remediation include the following:

- Discharge to public water supply

- Discharge for use as industrial process water
- Discharge to groundwater
- Discharge to surface water
- Discharge for use as irrigation

3.0 Footprint Methodology

- Discharge to a brackish or saline water body
- Discharge to the atmosphere through evapotranspiration or vaporization.

An onsite water metric is established for each combination of a water source, water use, and water fate that involves significant water use. For example, extracted groundwater from a specified aquifer used for two purposes, each with its own fate, results in two onsite water metrics. Water use from each major water resource that exceeds the screening limits discussed in Section 3.2 and Exhibit 3.2 would be included in the calculation of the water footprint. Water uses from the various sources that fall below these limits would be excluded from the footprint but would be documented; these uses can be addressed through qualitative BMPs for green remediation.

Although water may be used during the remedy, the use and the fate of the used water does not necessarily result in a net effect on the onsite water resource. For example, groundwater may be extracted, treated, and reinjected into the same aquifer, representing no net effect on the onsite water resource. However, if the treated water is of substantially improved quality (e.g., lower total dissolved solids) than the groundwater, then returning the treated water to the aquifer may be a lost opportunity for beneficial reuse. Similarly, groundwater of relatively high quality that is extracted, treated, and discharged to brackish or saline water inherits the brackish or saline quality. In this circumstance, groundwater that was extracted (before or after treatment) now has increased salinity, and its potential uses may now be limited. In addition, discharging the groundwater to naturally brackish water may reduce the salinity of the brackish or saline water in localized areas.

Quantifying onsite water use is generally straightforward during remedy implementation and remedy optimization when actual data is available. It is also generally straightforward during the design process because engineering estimates made at that point can be converted into water use. For example, engineering estimates are typically available for the extraction rate for a P&T system or the amount of water that will be used for injecting nutrients or reagents into the subsurface for an *in situ* remedy. These types of engineering estimates should be used where available. General assistance is provided below to elaborate on some categories of water use and how to quantify that water use.

Appendix B includes a sample table format for organizing a water footprint analysis. Examples of completed tables are presented in the footprint reduction scenarios provided in Appendix C.

Chemical Solutions – Chemical solutions brought to the site from a chemical vendor can contain a significant amount of water. Absent other information, it is appropriate to consider the water content of the solution to be public water that is used on site at the cleanup project. Relevant information for many common aqueous solutions used in remediation is available in Exhibit 3.4. This and other uses of public water are also considered in quantifying the energy and air metrics as described in Section 3.5.

3.5 Step 5: Quantify Energy and Air Metrics

Step 5

The energy and air metrics as calculated by the methodology attempt to account for as much of the life cycle of the material or activity as is practicable. For example, the energy and emissions associated with electricity use includes resource extraction for fuel, use of the fuels, and transmission and distribution losses. In addition, for gasoline and diesel used on site or for transportation, the energy and emissions for extracting crude oil and refining the oil into the gasoline and diesel are included, in addition to combustion of the fuels in equipment and during transportation.

The methodology purposefully does not include energy use and air emissions resulting from the following aspects of the remedy:

3.0 Footprint Methodology

- The manufacturing of rental or temporary equipment for the site (e.g., the manufacturing of an excavator that is used for removing contaminated soil) is not included in the footprint because 1) it is assumed that a small fraction of the equipment lifetime operating hours are spent on a single project and 2) the footprint associated with manufacturing the equipment is expected to be small relative to the footprint of operation over the life of the equipment.
- Office-related work and other offsite personnel activities (other than routine transportation between the site and the office) are not included because office-related work is anticipated to have a relatively small footprint relative to site work.
- Items or activities that are non-additional (i.e., would have occurred in the absence of site remediation) are not included because actions taken to reduce the footprint for a remedy would not address the footprint of such items or activities.
- Items or activities external to the remediation process associated with redeveloping a property are not included because they are external to the remediation process.

This methodology recommends including offsite energy use and air emissions because for some sites the offsite energy use and emissions may represent the majority of the remedy footprint and project teams can influence the offsite energy use and air emission by modifying the amounts or types of energy, materials, and offsite services used in the remedy.

Step 5 is divided into the following three parts to facilitate organizing, presenting, and calculating the energy and emission footprints:

- Part 1 – Inventory Remedy Transportation, Equipment Use, Materials and Waste, Public Water Use, and Offsite Services
- Part 2 – Determine Remedy Energy Use
- Part 3 – Convert the Remedy Inventory into Energy and Air Metrics.

Each of these parts is discussed in the following sections.

3.5.1 Part 1 - Inventory Remedy Transportation, Equipment Use, Materials and Waste, Public Water Use, and Offsite Services

The first part of Step 5 is to make an inventory of the transportation, equipment use, materials and waste, public water use, and offsite services required for the remedy. Much of the information required for this inventory is based on the information previously gathered for the materials, waste, and water footprints. Additional information is gathered on transportation, equipment use, and offsite services required for the remedy. As noted earlier for the materials, waste, and water footprints, the quality of the inventory information gathered in this step depends on the phase of the remedy when the footprint methodology is conducted, with greater certainty associated with later phases of the remedial process.

The type of information collected varies by remedy technology and by remedy phase. Exhibits 3.10A and 3.10B provide checklists as suggestions of the types of information to be gathered. Exhibit 3.10A provides a checklist for the remedy construction phase, and Exhibit 3.10B provides a checklist for the remedy operation phase.

In an effort to streamline the footprint analysis process, it is appropriate to screen the information to be included in the analysis. The materials use, waste disposal, and public water use described in Steps 2 and 3 (which have already been screened) can be included directly. The transportation, equipment use, and other offsite services are screened against the limits discussed in Section 3.2 and Exhibit 3.2. Items and activities that exceed the limits

would be included, and items and activities that fall below the limits would be excluded. Items and activities that are excluded should be described with an appropriate level of documentation; these aspects can be addressed through qualitative BMPs for green remediation.

The outcome of part 1 of this step is a reference to the previously documented materials, waste, and public water from Steps 3 and 4 along with a bulleted list of types and quantities of transportation, equipment use, and offsite services that are involved in the remedy.

3.5.2 Part 2 – Determine Remedy Energy Use

The second part of Step 5 is to organize and refine the inventory information that was developed in Step 2 and to use that information to determine the amount of energy involved.

This part is divided into the following processes:

- Determining fuel use
 - Converting personnel transportation into fuel use
 - Converting onsite equipment use into fuel use
 - Converting transportation of equipment, materials, and waste into fuel use
 - Gathering information about actual fuel use (when such information is available)
- Determining electricity use
 - Converting electrical equipment and power requirements into electricity use
 - Gathering information about actual electricity use (when such information is available).

Determining Fuel Use

Converting Personnel Transportation into Fuel Use

Fuel use associated with personnel transportation is a function of the type of vehicle, the type of fuel, and the distance traveled. During remedy construction or remedy operation, this information may be readily available, and in some cases, actual fuel use may be tracked. If fuel use has been tracked for some or all of the remedy, it should be used directly and/or used to estimate other fuel use. However, in most cases, particularly during remedy design, it may be necessary to make some assumptions regarding fuel use. Exhibit 3.11A provides information for quantifying fuel use for personnel transportation.

Fuel use associated with relatively routine personnel travel is considered in the footprint calculations. However, it may not be necessary to include fuel use for non-routine or one-time travel because it likely falls below the established screening limits. For example, it is typically appropriate to include daily or weekly travel of a site operator to the site, whereas it may not be necessary to include travel by multiple parties for a kickoff planning meeting. Carpooling can be assumed where appropriate (e.g., two sampling technicians traveling together to conduct a monitoring event). The process of estimating fuel use for personnel transportation is illustrated in the footprint reduction scenarios presented in Appendix C.

Converting Onsite Equipment Use into Fuel Use

Equipment operation typically involves the use of a diesel or gasoline engine that may or may not have been modified to operate on biodiesel or fuel blends. Fuel use associated with equipment operation is a function of the following:

3.0 Footprint Methodology

- Horsepower rating of the equipment
- Type of fuel
- Engine efficiency
- Load on the engine
- Hours of operation.

Although the horsepower rating and fuel type may be known, the load on the engine, the engine efficiency (which varies with load), and the hours of operation may not be known. During remedy construction or operation, it may be feasible to track fuel use or contact equipment owners/operators about estimated fuel use. However, during remedy design, this may not be practical and a means of approximating fuel use is needed. Exhibit 3.11B provides assistance with quantifying fuel use for operation of heavy equipment. The process of estimating fuel use associated with heavy equipment operation is illustrated in the footprint reduction scenarios presented in Appendix C.

Converting Transportation of Equipment, Materials, and Waste into Fuel Use

Fuel use associated with transportation of equipment, materials, and waste is a function of the type of vehicle, the type of fuel, the weight of the cargo, the presence of other cargo, the distance traveled, and whether or not the vehicle makes an empty return trip. During remedy construction or remedy operation, this information may be readily available. In some cases, actual fuel use may have been tracked or can be estimated by freight carriers. If fuel use has been tracked for some or all of the remedy, it should be used directly and/or used to estimate other fuel use. In most cases, however, particularly during remedy design, it may be necessary to make some assumptions regarding fuel use. Exhibit 3.11C provides assistance with quantifying fuel use for equipment, materials, and waste transportation. The following additional considerations are noted:

- Empty return trips for trucks should be considered where appropriate (e.g., when items are transported directly to the site from the supplier or when waste is transported to a disposal facility).
- Consideration should be given to how a specific item is transported. For example, large quantities of materials and waste are typically carried in bulk, whereas equipment is typically transported via specialty freight (i.e., with no other cargo on board).
- In general, fuel requirements for transportation from the manufacturer to the vendor and then from the vendor to the site should be considered where practical.
- It is common for heavy equipment such as drill rigs to remain at the site throughout the project, reducing the amount of equipment mobilizations. This can be assumed unless site-specific information suggests otherwise.

The process of estimating fuel use for equipment, materials, and waste transportation is illustrated in the footprint reduction scenarios presented in Appendix C.

Converting Electrical Equipment and Power Requirements into Electricity Use

Electricity use associated with a remedy typically results from one of the following types of equipment:

- Electric motors for pumps, blowers, air compressors, and mixers
- Specialized treatment equipment such as ozone generators or ultraviolet oxidation units
- Subsurface electric resistive heating for *in situ* thermal remedies
- Electric heating, ventilation, and air conditioning for buildings

- Building lighting
- Process controls (typically with negligible electrical use compared to the equipment that is controlled).

3.0 Footprint Methodology

Electricity provided by an onsite generator should not be included in quantifying electricity use. Rather, the fuel used to power the generator should be included when converting equipment use into fuel use, as noted above.

Electricity obtained from a utility is easily tracked through past utility bills. When the footprint analysis is conducted on an operating remedy and past electricity use is representative of future electricity use, the electricity use from the electric utility bills should be used in the energy footprint. During the remedy design and remedy construction phases, utility bills are not available and assumptions regarding electricity use are made. In either case, an attempt should be made to document the individual demands for electricity from various pieces of equipment because this information is useful for identifying areas for reducing electricity use during interpretation of the results. Exhibit 3.12 provides equations for estimating equipment power ratings based on remedy information, and Exhibit 3.13 provides equations for estimating electricity use given the equipment power rating. The process of estimating electricity use is illustrated in the footprint reduction scenarios in Appendix C.

Like other forms of energy used on site, electricity generated from onsite renewable energy contributes to the metric of total energy use. Onsite renewable energy is also an important component of the metric for energy voluntarily derived from renewable resources and for avoiding emissions typically associated with conventional energy use. Onsite renewable energy systems that generate electricity commonly include meters tied to the utility grid; data supplied by these meters and associated net metering by the utility can be used to quantify these metrics. Electricity generated from an onsite but off-grid renewable energy system also should be tracked separately so that conversion factors for grid electricity are not applied to the electricity generated from the renewable energy system. During the feasibility study and design stage of a renewable energy system, engineering estimates of electricity generation are often available for footprint analysis. When electricity use is estimated by considering electrical demand of individual pieces of equipment, it is similarly important to subtract from this estimate the amount of electricity generated by the onsite renewable energy system so that the conversion factors for grid electricity are not applied to the electricity generated from the renewable energy system.

3.5.3 Part 3 – Convert the Remedy Inventory into Energy and Air Metrics

The third part of Step 5 is to convert the fuel, electricity, materials, and offsite services involved in the remedy into energy and air metrics. Footprint conversion factors are used for this purpose. Each item noted above (i.e., each type of fuel, each source of electricity, each material, and each offsite service) has its own set of conversion factors related to the production, manufacturing, or provisioning of that item or service. In addition, fuels such as diesel, gasoline, and natural gas each have an additional set of conversion factors related to the combustion of the fuels. For example, for a fuel such as diesel, conversion factors are used to calculate metrics for energy, GHGs, NO_x, SO_x, PM₁₀, and HAPs associated with the production of the fuel and the combustion. The application of the conversion factors for one of the metrics (GHG emissions measured as CO₂e) is illustrated in the following example for diesel fuel. First, the CO₂e conversion factor for offsite production of a gallon of diesel from the well field through the refinery (which is distinct from using a gallon of diesel) is applied.

<i>Diesel used (gallons</i>	<i>;</i>	<i>Footprint conversion factor for converting production of a gallon of diesel to tons of CO₂e</i>	<i>=</i>	<i>CO₂e footprint from diesel production</i>

Second, the CO₂e conversion factor for diesel use (combustion) is applied.

<i>Diesel used (gallons)</i>	<i>x</i>	<i>Footprint conversion factor for converting use of a gallon of diesel to tons of CO₂e</i>	<i>=</i>	<i>CO₂e footprint from diesel</i>

3.0 Footprint Methodology

Footprint conversion factors are applied in a similar manner to calculate the other metrics (energy use and emissions of NO_x, SO_x, PM₁₀, and HAPs) for production and use of diesel fuel. In addition, unique conversion factors are applied in a similar manner to the production and use of all the other fuels, to the generation and use of electricity, and to the manufacturing or provision of materials and services used for the remedy. The results are then compiled and presented. Example tables for applying the conversion factors, summing the various contributions, and presenting the results are presented in Appendix B and in the footprint reduction scenarios in Appendix C.

One of the challenges of conducting a footprint analysis is establishing accurate conversion factors for the fuels, electricity, materials, and services used in a remedy. Exhibit 3.14 (Appendix A) provides suggested default footprint conversion factors to use in footprint analyses of environmental cleanups. Most of these conversion factors are obtained from publicly available life cycle inventory databases. Others represent reasonable approximations based on analysis of a compilation of conversion factors. The values presented in life cycle inventory databases are generic or industry-wide averages that may not be accurate for specific manufacturing facilities. There is therefore a degree of uncertainty associated with using these values for footprinting specific remedies. These conversion factors are made available in Exhibit 3.14 to provide a means for quantifying green remediation metrics specified in this methodology and are not intended to guide procurement decisions or to suggest that one material should be used in place of another. In some cases, a site team may identify more specific footprint conversion factors that are based on site-specific or vendor-specific information. Site-specific conversion factors can be used for footprint analyses but the source of the conversion factor should be documented as part of the footprint analysis. For example, a site team that uses a vendor who provides “carbon neutral” solid waste disposal (if properly documented by the vendor) would choose a CO₂e conversion factor of zero for solid waste disposal rather than the “default” conversion factor, and documentation for choosing the site-specific conversion factor should be referenced as part of the footprint analysis. Another example is the use of emission control technologies (e.g., particulate filters) on diesel engines, which can reduce emissions of NO_x, SO_x, or PM. Emissions from diesel engines, in particular, are subject to substantial variation based on idling practices, type of vehicle or engine, model year, retrofits, and emission control technologies. For more thorough analysis of emissions from diesel engines refer to information available from EPA’s National Clean Diesel Campaign (<http://www.epa.gov/cleandiesel/>).

In addition to emissions from fuel combustion on site, other onsite sources of emissions may be identified for cleanup activities, particularly for the GHG and air toxics footprints. For example, air pollutants may be emitted in the off-gas of an air stripper, in the exhaust of a soil vapor extraction (SVE) system, by vaporization from exposed contaminated soil or groundwater, landfill gas emissions, dust generation, or perhaps other site-specific activities. In addition, onsite activities may result in carbon storage or other reductions of the GHG footprint (e.g., combusting landfill gas or carbon storage in tree biomass). Exhibit 3.15 provides a method of calculating air pollutant emissions from treatment processes and a reference for calculating dust and HAP emissions from construction activities. Exhibit 3.16 provides a method of calculating carbon stored in the biomass of trees that have been planted as part of remedial activities.

Conversion factors for energy and air emissions from offsite electricity generation are dependent on the specific grid mix supplied to the site and are determined on a site by site basis. The type of information used to determine the conversion factors is generally available from the individual electricity service providers. Otherwise, related information at the U.S. state level is available online from the U.S. Energy Information Administration (<http://www.eia.gov/state/>) or can be accessed for U.S. regions defined in the federally sponsored Emissions & Generation Resource Integrated Database (eGRID) (www.epa.gov/egrid). Exhibit 3.17 illustrates how to use the information from these sources to obtain the footprint conversion factors for grid electricity.

The footprint conversion factors suggested in Exhibit 3.14 and calculated as discussed above are not intended for use by site owners or regulatory agencies in submittals of footprint information to other organizations such as climate registries. Rather, they are intended to provide a sufficient level of information to allow a site team to

3.0 Footprint Methodology

make educated decisions regarding energy use and pollutant emissions associated with the cleanup. It is expected that updates or refinements to these emission factors will be provided as more information becomes available.

Appendix B provides example tables for applying conversion factors and presenting results, and the footprint reduction scenarios in Appendix C provide examples of calculating and presenting the energy and air metrics.

3.6 Step 6: Qualitatively Describe Affected Ecosystem Services

Step 6

In its current form, the methodology suggests the use of qualitative descriptions of the effects of a remedy on land and ecosystem services such as nutrient uptake and erosion control. Concepts related to ecosystem services are available online from EPA's Ecosystem Services Research Program at <http://www.epa.gov/ecology>.

3.7 Step 7: Present Results

Step 7

A suggested format for presenting results of each step is presented in Appendix B. In addition to the information gained through each step, documentation in a footprint analysis should be provided for:

- The screening process
- Analytical assumptions
- Possible areas of uncertainty
- Specific ideas of how to reduce the footprint.

Project teams may wish to supplement the methodology with additional metrics meeting project or organization needs and to tailor the presentation of footprint analysis results accordingly.

4.0 Considerations for Interpreting Footprint Results

Interpreting the results of a footprint analysis is influenced by a number of considerations, including the quality of the data used in the analysis, trade-offs among footprint metrics, and the magnitude of the footprint. The following sections discuss each of these considerations, and the footprint reduction scenarios provided in Appendix C demonstrate how they are considered.

4.1 Data Quality

There are three main factors that influence data quality:

- The first influence is the **quality of the remedy information input** into the footprint analysis. Variations in remedy information, such as the volume of soil to be treated or the groundwater extraction rate, can result in significant variations in the footprint results. This influence affects all green remediation metrics. The quality of the data input is generally lowest during the development of remedy alternatives when design studies have not been conducted and design-level engineering estimates have not been made. By contrast, the quality of data input is generally highest during remedy operation when actual data is available and the site has been thoroughly studied. The data quality during the design stage generally has benefited from several design studies and engineering estimates but does not have the benefit of actual data for input into the footprint analysis.
- The second influence is the **accuracy or appropriateness of the formulas** for quantifying use of electricity, fuel, water, materials, and offsite services involved in a specific remedy. Although formulas are provided in this methodology to help provide reasonable estimates of these quantities, they do not necessarily apply accurately to each site or scenario. This influence primarily affects the energy and air metrics but can also affect the other metrics to some degree. Example #1 (at the end of this section) demonstrates how assumptions regarding materials transport can greatly affect the footprint results.
- The third influence is the **accuracy of the conversion factors** used to convert the remedy inventory into green remediation parameters. Although the methodology includes conversion factors to use for this purpose, the conversion factors are general in nature and cannot account for differences that might occur from one manufacturing facility to another. Even the footprint conversion factors associated with converting electricity generation to emissions can impart significant variation in the footprint results. Example #2 (at the end of this section) provides an example of this influence and demonstrates that footprint conversion factors could vary by as much as one order of magnitude. This third influence also predominantly affects the energy and air metrics.

Based on the above discussion, it is apparent that the energy and air metrics may have the largest amount of uncertainty relative to the other metrics because the energy and air metrics are affected by all three data quality influences and the other metrics are primarily affected by the first data quality influence.

Project teams are encouraged to perform sensitivity analyses on the results by varying key input parameter values within reasonable ranges and evaluating the resulting changes in the metric values. Large changes in the metrics from relatively minor variations in a particular input parameter value suggests that the metric calculations are highly sensitive to that parameter and that uncertainty in that input parameter translates to a similar level of

uncertainty in the metric calculation. Sensitivity analyses are helpful tools for project teams to understand the implications of variations in data quality and better understand the quality of the footprint analysis results.

4.0 Considerations for Interpreting Footprint Results

4.2 Tradeoffs between Metrics

The methodology helps quantify metrics for more than 15 different parameters in four different green remediation core elements. Some of the parameters are local in nature (e.g., onsite HAP emissions or local water use), and others are more regional (e.g., NO_x/SO_x/PM₁₀ emissions) or global in nature (e.g., total GHG emissions). A potential modification to an existing remedy may increase the values for some metrics and decrease the values for others.

For example, a bioremediation remedy using water from the public supply results in significant use of public water but relatively minimal onsite emissions of NO_x, SO_x, and PM₁₀ because a generator or other equipment is not needed to provide power for extracting groundwater. Potentially modifying the remedy to use extracted groundwater will decrease or eliminate the use of public water but may increase the onsite NO_x, SO_x, and PM₁₀ emissions from a generator that provides the power for groundwater extraction. Different site teams and different stakeholders may favor one option over another depending on their prioritization of green remediation parameters, cost, and other factors. When such tradeoffs exist, it is helpful to know the metrics or parameters that are more important to site stakeholders as well as the influence of parameters relative to regulatory requirements.

4.3 Footprint Magnitude

Two main questions regarding the magnitude of a footprint may arise when interpreting the results of a footprint analysis:

- *“What is considered a large footprint or footprint reduction?”* When seeking to reduce a footprint, it is helpful to understand the significance of the magnitude of the potential reduction and the appropriate level of resources (e.g., time, materials, and money) that could be reasonably invested to achieve the reduction. A small percentage decrease in a footprint of a remedy with a large footprint may be greater in magnitude and more cost-effective to achieve than a large percentage decrease in the footprint of another remedy with a relatively small footprint.
- *“What is considered a significant difference between footprints of two or more potential modifications that are under consideration?”* The data quality influences noted above are crucial elements in determining if there is a significant difference between the footprints of two potential modifications to a remedial system, and comparisons of footprints should be interpreted with a degree of caution that is commensurate with the degree of uncertainty in the input data.

4.0 Considerations for Interpreting Footprint Results

Example 1. Data Quality - Transportation

Consider the example of transporting 1.5 tons of emulsified vegetable oil (equivalent to approximately 400 gallons) 500 miles via specialty freight and common freight. The fuel economies used are from Exhibit 3.11C and assume that the weight of the freight negligibly affects fuel economy relative to other factors that affect fuel economy.

Specialty freight (includes empty return trip)

Delivery trip:	500 miles	÷	6 miles per gallon	=	83 gallons
Empty return trip:	500 miles	÷	6 miles per gallon	=	83 gallons
Total:					166

Specialty freight (excludes empty return trip)

$$500 \text{ miles} \div 6 \text{ miles per gallon} = 83 \text{ gallons}$$

Common freight “heavy load” (i.e., truck is fully loaded, including freight not related to the site)

$$1.5 \text{ tons} \times 500 \text{ miles} \times 0.029 \text{ gallons per ton-mile} = 22 \text{ gallons}$$

The fuel use differs by 750 percent depending on the mode of transportation assumed. This example also assumes that the distance transported is known and correct. In many cases, especially during the remedy design stages, the transport distance or mode of transportation may not be known, introducing additional data quality concerns.

4.0 Considerations for Interpreting Footprint Results

Example 2. Data Quality – Electricity Generation

Consider the following example of estimating the GHG emissions (measured in CO₂e) from a P&T system in Tacoma, WA, where electricity use is 100,000 kilowatt-hours (kWh) per year and represents the large majority of the GHG footprint for the remedy. Various sources of information on the fuel blend or generation mix for grid electricity supplied to the site may be found on the internet or may be obtained from electricity providers. The sources include the 2007 generation mix for the eGRID (www.epa.gov/egrid) Northwest Power Pool (NWPP) subregion (where Washington is located), the 2009 generation mix for the NWPP from the Washington State Department of Commerce (“Commerce”), the 2007 Washington state generation mix from eGRID, the 2009 Washington state generation mix from Commerce, and the 2009 generation mix for Tacoma Power (local utility) provided by Commerce.

	NWPP (eGRID 2007)	NWPP (Commerce 2009)	WA (eGRID 2007)	WA (Commerce 2009)	Tacoma Power (Commerce)
Generation Mix					
Coal	31	44.	8.	17	3.
Hydropower	48	34.	73	64	87
Natural Gas	12	17.	6.	13	1.
Nuclear	3.	1.4	7.	4	6.
Other	3.	2.0	3.	2	0.
Total	10	100	10	10	10
CO₂e emissions generation (lbs/kWh)	0.	1.2	0.	0.	0.
CO₂e footprint (lbs) for 100,000 kWh of electricity use	87	12	26	54	10

Notes:

- “Commerce” = Washington State Dept. of Commerce <http://www.commerce.wa.gov/site/539/default.aspx>)
- Coal, natural gas, and nuclear CO₂e emissions for “Commerce” generation mixes are based on data from the National Renewable Energy Laboratory Lifecycle Inventory (NREL, www.nrel.gov/lci). Hydropower CO₂e emissions are assumed to be 0 lbs/kWh. “Other” fuels are assigned CO₂e emissions of 0 lbs/kWh in calculating conversion factors for each fuel blend, which may slightly underestimate emission factors for these generation mixes. The footprint for extracting and transporting fuels is not included.

This analysis demonstrates that the generation mixes vary considerably among the various sources of information. For example, the percentage of electricity generated from coal varies from 8 percent to 44 percent. The variation in the generation mix results in a variation in the footprint from 10,000 to 120,000 pounds of CO₂e per year, which is more than one order of magnitude. The conversion factor even varies by over 35 percent for the NWPP sub-region depending on the year, the entity compiling the data, or both. The method for calculating the conversion factors for electricity generation therefore has a significant influence on the footprint results. The conversion factors for electricity are relatively straightforward to calculate compared to the conversion factors for other items associated with a remedy, and it is reasonable to expect that the conversion factors for manufactured goods also vary significantly based on factory location and several other factors.

5.1 Approaches to Reducing Footprints

The process of conducting a footprint analysis and the results from analysis can help project teams identify the largest contributions and develop potential approaches to reducing those contributions and achieving a greener cleanup. The largest footprint reductions for any one metric typically result from modifying certain processes or project components. For example, if electricity use is the largest contributor to the energy footprint, the largest footprint reduction will likely come from reducing overall electricity use. In many cases, the electricity use can be reduced by modifying specific remedy components that use the most electricity.

Each approach should be tailored to a site's unique conditions and the expected operating parameters of a particular cleanup remedy. Some contributions to a metric may appear to be small relative to other contributions from the same project but are large when compared to comparable remedies implemented at other sites. For example, the energy footprint associated with materials used for a large P&T remedy may be small relative to the energy footprint associated with electricity use at the same site. However, the energy footprint associated with materials at that site may be large when compared to the energy footprint of a comparable P&T remedy at a different site. Appendix B includes figures that can be used to illustrate the magnitudes of various footprint contributions relative to each other or a threshold value to help identify those that merit the most attention for footprint reduction.

Experience and documentation gained through EPA's green remediation initiative, including illustrative profiles of green remediation strategies (available online at http://www.cluin.org/greenremediation/tab_d.cfm), suggests that the greatest opportunities for footprint reduction often relate to renewable energy or remedy optimization. Example #3 (in Section 5.3) illustrates footprint reductions that could result from applying both strategies. Renewable energy can be incorporated through onsite systems that generate direct power for cleanup equipment or through purchases from the local utility or a competitive provider. Optimization could involve changes in the conceptual site model, data interpretation, or specific system components that result in more cost-effectiveness and higher project efficiencies. Planning and implementation of either strategy can benefit from the additional perspective provided by a footprint analysis.

Footprint reduction approaches can be linked to specific or general categories of EPA's green remediation BMPs. The Agency has compiled a series of quick-reference fact sheets describing BMPs for specific remedial technologies, project phases, and issues common to many sites. These documents (available at http://www.cluin.org/greenremediation/docs/GR_factsheet_topics_update.pdf) include:

- Excavation and Surface Restoration (EPA 542-F-08-012, December 2008)
- Site Investigation (EPA 542-F-09-004, December 2009)
- Pump and Treat Technologies (EPA 542-F-09-005, December 2009)
- Bioremediation (EPA 542-F-10-006, March 2010)
- Soil Vapor Extraction & Air Sparging (EPA 542-F-10-007, March 2010)
- Clean Fuel & Emission Technologies for Site Cleanup (EPA 542-F-10-008, August 2010)
- Integrating Renewable Energy into Site Cleanup (EPA 542-F-11-006, April 2011)
- Sites with Leaking Underground Storage Tank Systems (EPA 542-F-11-008, June 2011)
- Landfill Cover Systems & Energy Production (EPA 542-F-11-024).

Sections 5.1 through 5.3 describe overall approaches and specific BMPs that could be used to reduce the environmental footprint posed by types of remedies that are commonly implemented for site cleanup. Results of a

footprint analysis can help project teams target the BMPs that most effectively reduce the footprint and track associated improvements to a project's environmental outcome.

5.0 Approaches to Reducing Footprints

5.1 Approaches to Reducing Materials and Waste Footprints

P&T remedies: The largest contributors to the materials and waste footprints for a P&T remedy are typically system construction, chemicals use, and waste disposal. All of these items are directly tied to the extraction rate and water quality, so the optimal extraction program would be a key focus for footprint reduction of P&T systems. Consider the GCL Tie & Treating Superfund Site in Sydney, NY. Potassium permanganate use and waste generation associated with removal of manganese (a nuisance parameter for treatment at this site, but not a contaminant of concern) is directly tied to manganese loading (flowrate multiplied by influent concentration). Optimizing the extraction network can reduce the flow rate and manganese loading, resulting in a reduction of both potassium permanganate use and waste generation. Another key focus for footprint reduction of P&T systems is the beneficial reuse of the treated water. Also consider the P&T system at the 10th Street Superfund Site in Columbus, NE. A dispersant is added to the water to reduce fouling of the air stripper. However, the treated water is distributed for public consumption, and the dispersant addition is required by the water provider to prevent scaling in distribution piping and piping in residential and commercial buildings. Because the dispersant is required for public distribution of the water, the dispersant use is not an “additional” item contributed by the remedy and need not be considered part of the materials footprint for the remedy. Therefore, the beneficial reuse of water not only reduces the water footprint but the materials footprint associated with dispersant production.

ISCO and *in situ* bioremediation: The largest contributors to the materials footprint associated with these *in situ* remedies is the amount of reagents used/injected and the construction of permanent injection locations. Optimizing the number of injection locations and the reagent demand could lead to significant footprint reductions. In some cases, using existing wells as injection points can reduce the number of additional wells needed. Optimizing the area to be treated (perhaps with more characterization) could reduce both the number of injection locations and the demand for reagents. Creating recirculation cells by using extracted groundwater for reagent blending and injection could help distribute the reagents in the subsurface, potentially reducing the number of injection points. The use of direct-push technology to deliver reagents instead of permanent injection wells may reduce materials use but increase energy use, presenting a potential tradeoff for site stakeholders.

Excavation remedies: The largest contributions to materials use and waste generation for excavation remedies are the disposal of excavated material in a landfill and the use of clean fill for backfill. Consideration could be given to conducting onsite treatment of impacted soils followed by reuse of the treated soil on site, using clean soil from the excavation to partially backfill the excavation, and locating crushed concrete or other reusable materials for fill. Consideration could also be given to *in situ* remediation via contaminant removal/destruction or soil stabilization. These alternative approaches may reduce waste generation but might also affect the materials use or energy and air footprints, presenting a potential tradeoff for the site team.

5.2 Approaches to Reducing Water Footprints

P&T remedies: The most important factor in quantifying the water footprints for many P&T remedies is the change in water quality through the extraction, treatment, and discharge process. Extracted and treated groundwater may be a valuable resource, but if the treated water is discharged to relatively low quality surface water (e.g., water with high dissolved or suspended solids), the higher quality of the treated water is degraded and its direct usefulness as a resource is lost. Finding beneficial use of the treated water (e.g., potable water, industrial process water, or irrigation) is preferred if an appropriate use can be identified and the water has been thoroughly tested. This is because using the treated water displaces demand on other water supplies and offsets the energy and footprint of obtaining that other water resource. If a beneficial use is not available, discharging the water to an aquifer or surface water body of equal quality and availability is another means of reducing the water footprint. Focus should also be placed on optimizing the groundwater extraction rate.

5.0 Approaches to Reducing Footprints

ISCO and *in situ* bioremediation: The largest contributors to the water footprint associated with these *in situ* remedies are reagent dilution, injection, and dispersal. Optimizing the number of injection locations, reagent demand, and delivery concentration could help reduce overall water use. In addition, the source of water used can be a factor. Using extracted groundwater in place of water from the public supply would be favorable because extracted groundwater is a less-refined water resource than public supply water. In addition, use of extracted groundwater may help disperse the reagents in the subsurface.

Excavation remedies: Large contributions to the water footprint for excavation and other earth moving remedies could include water used for dust control or water from dewatering. Water used for dust control could be reduced by planning work for the appropriate season or weather condition. Water use could also be reduced through use of chemicals, but this would result in an increase in the materials footprint. With respect to dewatering, excavations below the water table can result in substantial dewatering efforts to lower the water table below the planned extent of the excavation. Cutoff walls or other engineering controls could help reduce the extraction rates for dewatering. Polymers or bentonite slurry may also help prevent trenches beneath the water table from collapsing and help avoid or reduce the need for dewatering.

5.3 Approaches to Reducing Energy and Air Footprints

P&T remedies: The largest contributors to the energy and air footprints are typically electricity, chemicals use, process sampling, and waste disposal. Electricity, chemical use, and waste disposal are directly tied to the extraction rate, so establishing the optimal extraction rate would be a key focus for footprint reduction of P&T systems. The intensive electricity use of P&T systems also makes them excellent candidates for the application of renewable energy. The renewable energy may be generated on site (e.g., by a photovoltaic system, wind turbine, or system for converting landfill gas to energy), purchased from the utility provider, or purchased as RECs. Significant energy is used to lift groundwater from the water table to the surface and to treat it. As a result, substantial footprint reduction can be achieved if the treated water can be put to an appropriate beneficial use (after appropriate testing), effectively eliminating the energy and emissions associated with the water supply that has been displaced. Process sampling can also be a large contributor to the energy and air footprints. For that reason, optimizing the process sampling program and utilizing surrogate parameters such as pressure drop, oxidation-reduction potential, pH, turbidity, and other parameters that help streamline the process sampling program can help reduce the energy and air footprints.

ISCO and *in situ* bioremediation: The largest contributors to energy and air footprints are typically the production and transport of the reagents to be injected. Therefore, optimizing the amount of reagent to be added would be a key focus for footprint reduction for *in situ* remedies that involve reagent injection. It may be appropriate to work in phases, beginning with the best estimate of reagent use and modifying or increasing reagent doses for future injection events rather than injecting too much reagent in the first event. Increased characterization of the treatment area may also help reduce the treatment volume and the reagent use. Selection of the reagent type can be a factor. Although most reagents for chemical oxidation are refined chemicals that are unlikely to be a manufacturing waste or byproduct, the reagents for *in situ* bioremediation may be food or agricultural waste products. Mulch, off-specification soft-drink syrup, low-grade molasses, and other waste products may be appropriate reagents for *in situ* bioremediation of chlorinated solvents. Because these items are waste products, the footprint for producing them would not be attributed to the remedy. Attention could also be given to the provider's location. Preference could be given to local providers to avoid long transport distances. Where multiple injections are required or the subsurface formations are relatively tight, it may be preferable to use permanent injection wells to avoid the repeated mobilization of heavy equipment (e.g., direct-push rigs) that would operate throughout the injection events.

Excavation remedies: The largest contributions to energy and air footprints for excavation remedies are the transport of the excavated material or backfill material from one location to another. The transport may be from one

portion of the site to another portion via dump truck, loader, or dozer. It may also be from the site to an offsite

5.0 Approaches to Reducing Footprints

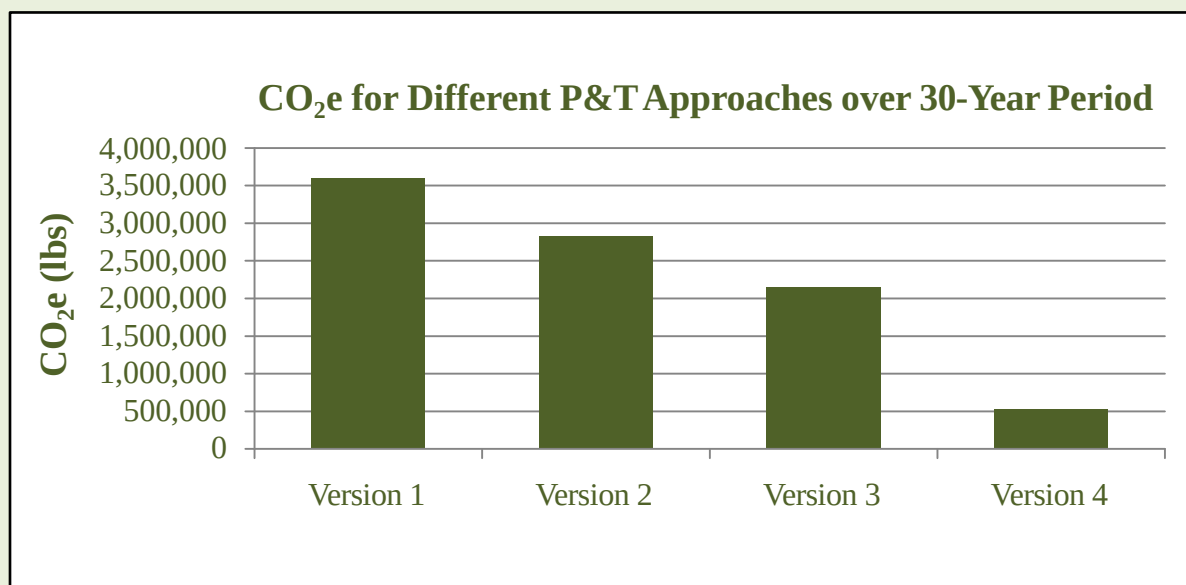
location for disposal or reuse. As a result, minimizing this horizontal transport distance and choosing the optimal mode of transportation would be key areas of focus in reducing the footprints of excavation remedies. In some circumstances, transportation by train or barge over long distances may have a lower footprint than transportation by truck. Consideration could be given to using onsite treatment of impacted soils followed by reuse of the treated soil on site, using clean soil from the excavation to partially backfill the excavation, locating local sources for fill, and minimizing the distance to disposal locations. If soil or material requires substantial transport on site, footprint reductions may be best achieved by loading dump trucks rather than carrying loads long distances in front loader buckets or transporting long distances with a dozer. The use of renewable fuels (e.g., biodiesel) could increase the percentage of energy from renewable resources. It could also reduce the GHG footprint for the remedy. Although there may be a GHG footprint for onsite soil treatment, there is also a footprint associated with landfill activities that could partially or completely offset the footprint of the onsite treatment.

It is noted that many footprint reduction approaches also result in cost reductions. For example, materials use and waste disposal can be significant contributors to the costs of a cleanup project. As a result, decreasing the materials and waste footprints often results in a cost savings. Similarly, energy use, materials use, and laboratory analysis also can be significant contributors to the costs of a cleanup project and significant contributors to the energy and air footprints. As a result, decreases in the energy and air footprints by decreasing these items can often result in cost savings. Actual costs and cost savings associated with these reductions will depend on the changes made and a variety of site-specific factors.

5.0 Approaches to Reducing Footprints

Example 3. Footprint Reductions from Optimization and Application of Renewable Energy

The chart below presents the greenhouse gas emissions for several alternative versions of a P&T system that treats approximately 50 gpm of extracted water with a trichloroethene (TCE) concentration of approximately 500 µg/L. The chart illustrates the footprint reductions associated with optimized versions of the P&T system plus the effect of using renewable energy. Although other parameters of are of importance, the greenhouse gas (CO₂e) footprint is used as an example parameter.



Version 1 – Treatment provided by air stripping with treatment of air stripper off-gas

Version 2 – Air stripping with off-gas treatment – but use of variable frequency drives on motors

Version 3 – Treatment provided by liquid phase GAC instead of air stripping

Version 4 – Version 1 with all electricity use provided by renewable electricity generated on-site

The example illustrates that the footprint can be reduced by energy efficiency efforts (e.g., variable frequency drives), potential changes to the treatment system components (e.g., GAC instead of air stripping), and application of renewable energy.

6.0 References

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<http://www.fedcenter.gov/programs/eo13514/>

Intergovernmental Panel on Climate Change Assessment Report 4, Chapter 2, *Changes in Atmospheric Constituents and in Radiative Forcing*

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National Renewable Energy Laboratory, U.S. Life Cycle Inventory Database

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<http://www.epa.gov/cleanenergy>

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6.0 References

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Superfund Green Remediation Strategy
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U.S. Environmental Protection Agency, Wastes – Resource Conservation – Reduce, Reuse, Recycle
<http://www.epa.gov/osw/conserve/rrr/>

U.S. Environmental Protection Agency, Greening EPA - Water Conservation
<http://www.epa.gov/oaintrnt/water/>

Appendix A: Exhibits

- EXHIBIT 2.1 – ACCOUNTING FOR RENEWABLE ENERGY
- EXHIBIT 2.2 – RENEWABLE ENERGY CERTIFICATES (RECs)
- EXHIBIT 2.3 – DEFINING GLOBAL WARMING POTENTIAL
- EXHIBIT 3.1 – EXAMPLE REMEDY INFORMATION TO GATHER FOR STEP 2
- EXHIBIT 3.2 – SCREENING APPROACH
- EXHIBIT 3.3 – DENSITIES OF COMMON MATERIALS
- EXHIBIT 3.4 – APPROXIMATE MATERIAL CONTENT OF AQUEOUS CHEMICAL SOLUTIONS
- EXHIBIT 3.5 – APPROXIMATE MATERIALS USE FOR PIPING AND WIRING RUNS
- EXHIBIT 3.6 – APPROXIMATE MATERIALS USE FOR WELL INSTALLATION
- EXHIBIT 3.7 – APPROXIMATE MATERIALS USE FOR PROCESS EQUIPMENT AND BUILDING CONSTRUCTION
- EXHIBIT 3.8 – APPROXIMATE CONTENT OF CONCRETE, ASPHALT, AND STEEL
- EXHIBIT 3.9 – STORMWATER DIVERSION
- EXHIBIT 3.10A – GENERAL CHECKLIST FOR TYPICAL ITEMS TO CONSIDER IN A FOOTPRINT ASSOCIATED WITH CONSTRUCTION OF A REMEDY
- EXHIBIT 3.10B – GENERAL CHECKLIST FOR TYPICAL ITEMS TO CONSIDER IN A FOOTPRINT ASSOCIATED WITH REMEDY OPERATION
- EXHIBIT 3.11A – QUANTIFYING FUEL USE FOR PERSONNEL TRANSPORTATION
- EXHIBIT 3.11B – QUANTIFYING FUEL USE FOR HEAVY EQUIPMENT USE
- EXHIBIT 3.11C – QUANTIFYING FUEL USE FOR EQUIPMENT, MATERIALS, AND WASTE TRANSPORTATION
- EXHIBIT 3.12 – ESTIMATING SIZES OF ELECTRICAL EQUIPMENT
- EXHIBIT 3.13 – ESTIMATING ELECTRICITY USE FOR TYPICAL REMEDIATION COMPONENTS
- EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS
- EXHIBIT 3.15 – ESTIMATING AIR POLLUTANT EMISSIONS FROM ONSITE SOURCES
- EXHIBIT 3.16 – ESTIMATING CARBON STORED IN PLANTED TREES
- EXHIBIT 3.17 – USING DATA FROM ELECTRIC SERVICE PROVIDERS TO DETERMINE FOOTPRINT CONVERSION FACTORS

EXHIBIT 2.1 – ACCOUNTING FOR RENEWABLE ENERGY

There are four main ways in which renewable energy can be applied to site remediation on a voluntary basis:

- Onsite systems that generate electricity, mechanical power, direct heat, or landfill gas
- Use of biodiesel in equipment and vehicles
- Renewable-sourced electricity purchased from the local utility or a competitive provider
- Direct purchase of renewable energy certificates (RECs)

A portion of standard grid electricity provided to the site may also include electricity that was generated from renewable resources. This form of renewable energy, which is provided by default to the site as part of a utility's basic electricity generation mix, is not considered "voluntary" in this methodology. This form of renewable energy is included in the total energy metric (metric E-1) of this methodology, but is not considered in the renewable energy metrics (metrics E-2A – E-2C) because project teams have little or no control over the sources of energy in the basic generation mix. The emission factors used for estimating emissions from electricity generation, however, do include the renewable energy component of the basic generation mix such that grid electricity with a relatively high percentage electricity from renewable resources will likely have lower emissions factors than grid electricity that has a relatively low percentage of electricity from renewable resources.

Each of the four voluntary ways of applying renewable energy to site remediation is discussed below in more detail.

Onsite Systems that Generate Electricity, Mechanical Power, Direct Heat, or Landfill Gas

The following table presents the forms of onsite energy use and the renewable resources that can be used to generate the energy.

Form of Energy	Renewable Resource for Generating Energy
Electricity	Solar Wind Hydroelectric Geothermal Biomass*
Mechanical energy	Wind Hydropower
Heat	Solar thermal Geothermal** Biomass*

* Biomass refers to woody waste, agricultural crops or waste, animal and other organic waste, energy crops, landfill gas, and methane generated from waste water that is used to generate usable energy.

** Geothermal refers to heat extracted from the subsurface for direct use and does not refer to heat exchange with water source heat pumps or air heat pumps.

Use of Biodiesel in Equipment and Vehicles

Biodiesel can be used on site to generate electricity, used on site to power heavy equipment, and used on site and off site for transportation. Biodiesel may be used alone or blended with regular diesel (e.g., B20 is 20 percent biodiesel and 80 percent petroleum-derived diesel). For biodiesel blends, only the percentage of the blend that is biodiesel counts as biodiesel use. Bio-ethanol is not considered a renewable energy source in this methodology.

EXHIBIT 2.1 – ACCOUNTING FOR RENEWABLE ENERGY (continued)

Renewable-Sourced Electricity Purchased from the Local Utility or a Competitive Provider

The EPA Green Power Purchasing Program *Guide to Purchasing Green Power* (Office of Air (6202J), EPA430-K-04-015, March 2010) describes renewable electricity products that project teams may have the ability to purchase directly from the electricity provider. In regulated electricity markets, a *green pricing* product could be voluntarily purchased from the local utility. Green pricing allows customers to voluntarily purchase renewable electricity by paying a premium that supports a greater level of utility investment in renewable energy. In competitive electricity markets, an electricity service provider can be selected that offers renewable electricity. In this type of market, a *green marketing* product can be voluntarily purchased (and delivered through the electric grid) from a provider other than the local utility. Similar to a green pricing product, a green marketing product involves paying a premium in exchange for electricity generated from renewable resources. For this methodology, the definition of renewable electricity as it applies to purchased electricity from renewable resources meets the definition of “green power” used by the U.S. EPA Green Power Partnership, *Partnership Requirements, Appendix A* as follows:

- Solar photovoltaic
- Wind
- Geothermal (not to be confused with the use of geothermal heat pumps)
- Eligible biomass
- Eligible hydropower

The reader is directed to the above reference for definitions of “eligible” biomass and hydropower. More information about purchasing renewable electricity is provided online by EPA’s Green Power Partnership at www.epa.gov/greenpower. The effects of voluntary purchases of renewable electricity on air emissions are discussed in Exhibit 2.2.

For the purpose of this methodology, potential emissions reductions from the voluntary purchase of renewable electricity are not applied to the emissions metrics (Metrics A-1 through A-5). See Exhibit 2.2 for more information.

Direct Purchase of Renewable Energy Certificates (RECs)

Where green pricing and green marketing products are not available, project teams can purchase renewable electricity in form of RECs. The EPA Green Power Purchasing Program *Guide to Purchasing Green Power* defines a REC as follows:

A REC is a certificate that represents the generation of one megawatt-hour (MWh) of electricity from an eligible source of renewable energy. Each REC denotes the underlying generation energy source, location of the generation, and year of generation (a.k.a. “vintage”), environmental emissions, and other characteristics associated with the generator.

RECs can be purchased and “bundled” with electricity purchased from the grid, resulting in renewable electricity. Once RECs are sold, the seller can no longer claim that the electricity it produces from its facility is renewable because those rights have been transferred to another party.

More information about RECs is provided at www.epa.gov/greenpower. The effects of purchasing RECs on air

emissions are discussed in Exhibit 2.2.

For the purpose of this methodology, potential emissions reductions from the voluntary purchase of RECs are not applied to the emissions metrics (Metrics A-1 through A-5). See Exhibit 2.2 for more information.

EXHIBIT 2.2 – EFFECTS OF VOLUNTARY PURCHASES OF RENEWABLE ELECTRICITY AND RECS ON AIR EMISSIONS

Many federal and non-federal programs support emission reductions from the voluntary purchase of renewable electricity from green pricing products, green marketing products, or RECs. One example is the EPA Green Power Purchasing Program (www.epa.gov/greenpower). The White House Council on Environmental Quality document titled *Federal Greenhouse Gas Accounting and Reporting Guidance*, October 6, 2010 and the associated document titled *Federal Greenhouse Gas Accounting and Reporting Guidance Technical Support Document* both provide similar guidance on reducing emissions through the purchase of renewable electricity in the form of RECs.

Selecting the appropriate renewable electricity products to purchase and appropriately accounting for potential reductions in air emissions can be complex. Further guidance on purchasing renewable electricity (including RECs) and quantifying air emission reductions from those purchases can be found in the above-noted resources.

The methodology encourages reduction of air emissions through onsite generation or use of energy from renewable resources and use of biodiesel (E-2A) prior to considering air emission reductions through voluntary purchase of renewable electricity or RECs (E-2B and E-2C).

This prioritization is intended to establish a primary focus on practices that directly reduce emissions associated with a remedy, including energy efficiency measures, engine retrofits, and emissions control technologies.

EXHIBIT 2.3 – DEFINING GLOBAL WARMING POTENTIAL

Different GHGs have different residence times and different effectiveness in absorbing and emitting back to Earth the infrared radiation that results in temperature increases. The concept of global warming potential (GWP) accounts for these differences and quantifies the contribution of a particular GHG to global warming in terms of a reference gas. Carbon dioxide is typically chosen as the reference gas, and GWP is measured in carbon dioxide equivalents (CO₂e). The GWP of common GHGs used for this methodology are as follows:

GHG	GWP (CO ₂ e)
Carbon dioxide (CO ₂)	1
Methane (CH ₄)	21
Nitrous oxide (N ₂ O)	310
Carbon tetrachloride (CCl ₄)	1,400
1,1,1-Trichloroethane (CH ₃ CCl ₃ , methyl chloroform)	146
Bromomethane (CH ₃ Br)	5
Chloromethane (CH ₃ Cl)	13
Methylene chloride (CH ₂ Cl ₂)	8.7
CFC-11 (CCl ₃ F, Freon-11)	3,800

Intergovernmental Panel on Climate Change Assessment Report 4, Chapter 2, Changes in Atmospheric Constituents and in Radiative Forcing (www.ipcc.ch), which is referenced by U.S. EPA at www.epa.gov/climatechange.

Example: the emission of 1 pound of methane has an equivalent warming effectiveness as the emission of 21 pounds of carbon dioxide.

Many other compounds, particularly chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and other perfluorinated compounds, are strong GHGs but are not typically associated with environmental cleanups. If these compounds are identified in the soil, groundwater, or sediments of a site, it may be important to include air emissions of the compounds in the GHG metric. Information pertaining to their global warming potential can be found in the Intergovernmental Panel on Climate Change Assessment Report 4, Chapter 2, *Changes in Atmospheric Constituents and in Radiative Forcing* (www.ipcc.ch).

EXHIBIT 3.1 – EXAMPLE REMEDY INFORMATION TO GATHER FOR

STEP 2

Excavation and Disposal

- Volume of soil to be excavated
- Percentages disposed of as hazardous waste and non-hazardous waste
- Methods of transportation available
- Facilities for disposal
- Associated sampling and analysis
- Material used for backfill
- Need for dewatering and discharge point for water

Pump and Treat (P&T) and Soil Vapor Extraction (SVE)

- Number of wells, trenches, etc. and distance to process area
- Extraction rates
- Expected influent concentrations
- Treatment processes
- Discharge location (for P&T)
- Frequency of operator visits

In situ Remedies Involving Nutrient or Reagent Injections

- Method of injection (direct-push, injection wells, delivery trenches)
- Aquifer volume to be treated
- Number of injection points
- Number of injections
- Nutrient demand for calculating mass of injected materials

Phytoremediation

- Number and types of trees
- Method of planting
- Fertilizer, pesticide, watering, and fencing needs

In situ Thermal Remediation

- Method of heating
- Volume of treatment area
- Type of contaminant and required heating temperature

- Size of vapor control system
- Method of treating off-gas
- Pounds of contaminants to be removed

Soil Amendments

- Amendment material
- Volume of soil to be treated
- Method of adding amendment
- Amendment demand

Monitoring for Various Remedy Types

- Process monitoring
- Long-term monitoring
- Performance monitoring

EXHIBIT 3.2 – SCREENING APPROACH

The screening approach uses user-specified limits, two streamlined comparison approaches, and professional judgment to determine items and activities that are included in the footprint analysis. Two types of user-specified limits are as follows:

- Limit based on a specified percentage of the maximum contributor to a particular metric
- Limit based on a specified magnitude for a particular metric

Based on professional judgment, an item or activity that is expected to contribute less than either of the limits can be excluded from the analysis with an appropriate level of documentation. These limits are applied to the following categories:

• Refined materials	• Each onsite water resource
• Unrefined materials	• Onsite NO _x , SO _x , PM ₁₀ emissions
• Non-hazardous waste	• Onsite HAP emissions
• Hazardous waste	• Total energy use*

** The total energy use category is assumed to be generally representative of the total emissions for CO₂e and other air pollutants.*

Comparing items for the materials, waste, and water metrics to the two limits noted above is reasonably straightforward. Comparison of emissions and energy use is more complicated. Streamlined approaches are provided below for comparing 1) various onsite sources of NO_x, SO_x, and PM₁₀ emissions and 2) various contributions to total energy use. An example is provided for developing the two screening limits noted above. The screening approach is also demonstrated in the footprint reduction scenarios in Appendix C.

Streamlined Comparison of Onsite NO_x, SO_x, and PM₁₀ Emissions

do not use this assumption for final footprint presentation.

The onsite NO_x, SO_x, and PM₁₀ emissions are generally linked to onsite fuel combustion; therefore, determining the largest contributor and gauging other contributions relative to the set limits is based on use of various fuels. The table to the right shows the approximate amounts of fuel that will result in generally equivalent NO_x, SO_x, and PM₁₀ emissions. For purposes of this screening process, assume that combustion of the volumes of fuel noted in the table to the right results in emissions of 0.2 pounds (lbs) of NO_x + SO_x + PM₁₀. However,

Approximate Equivalencies for NO_x, SO_x, and PM₁₀ from On-Site Fuel Combustion	
Diesel combustion	1 gallon (gal)
Gasoline	1 gal
combustion	10 ccf

ccf = 100 cubic feet, which contains a similar amount of energy as 1 therm Note: The

sum of the NO_x, SO_x, and PM₁₀ emissions from the combustion of the indicated amounts of the fuels are generally comparable. This table is not intended to suggest that they are equal. This table is based on the information provided elsewhere in this document.

***FOR SCREENING COMPARISON PURPOSES ONLY
DO NOT USE THESE APPROXIMATE EQUIVALENCIES FOR FINAL FOOTPRINT PRESENTATION***

EXHIBIT 3.2 – SCREENING APPROACH (continued)

Streamlined Comparison for Total Energy Use

Contributions to the total energy use metric are based on a variety of factors, including electricity use, fuel combustion, and materials manufacturing. The following table provides approximate amounts of energy-related items, materials, or services that result in generally equivalent amounts of energy use. The table also defines an “energy screening unit”. As shown in the example below, the energy screening units and values in this table can be used to compare the magnitudes of various contributors to the total energy footprint to determine those contributors that exceed screening limits and will be included in the footprint analysis.

Item	Physical Unit	# of Physical Units in One Screening	# of Screening Units in One Physical
Electricity use	kWh	1	1
Continuous electric motor operation	Horsepower	1	1
Natural gas use	ccf or therm	0.1	10
Diesel or gasoline use	Gal	0.1	10
Onsite heavy equipment use	HP-hr	2	0.5
Excavation	Cubic yard	5	0.2
Trenching and pipe installation	Linear foot	10	0.1
Well installation (including drill rig)	Vertical foot	0.02	50
Personnel transport	Mile	2	0.5
Materials or waste transportation	Mile	0.5	2
Materials or waste transportation	Ton-mile	3	0.33
Refined materials use	lb	1	1
Unrefined materials use	Ton	1	1
Water discharged to the sanitary sewer	1,000 Gal	1	1
Waste disposal (drums)	Drum	10	0.1
Waste disposal (bulk)	Ton	0.1	10
Laboratory analysis	\$	1	1

Note: The total energy uses associated with a screening unit is generally between 0.01 and 0.02 MMBtus (with some exceptions) based on information provided elsewhere in this document. The values are only intended to be used to assist with screening, not for final footprint presentation.

Example: A remedy involves the following:

Item	Number of Screening
10,000 lbs of refined materials	$10,000 \times \mathbf{1} = 10,000$
5,000 ton-miles of materials transport	$5,000 \times \mathbf{0.33} = 1,650$
250,000 kWh of electricity	$250,000 \times \mathbf{1} = 250,000$

The numbers in bold in the table to the left are taken from the far right-hand column of the above table. The use of a screening unit facilitates comparison between various items that involve energy use. For example, 1,650 is a small fraction of 250,000 (<1%), indicating that materials transport can be omitted from the footprint analysis.

EXHIBIT 3.2 – SCREENING APPROACH (continued)

Example Development of Screening Limits

The table below demonstrates the development of screening limits for the screening categories presented at the beginning of this exhibit. The user identifies the “largest contributor” and the magnitude of the contribution (“largest contribution”) for each of the 10 categories (rows). Based on the level of detail and accuracy sought in the footprint analysis, the user also specifies for each category 1) the “selected % of largest contributor” to calculate the “percent-based limit” and 2) the “selected magnitude-based limit”. The “applicable screening limit” is the larger of the “percent-based limit” and the “selected magnitude-based limit”. A simplified *in situ* bioremediation remedy is used for example purposes in this table.

Once the “applicable screening limits” are determined, various items in each screening category would then be compared to “applicable screening limit” for that category (comparison not shown in this example). Items in each category that are expected to be less than the limit by professional judgment are excluded from the footprint analysis. Refer to the footprint reduction scenarios in Appendix C for detailed application of the screening approach.

Category	Unit	Largest	Large st	Selected % of Largest	Perce nt-	Selected Magnitude-b ased Limit	Applic able Screen
Refined Materials	tons	Vegetable oil	150	1%	1.5	0.5	1.5
Unrefined Materials	tons	Sand for sand pack	1.5	1%	0.015	0.5	0.5
Non-hazardous Waste	tons	Drill cuttings	6	1%	0.06	0.5	0.5
Hazardous Waste	tons	None	0	1%	0	0.5	0.5
Public water	gals	Water for drilling	500	1%	0.05	1,000	1,000
Shallow groundwater	gals	Pump test	1,000,00 n	1%	10,000	1,000	10,000
Shallow groundwater	gals	Nutrient blending	3,000,00 n	1%	30,000	1,000	30,000
Onsite NOx, SOx, PM10 emissions	lbs	Drilling	120	1%	1.2	1	1.2
Onsite HAP emissions	lbs	Drilling	<1	1%	0.01	1	1
Total Energy use	Screen in	Vegetable oil	300,000	1%	3,000	1	3,000

* Energy screening units defined above.

EXHIBIT 3.3 – DENSITIES OF COMMON MATERIALS

The following table provides approximate densities of common materials that can be used to convert a known volume of a material into a mass of that material for documenting material use by mass. This information has been provided to help streamline the process of gathering information for the materials metric.

Material	Density
<i>Refined</i>	
Cement	94 lbs/ft ³
GAC	30 lbs/ft ³
HDPE	59.6 lbs/ft ³
Lime (hydrated)	30 lbs/ft ³
PVC	87.36 lbs/ft ³
Steel	490 lbs/ft ³
<i>Unrefined</i>	
Asphalt	1.95 tons/cy
Concrete	1.95 tons/cy
Compacted clay	1.5 tons/cy
Mulch/compost	0.4 tons/cy
Sand, gravel, soil	1.5 tons/cy

ft³ = cubic foot

tons = short tons (2,000 pounds)

cy = cubic yard

REFERENCES:

Cement – Portland Cement Association (www.cement.org)

GAC – consistent with various GAC vendor specifications

HDPE – consistent with HDPE pipe made to ASTM International standards

Lime – consistent with National Lime Association fact sheet values for hydrated lime

PVC – consistent with PVC pipe made to ASTM International standards

Steel – various materials handbooks (specific gravity of 7.8)

Asphalt – Nation Asphalt Pavement Association

Concrete – Portland Cement Association (www.cement.org)

Compacted clay, sand, gravel and soil – generally accepted engineering assumption

Mulch/compost – generally consistent with purchased bagged mulch

Example conversion from volume to mass

10 cubic yards of concrete × 1.95 tons per cubic yard = 19.5 tons of concrete

EXHIBIT 3.4 – APPROXIMATE MATERIAL AND WATER

CONTENT OF AQUEOUS CHEMICAL

SOLUTIONS

Environmental remedies commonly involve the use of chemical solutions, and in some cases a substantial portion of the solution may be water. For the purpose of this methodology, the water use in chemical solution preparation is considered to be of equal quality to public water. Public water is not considered part of the materials metrics but is part of the water metrics and is also used in the calculation of the energy and air footprints. In general, for chemical solutions, the mass of the chemical itself (not the full solution) is used for determining the mass of the refined material. The following table lists common chemical solutions, the specific gravity of the solution, the solution density, and the mass of the chemical per gallon of solution. The table is intended to help determine the mass of a chemical present in the solution for the purpose of calculating the materials metrics and to help determine the amount of water present in the solution for the further purpose of calculating the water, energy, and air metrics.

Chemical Solution	Specific	Density of Solution	Mass of Chemical per Gallon of Solution (lbs/gal)	Volume of Water per Gallon
Hydrochloric acid (37%)	1.1	9.92	3.67	0.75
Sulfuric acid (98%)	1.8	15.3	15.0	0.04
Sodium hydroxide (20%)	1.2	10.2	2.03	0.98
Sodium hydroxide (50%)	1.5	12.8	6.40	0.77
Hydrogen peroxide (30%)	1.1	9.26	2.78	0.78
Hydrogen peroxide (50%)	1.1	9.92	4.96	0.59
Ferric chloride (37%)	1.4	11.7	4.33	0.88
Sequestering agent (assume 40%)	1.2	10.0	4.00	0.72

Information obtained from Material Data Safety Sheets for these chemical solutions

Example conversion from gallons of solution to pounds of chemical

4,000 gallons of 20% NaOH solution × 2.03 pounds per gallon = ~800 pounds of NaOH

NaOH = sodium hydroxide

Equation for determining water content of an aqueous solution

<i>Water content</i>		<i>Volume of solution</i>		<i>Specific gravity</i>		<i>(100 - % concentration)</i>

Example: 10,000 gallons of 20 percent Sodium Hydroxide (Specific gravity = 1.22)

$$9,760 \text{ gallons} = 10,000 \text{ gallons} \times 1.22 \times 80\%$$

EXHIBIT 3.5 – APPROXIMATE MATERIALS USE FOR PIPING AND WIRING RUNS

Some remedies include long runs of piping and wiring to connect extraction wells to a treatment system. The following table can be used to estimate the mass of refined materials involved in long runs of plastic piping and wiring/conduit based on an approximate flow rate carried in the pipes. Values for PVC or HDPE pipe are provided. This information has been provided to help streamline the process of gathering information for the materials metric.

Pipe	Approx. Flow	SDR 11 HDPE Pipe	SCH 80 PVC Pipe	Estimated Wire and Conduit
1-in	5	0.196	0.405	N/A
2-in	25	0.639	0.936	1
3-in	50	1.387	1.911	1.5
4-in	90	2.294	2.793	2
6-in	200	4.971	5.327	2.5
8-in	350	8.425	8.089	3

REFERENCES/METHODOLOGY:

Pipe size is based on approximate flow velocity of 2 to 2.5 feet per second. Pipe weight is based on pipe made to ASTM International standards. Conduit values are general estimates based on one PVC or HDPE power cable conduit and one PVC or HDPE control cable conduit that are sized appropriately for the necessary cable/wire conductors. Wire values are general estimates based on four conductors (including a ground) appropriately sized to provide power to a submersible pump providing the specified flow and the associated control cables.

Example Application

1,000 feet of 6-inch HDPE pipe × 4.971 pounds per foot = ~5,000 pounds of HDPE

EXHIBIT 3.6 – APPROXIMATE MATERIALS USE FOR WELL

INSTALLATION

Wells are a common element of groundwater remedies and can be complex from a materials inventory perspective. The following table lists approximate materials use for well construction on a per foot basis of well depth that may be helpful in quantifying materials use for the materials metrics.

Well	Pounds per Foot of Well Depth						
	SCH 40 PV	Steel	Stainless Steel	Grout for	Grout to Abandon	Sand for	Drill Cuttings for
2-in	0.681	3.65	1.5	13	2	19	22
4-in	2.012	10.7	2.9	19	6	29	39
6-in	3.537	18.9	4.8	25	14	39	61
8-in	5.323	28.5	7.0	32	25	48	87
10-in	7.547	40.4	8.9	38	40	58	119
12-in	9.979	49.5	13.6	45	57	68	155

REFERENCES/METHODOLOGY: Grout and sand use assumes annulus around casing has a diameter that is 4 inches larger than the casing. Grout values are for neat cement assuming 6 gallons of water is mixed with 94 pounds of neat cement with a blended density of 15 pounds per gallon (generally typical of engineering specifications). Pipe values based on typical of pipe specifications made to ASTM International standards. Screen values are typical of manufacturer specifications for a 250-foot deep well. Actual values may vary depending on the specific application. Drill cutting volume does not include drilling mud for mud rotary drilling

EXHIBIT 3.7 – APPROXIMATE MATERIALS USE FOR PROCESS

EQUIPMENT AND BUILDING

CONSTRUCTION

The following approximate rules of thumb have been established to assist in estimating materials use for complex items in an attempt to streamline the level of effort to conduct a footprint analysis. Actual materials use will vary, and use of site-specific values for these items is encouraged when these items are believed to be significant contributors to the footprint.

Process Equipment and Controls

Permanent process equipment, piping, valves, and controls at a site can be comprised of many different types of materials, and therefore can be complex from a materials inventory perspective. For simplicity, this methodology suggests using the weight of the primary components (for example, the weight of steel in an air stripper) and adding 25 percent to this weight as a general rule of thumb to obtain a reasonable approximation of the refined materials associated with the piping, pumps, and controls for an overall system. The weight of process equipment is typically readily available from a vendor web site.

Building Construction

Building construction is another type of materials use that can be difficult to inventory, especially during the design stage if building vendors have not been contacted. Absent other information, the following general rules of thumb can be used for estimating materials use associated with steel building construction.

- Approximately 1 pound of steel per cubic foot of building space
- Approximately 1.3 pounds of steel per square foot of 6-inch slab
- Approximately 72.5 pounds of concrete per square foot of 6-inch slab

EXHIBIT 3.8 – APPROXIMATE CONTENT OF CONCRETE, ASPHALT, AND STEEL

Concrete, asphalt, and steel are construction materials that are commonly used in environmental cleanups and can represent a substantial portion of the materials used. General information about these materials that is relevant to the footprint methodology, such as the typical proportions of the components in concrete and asphalt, and the typical recycled content in steel, is provided in the following table and discussed below. *Note that if specific information is available from the manufacturer on the content of the material used, the specific information should be used instead of the information provided below.*

Material	Density	Pounds per Cubic Foot of Material			
		Refined Material		Unrefined Material	
		Total	Recycled/Reused	Total	Recycled/Reused
Concrete	145	22	0	115	0
Fly ash	145	22	4	115	0
Asphalt	145	7	1.4	138	28
Steel	490	490	270	0	0

Concrete – Mixed concrete (by volume) is typically 0.5 parts water, 1 part cement (a refined material), and 4.5 parts aggregate (an unrefined material). Water is covered separately under the water footprint and is not considered a material in this methodology. Using the densities in Exhibit 3.3, concrete is 15 percent refined material and 79 percent unrefined material by weight, with the remaining 6 percent attributed to the water. The density of concrete is approximately 145 pounds per cubic feet. Therefore, for every cubic foot of concrete, approximately 22 pounds is refined material, 115 pounds is unrefined material, and the remainder is water. For many applications, fly ash can be used as an admixture to replace up to 20 percent of the cement component. Therefore, for fly ash concrete, 20 percent of the refined material (4 pounds) can be considered recycled/reused.

REFERENCES: Values for proportions by volume obtained from Portland Cement Association (www.cement.org) and converted to mass using densities provided from same source. Information on fly ash from the Federal Highways Administration Materials Group: <http://www.fhwa.dot.gov/infrastructure/materialsgrp/flyash.htm>.

Asphalt – Asphalt is approximately 5 percent asphalt cement (a refined material) and 95 percent aggregate (unrefined) by weight. Therefore, for the purpose of this methodology, asphalt is assumed to be 5 percent refined material and 95 percent unrefined material. Asphalt has an approximate compacted density of 145 pounds per cubic foot. Therefore, for every cubic foot of asphalt, approximately 7 pounds is refined material and 138 pounds is unrefined material. Asphalt pavement typically contains up to as much as 20 percent recycled material. For the purpose of this methodology, this recycled content is assumed to be evenly distributed among the refined and unrefined portions. Therefore, for one cubic foot of compacted asphalt, approximately 1.4 pounds of the refined material is from recycled material and approximately 28 pounds of the unrefined material is from recycled material.

REFERENCES: National Asphalt Pavement Association (www.hotmix.org).

Steel – Recycling is an inherent part of the steel industry, and the recycled content of steel varies depending

on the furnace technology, which is somewhat specific to the type of product produced. The recycled content for steel produced from a blast oxygen furnace is approximately 30 percent and the recycled content for steel produced from an electric arc furnace is approximately 80 percent. For the purpose of this methodology, the recycled content of steel is assumed to be the average (approximately 55 percent).

REFERENCES: Steel Takes LEED® with Recycled Content, American Iron and Steel Institute, November 2009

EXHIBIT 3.9 – STORMWATER DIVERSION

Significant diversions of stormwater can be considered a “use” because it results in transferring (using) water from one resource and adding (discharging) it to another. For example, a large cap might divert stormwater to a local surface water body rather than allowing it to recharge an aquifer. This diversion has two effects. First, it reduces the recharge to the aquifer. The significance of this effect will vary from site to site. If the site is in the recharge area of a drinking water aquifer, then diversion of precipitation would affect replenishment of a potential drinking water resource. By contrast, a site might be located along a creek such that infiltrating water would migrate only a short distance in the subsurface before discharging to the creek. Preventing the water from recharging the aquifer in this latter case will not significantly affect the local groundwater resource. Second, diversion of stormwater results in higher peak flows in the receiving stream. This may have an effect on soil erosion or local ecosystems, potentially affecting one of the other core elements of green remediation. It could also increase loading to a storm sewer or combined sewer infrastructure. The significance of stormwater diversion can be conveyed by describing the quantity and quality of the water diverted and the fate of the water. The quality of the water diverted is considered the same quality as if it had naturally infiltrated and recharged the aquifer.

Diverted stormwater does not necessarily need to be discharged to surface water. Depending on the facility, the surrounding environment, and the local land uses, the diverted stormwater may be collected and used for beneficial purposes such as irrigation. The use of collected stormwater could then displace the need to use other potentially valuable local water resources for these purposes. The collected stormwater could also be diverted to facilitate infiltration into a different area of the same aquifer.

Calculating the amount of stormwater diverted depends on the percentage of precipitation water that typically infiltrates. This is dependent on the surface soil, vegetation, slope, and other factors. Unless site-specific calculations have been made to estimate changes in infiltration, the maximum amount of water diverted can be used. This conservative approach assumes that all water naturally infiltrates into the subsurface and the cap or remedy involves diversion of all of this water. Using these conditions, the amount of water diverted annually is the average precipitation multiplied by the area of water diverted according to the following equation:

Annual water diverted	=	Annual precipitation (inches/year)	×	Area (ac)	:	27,157 (gallons/acre-inches)

Total water diverted as a result of the remedy would be the annual water diverted multiplied by the number of years diversion would occur.

EXHIBIT 3.10A – GENERAL CHECKLIST FOR TYPICAL ITEMS TO CONSIDER IN A FOOTPRINT ASSOCIATED WITH CONSTRUCTION OF A REMEDY

This exhibit applies to the construction of remedies such as P&T, SVE, multi-phase extraction, or other remedies that involve installing wells, laying pipe, erecting a building, and site grading (e.g., *in situ* bioremediation remedies that involve permanent water supply wells and/or injection wells). This checklist is intended to serve as an aid in identifying relevant components and is not necessarily an exhaustive list. Other items related to the remedy, but not included below, should also be included if they are believed to contribute significantly to the remedy footprint.

Transportation	Equipment Use	Quantities of Materials and Offsite
- Distance between site and - Office of primary consultant - Offices of primary contractors - Manufacturers of various construction materials - Non-hazardous waste landfill - Hazardous waste landfill - Types of vehicles or modes of transportation for personnel, equipment, material, and waste transport - Quantity of material or waste transported per trip - Type of fuel used in vehicles - Material or waste transport that requires an empty return trip after	- Equipment type, horsepower rating, and total hours of operation for - Drilling wells - Laying extraction and injection network piping - Trenching - Clearing and grubbing - Excavation and backfilling - Grading - Dredging - Erecting buildings - Dewatering - Onsite electricity generation - Providing compressed air - Major electrical equipment not running off of generators - Pumps - Blowers - Mixers	- Materials* - Services - Waste disposal* - Offsite water treatment** - Laboratory analysis * SEE MATERIALS AND WASTE SECTION ** SEE WATER SECTION

EXHIBIT 3.10B – GENERAL CHECKLIST FOR TYPICAL ITEMS TO

CONSIDER IN A FOOTPRINT ASSOCIATED WITH

REMEDY OPERATION_N

This exhibit applies to the operation of remedies such as P&T, air sparging (AS)/SVE, multi-phase extraction, or other remedies that involve long-term operation (e.g., *in situ* bioremediation or monitored natural attenuation). This checklist is intended to serve as an aid in identifying relevant components and is not necessarily an exhaustive list. Other items related to the remedy, but not specified below, should also be included if they are believed to contribute significantly to the remedy footprint.

Transportation	Equipment Type, Power Rating, Hours of	Quantities of Materials and Services
- Distance between site and - Office of primary consultant - Office of primary contractors - Manufacturers of various construction materials - Non-hazardous waste landfill - Hazardous waste landfill - Types of vehicles or modes of transportation for personnel, equipment, material, and waste transport - Quantity of material or waste transported per trip - Type of fuel used in vehicles - Material or waste transport that requires an empty return trip after delivery	- Electrical equipment - Extraction pumps - Transfer pumps - Chemical feed pumps - Blowers - Air compressors for pneumatic equipment and air sparging - GAC pre-heaters - Mixers - Ozone generators - Subsurface electric heating - Electric building heat - Building lighting - Building ventilation - Catalytic oxidizers - Gasoline, diesel, and biofuel equipment - Direct-push rigs for chemical injection - Other heavy equipment - Generators - Fuel-powered pumps and compressors - Subsurface heating	- Materials* - Services - Waste disposal* - Offsite water treatment** - Laboratory analysis * SEE MATERIALS AND WASTE SECTION ** SEE WATER SECTION
		Onsite Emissions and Reductions

	- Major landscaping - Vehicles for onsite transportation • Natural gas equipment - Building heat - Process heaters - Generators	• Landfill gas emissions • Air stripper or SVE off-gas • Emissions from large open excavations • Planted trees and biomass

EXHIBIT 3.11A – QUANTIFYING FUEL USE FOR

PERSONNEL TRANSPORTATION

The following table can be used to organize and calculate fuel use for personnel transportation. Two different calculation options are provided in decreasing order of known information. It is preferable to use the calculation Option 1 where possible. Option 2 can be used if the information is not available for Option 1.

Activity	Input #1		Input #2		Fuel Use
Option 1 – Known Number of Events and Known Fuel Use per Trip					
	# of events		Fuel use per event	=	Fuel Use
Option 2 – Known Distance and Vehicle Type					
	Distance traveled		Fuel efficiency	=	Fuel Use

Notes:

“Event” can refer to a specific trip, time period, or broader activity for which fuel use is known.

“mpg” = miles per gallon

“pmpg” = passenger miles per gallon

If the distance of travel is not known, it should be estimated based on professional judgment (e.g., the approximate distance to the nearest suburban or metropolitan area where a consultant or contractor may be located). If the vehicle type is not known, it can be assumed based on professional judgment and applying the fuel efficiencies from the following table.

Vehicle Type	Fuel Efficiency (mpg or pmpg)	
	Gasoline	Diesel or
Airplane (pmpg)	N/A	45
Bus (pmpg)	N/A	96
Passenger car (mpg)	24	28
Light-duty truck (mpg)	17	20
Light-duty truck with trailer or heavy load (mpg)	N/A	6
Train (pmpg)	N/A	59

- Airplane/jet fuel calculated as diesel for simplicity and due to similarities between kerosene and diesel

- Gasoline car and truck efficiencies and diesel car, truck, airplane, bus, and train efficiencies from converting average CO₂ emissions for each mode of transportation using values of 22.3 pounds of CO₂ per gallon of diesel and 19.4 pounds of CO₂ per gallon of gasoline. Average CO₂ emissions are from Climate Leaders from Commuting, Business Travel and Product Transport to diesel use assuming Climate Leaders. CO₂ emissions

per gallon of fuel are from Climate Leaders Direct Emissions from Mobile Combustion Sources.

EXHIBIT 3.11B – QUANTIFYING FUEL USE FOR HEAVY

EQUIPMENT USE

The following table can be used to organize and calculate fuel use associated with heavy equipment use. Two different calculation options are provided in decreasing order of known information. It is preferable to use the calculation Option 1 where possible. Option 2 can be used if the information is not available for Option 1.

Activity	Input #1				Input #2				Fuel Use
Option 1 – Known Fuel Use or Equipment Owner Estimated Fuel Use									
	Event			×	Fuel use per event				Fuel Use
Option 2 – Known or Estimated Horsepower Rating, Fuel Type, and Hours of Operation									
	HP		Hours	×	BSF G		PL F		Fuel Use

Notes:

Option 1 – “Event” can refer to a specific task, time period, or entire scope of work. Fuel use per event is assumed to be a reasonable estimate by the equipment owner based on fuel use for a similar, but previously executed event.

Option 2 – “HP” = horsepower rating of equipment “Hours” = hours of operation

“BSFC” = brake-specific fuel capacity “PLF” = partial load factor

The assumed BSFC for diesel and biodiesel is 0.050 gallons per HP-hr.

The assumed BSFC for gasoline is 0.056 gallons per HP-hr.

BSFC values are consistent with 7,000 British thermal units (Btu)/HP-hr (as used by EPA AP-42, Compilation of Air Pollutant Emission Factors, Chapter 3) and fuel higher heating values of 139,000 Btus for diesel and 124,000 Btus for gasoline (as used by Climate Leaders).

The following table provides HP and PLF values for common types of equipment.

Equipment Type	HP	PLF	Production
Medium/large excavator (2 CY	175	0.75	720 cy/day
Medium loader (3 CY bucket)	200	0.75	1200 cy/day
Medium dozer, 100+ foot haul	200	0.75	500 cy/day
Direct-push rig for soil sampling	60	0.75	250 ft/day
Hollow-stem auger for well	150	0.75	100 ft/day
Air or mud rotary for well	500	0.75	200 ft/day

Production rates and equipment sizes are generally consistent with production rates reported RS Means Building

Construction Cost Data and are representative averages. Actual production rates may vary due to a number of factors including site conditions and operator experience. Site teams are encouraged to use more site-specific production rates if they can be documented. Absent other information a PLF of 0.75 is a reasonable estimate for heavy equipment. The PLF may decrease if work is inefficient for a variety of reasons. Many of the same inefficiencies would also reduce the production rate. Therefore, if the assumed production rate is lower, it is appropriate for the PLF to be lowered by a commensurate amount resulting in no net change in fuel use.

EXHIBIT 3.11C – QUANTIFYING FUEL USE FOR EQUIPMENT, MATERIALS, AND WASTE TRANSPORTATION

The following table can be used to organize and calculate fuel use for equipment, materials, and waste transportation. Two different calculation options are provided in decreasing order of known information. It is preferable to use Option 1. Option 2 can be used if information is not available for Option 1.

Activity	Input #1				Input #2			Fuel Use
Option 1 – Known Number of Events and Known Fuel Use per Trip								
	# of events			×	Fuel use per event		=	Fuel Use
Option 2a – Common Freight - Known Distance, Cargo Weight, and Vehicle Type								
	Distance		Weight	×	Fuel efficiency		=	Fuel Use
Option 2b – Specialty Freight Load or Empty Load by Truck – Known Distance								
	Distance			×	Fuel efficiency		=	Fuel Use

Notes:

“Event” can refer to a specific trip, time period, or broader activity for which fuel use is known.

“gptm” = gallons per ton-mile

“mpg” = miles per gallon

The distance for materials transport should be from the manufacturer, not just from the local distributor. If the distance of travel is not known, it should be estimated based on professional judgment considering the following examples: 1,000 miles for specialty items and hazardous waste transport, 500 miles for most materials, and 25 miles for borrow, fill, sand/gravel, asphalt, concrete, and non-hazardous waste transport. Empty return trips should be considered as appropriate. Fuel efficiencies reported in gallons per ton-mile (gptm) are assumed to include the empty return trip:

Vehicle Type	Fuel Efficiency

	Units	Value
Truck (include separate empty return trip as appropriate)	mpg	6
Truck Common Freight (empty return trips included)	gptm	0.029
Train (empty return trips included)	gptm	0.0025
Barge (empty return trips included)	gptm	0.0047
Aircraft (empty return trips included)	gptm	0.15

- *Airplane/jet fuel calculated as diesel for simplicity and due to similarities between kerosene and diesel.*
- *Fuel efficiencies are obtained by from converting average CO₂ emissions reported in Climate Leaders: Commuting, Business Travel and Product Transport (EPA430-R-08-006) to diesel use.*
- *Provided fuel efficiencies are representative averages. Actual efficiencies may vary due to a number of factors. Site teams are encouraged to use more site-specific fuel efficiencies if those efficiencies can be documented.*

EXHIBIT 3.12 – ESTIMATING SIZES OF ELECTRICAL EQUIPMENT

Estimating Pump Size Based on Expected Flow Parameters

$$HP = \frac{QH}{3956 \eta} \times 1$$

HP = horsepower

Q= flowrate (gpm)

H=total dynamic head (feet of water)

η =pump efficiency (absent other information, assume (70%)

3956 = conversion factor from ft-gpm to HP

Round HP to the next highest value of (0.5, 0.75, 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 30, 40, 50,...) to determine motor size

Estimating Blower Size Based on Expected Air Flow Requirements

$$HP = \frac{QH}{527 \eta} \times 1$$

HP = horsepower

Q= flowrate (cfm)

H=total dynamic head (inches of water)

η =blower efficiency (absent other information, assume (55%) 527

= conversion factor from cfm-inches of water to HP

Round HP to the next highest value of (0.5, 0.75, 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 30, 40, 50,...) to determine motor size

Estimating Compressor Size Based on Compressed Air Requirements

Absent more specific information, based on a general rule of thumb, at 100 pounds per square inch (psi), assume approximately 3.6 standard cubic feet per minute (scfm) per HP.

$$HP = \frac{scfm}{3.6}$$

Off-gas Preheating

Absent more specific information, based on a general rule of thumb, assume approximately 0.003 kW of electricity demand per scfm of air flow.

$$kW = 0.003 \times scfm$$

Note: The above formulas are intended to provide approximate values for the purpose of estimating an energy footprint and are not intended to provide estimates for design purposes or financial forecasting. If more specific information is available, it should be used in place of these formulas.

EXHIBIT 3.13 – ESTIMATING ELECTRICITY USE FOR TYPICAL REMEDIATION COMPONENTS

During operation, electricity use can typically be determined by referring to electrical bills; however, during the early remedy design stages, estimating electrical use is not as straightforward. In addition, even if electrical bills are available during operation, it is helpful to estimate electricity use from all major remedial components. This exhibit provides general rules of thumb for estimating electricity power requirements.

Item	Calculation for Estimating Electricity Use
Small motors (< 1 HP) (e.g., for pumps, blowers, minimizers)	$kWh = \frac{HP \times L_M}{\eta_m} \times 0.746 \times hours$ ($\eta_m = 0.65$, $L = 80\%$)
Large motors (≥ 1 HP) (e.g., for pumps, blowers, minimizers)	$kWh = \frac{HP \times L_M}{\eta_m} \times 0.746 \times hours$ ($\eta_m = 0.75$, $L = 80\%$)
Items with known electrical ratings (e.g., kW)	$kWh = kW \times hours$
Interpreting VFD settings	$kWh = \frac{HP \times L^3}{\eta_m \times \eta_v} \times 0.746 \times hours$
<i>kW = kilowatts of electric power kWh = kilowatt-hours of electricity HP = horsepower</i> <i>L_M = percent of motor full load</i> <i>L_V = percent of VFD full load (or speed in Hertz divided by 60 Hertz)</i> <i>η_m = motor efficiency (typically 60% for less than 1 HP to 85% for 15 HP or greater)</i> <i>η_v = VFD efficiency (typically 75% for less 50% load to 93% for more than 90% load)</i> <i>hours = hours of operation over time frame of project</i> <i>0.746 = conversion of HP</i>	

Note: The above formulas are intended to provide approximate values for the purpose of energy footprinting and are not intended to provide estimates for design purposes or financial forecasting. If more specific information is available, it should be used in place of these formulas.

EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS

Suggested conversion factor values are provided to help convert various forms of fuel use, materials manufacturing, and offsite services into energy use and air pollution emissions. The conversion factors presented here are from a variety of sources, most of which are publicly available life cycle inventory databases, and there is an inherent degree of uncertainty in the values. First, the life cycle inventory data may not be able to accurately represent complex processes involved in manufacturing materials or providing offsite services. Second, the life cycle inventory data represent overall averages of a particular industry rather than the specific processes or resources used at a particular facility that may produce the majority of a particular material used in a project. Actual conversion factors may vary substantially due to a variety of factors including variations in manufacturing practices and in sources of energy used in the manufacturing process. Third, there are many materials or services that may be used in a remedy that are not included in the publicly available databases. More robust proprietary life cycle inventory databases exist and were consulted as part of developing this methodology, but proprietary conversion factors are not presented in the tables below due to restrictions in database licensing agreements. Project teams are encouraged to identify more specific conversion factors and to follow green procurement practices when practicable. The data quality and the sources of alternative conversion factors, whether obtained from life cycle inventory databases or developed independently by the project team, should be well documented as part of the footprint analysis.

Item or Service			Suggested Conversion Factors						Reference
			Parameters Used, Extracted, Emitted, or Generated						
			Ener	CO ₂ e	NO _x	SO _x	PM	HAPs	
			Used	Emit	Emitt	Emitt	Emitt	Emitt	
		Uni	MM	lbs	lbs	lbs	lbs	lbs	
Fuel Combustion									
Biodiesel use		gal	0.12	22.3	0.20	0	0.0009	NP	1
Diesel use		gal	0.13	22.5	0.17	0.005	0.0034	0.000	2
Gasoline use		gal	0.12	19.6	0.11	0.004	0.0005	0.000	3
Landfill gas use		ccf	0.10	13.1	0.01	0.000	0.0007	0.000	4
Natural gas use		ccf	0.10	13.1	0.01	0.000	0.0007	0.000	4

See notes on last page of this exhibit for references.

EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS (continued)

Item or Service Used			Suggested Conversion Factors						Refere
			Parameters Used, Extracted, Emitted, or Generated						
			Ener	CO2e	NOx	SOx	PM	HAPs	
			Used	Emitte	Emitt	Emitt	Emitted	Emitt	
		Uni	MM	lbs	lbs	lbs	lbs	lbs	
Construction Materials									
Cement		Dry	0.002	0.9	0.001	0.001	0.0000032	0.000	5
Concrete		lb	0.000	0.171	0.000	0.000	0.00001	0.000	6
Gravel/sand/clay		lb	0.000	0.0034	0.000	0.000	0.0000020	2.1E-	7
HDPE		lb	0.031	1.9	0.003	0.004	0.00064	0.000	8
Photovoltaic system (installed)		Wa	0.034	4.5	0.015	0.032	0.00063	0.000	9
PVC		lb	0.022	2.6	0.004	0.007	0.0012	0.000	10
Stainless Steel		lb	0.012	3.4	0.007	0.012	0.0044	0.000	11
Steel		lb	0.004	1.1	0.001	0.001	0.00056	0.000	12
Other refined construction		lb	0.014	1.9	0.003	0.005	0.0014	0.000	13
Other unrefined construction		lb	0.000	0.0033	0.000	0.000	0.000002	2.1E-	14

See notes on last page of this exhibit for references.

EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS (continued)

Item or Service Used			Suggested Conversion Factors						Refere
			Parameters Used, Extracted, Emitted, or Generated						
			Ene	CO ₂ e	NO x	SO x	PM	HAPs	
			Use	Emit	Emitt	Emitt	Emitt	Emitt	
		Unit	M	lbs	lbs	lbs	lbs	lbs	
Treatment Materials and									
Cheese Whey		lb	0.00	0.031	0.0000	0.000	0.0000	NP	15
Emulsified vegetable oil		lb	0.00	3.44	0.0066	0.001	0.0000	NP	16
Molasses		lb	0.00	0.48	0.0011	0.000	0.0000	NP	17
Treatment materials and chemicals		lb	0.01	1.7	0.003	0.006	0.0006	0.000	18
Virgin GAC (coal based)		lb	0.01	8.5	0.014	0.034	0.0007	0.001	19
Fuel Processing									
Biodiesel Produced		gal	0.02	-16.8	0.018	0.033	0.0008	NP	1
Diesel Produced		gal	0.01	2.7	0.0064	0.013	0.0003	0.000	20
Gasoline Produced		gal	0.02	4.4	0.008	0.019	0.0005	0.000	21
Natural Gas Produced		ccf	0.00	2.2	0.0037	0.004	0.0000	0.000	22
Public water		gal x	0.00	5	0.0097	0.005	0.016	0.000	23

See notes on last page of this exhibit for references.

EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS (continued)

Item or Service Used			Suggested Conversion Factors						Refere
			Parameters Used, Extracted, Emitted, or Generated						
			Energy	CO ₂ e	NO _x	SO _x	PM	HAPs	
			Used	Emit	Emitt	Emitt	Emitt	Emitt	
		Unit	MMBtu	lbs	lbs	lbs	lbs	lbs	
Offsite Services									
Offsite waste water treatment		gal x	0.015	4.4	0.016	0.015	NP	NP	24
Offsite Solid Waste Disposal		ton	0.16	25	0.14	0.075	0.4	0.001	25
Offsite Haz. Waste Disposal		ton	0.18	27.5	0.154	0.082	0.44	0.001	26
Offsite Laboratory Analysis		\$	0.006	1	0.0048	0.003	0.0004	0.000	27
Electricity Generation		See Exhibit 3.17							
Resource Extraction for									
Coal extraction and processing		MWh	3.1	180	0.77	0.15	0.018	NP	28
Natural gas extraction and		MWh	1.6	270	0.18	13	0.0071	NP	29
Nuclear fuel extraction and		MWh	0.16	250	0.15	0.5	0.0015	NP	30
Oil extraction and processing		MWh	2.3	270	1.7	0.069	0.042	NP	31
Electricity Transmission		10 percent of electricity generation footprint for each parameter							32

MMBtu = millions of British thermal units

lbs = pounds

NP = not provided

gal = gallon

ccf = hundred cubic feet

MWh = megawatt-hour

ton = short ton (2,000 pounds)

See notes on last page of this exhibit for references.

EXHIBIT 3.14– SUGGESTED CONVERSION FACTORS (continued)

REFERENCES:

1. *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, NREL/SR-580-24089 UC Category 1503, U.S. Department of Agriculture and U.S. Department of Energy, May 1998. The CO₂e emissions for “biodiesel produced” are negative because of the uptake of CO₂ in the crops used to produce the fuels. This CO₂ is emitted during fuel combustion and is reflected in the CO₂e emissions for “biodiesel use”.*
2. *Multiple sources*
 - a. *Energy and CO₂e emissions from Direct Emissions from Mobile Combustion Sources, EPA430-K-08-004, U.S. EPA, May 2008.*
 - b. *NO_x, SO_x, PM, and HAPs from NREL: SS_Transport, single unit truck, diesel powered.xls*
3. *Multiple sources*
 - a. *Energy and CO₂e emissions from Direct Emissions from Mobile Combustion Sources, EPA430-K-08-004, U.S. EPA, May 2008.*
 - b. *NO_x, SO_x, PM, and HAPs from NREL: SS_Transport, single unit truck, gasoline powered.xls*
4. *Multiple sources and simplifying assumption that emissions of natural gas reasonably represent combustion of methane component of landfill gas*
 - a. *Energy and CO₂e emissions for compressed natural gas in heavy vehicles from Direct Emissions from Mobile Combustion Sources, EPA430-K-08-004, U.S. EPA, May 2008.*
 - b. *NO_x, SO_x, PM, and HAPs from NREL: SS_Natural gas, combusted in industrial boiler.xls*
5. *EUROPA – Portland cement*
6. *Calculated from presented emission factors for public water, cement, and gravel/sand/clay by assuming typical concrete proportions by weight of 0.45:1:4 of water, cement, and sand/gravel*
7. *EUROPA – Gravel 2/32*
8. *EUROPA – Polyethylene high density granulate (PE-HD)*
9. *Life-Cycle Assessment of the 33 kW Photovoltaic System on the Dana Building at the University of Michigan Thin Film Laminates, Multi-Crystalline Modules, and Balance of System Components Sergio Pacca, Deepak Sivaraman and Gregory A. Keoleian Center for Sustainable Systems, University of Michigan Report No. CSS05-09, June 1, 2006*
10. *EUROPA - Suspension Polymerisation PVC*
11. *EUROPA – Stainless steel*
12. *EUROPA – Average of Steel hot rolled section, Steel hot rolled coil, Steel rebar*
13. *Averages of conversion factors for cement, HDPE, PVC, stainless steel, and steel*
14. *Same as conversion factors for gravel/sand/clay*
15. *Offset values for cheese whey obtained from the module for yellow cheese from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N*

- (2003). LCA food data base. www.lcafood.dk, Andersen M and Jensen JD (2003). *Marginale producenter af udvalgte basislevnedsmidler* (in Danish) Udkast d. 5. februar 2003.
16. Values for rapeseed oil from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food data base. www.lcafood.dk. Landbrugets rådgivningscenter (2000). *Tal fra Fodermiddeltabellen*, Raport nr. 91. In Danish. Weidema BP (1999). *System expansions to handle co-products of renewable materials*. Presentation Summaries of the 7th LCA Scenarios Symposium SETAC-Europe, 1999. Pp. 45-48. pdf. Weidema B (2003). *Market information in life cycle assessments*. Technical report, Danish Environmental Protection Agency (Environmental Project no.863).
17. Offset values for molasses obtained from the module for sugar from Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food data base. www.lcafood.dk, Sugar Production based on Danisco Sugar Author: Per H. Nielsen July 2003

EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS (continued)

18. *Intended for any common treatment chemical in pure form including chemical oxidants and regenerated granular activated carbon. For chemical solutions, use only the mass of the chemical portion of the solution. Conversion factor is based on average value of conversion factors for the following seven common treatment chemicals as reported by Ecoinvent v2.1 from the Ecoinvent Centre for Life-Cycle Inventories, <http://www.ecoinvent.ch/>*

- Hydrochloric Acid (30 percent) – normalized to pure hydrochloric acid by dividing by database results by 0.3.
- Sodium hydroxide (50 percent) – normalized to pure sodium hydroxide by dividing database results by 0.5.
- Ferric chloride (iron III chloride)
- Potassium permanganate
- Sodium persulfate
- Chlorine gas
- Hydrogen peroxide (50 percent) – normalized to pure hydrogen peroxide by dividing database result by 0.5.

This averaging approach adds an additional layer of uncertainty to the conversion factors provided. For example, the range for energy is approximately 0.007 MMBtu to 0.025 MMBtu. The average (0.015 MMBtu) may overestimate the energy use value for some of the chemicals below by more than 100 percent and underestimate the energy use value for other chemicals by 40 percent. Additionally, some common treatment chemicals (e.g., sulfuric acid and ferrous sulfate) have energy footprints that are substantially outside the presented range and would not be accurately represented by these values. If an additional level of accuracy is preferred, readers of this methodology are encouraged to seek and document well referenced conversion factors as part of footprint analysis submittals.

19. *Based on “treatment materials and chemicals” above plus the result of combusting 1.86 pounds of bituminous coal. The additional coal combustion represents the coal that is combusted in the activation process. The 1.86 pounds of bituminous coal assumes that the activated carbon yield is approximately 35 percent of the coal used as a feedstock (e.g., 2.86 pounds of coal yields 1 pound of granular activated carbon), which is consistent with values reported in Pore Develop of Activated Carbon Prepared by Steam Activate Process, Kim SC and Hong, IK, Journal of Industrial and Engineering Chemistry, Vol. 4, No. 3, September 1998, 177-184.*

20. *EUROPA – diesel at refinery*

21. *EUROPA – gasoline at refinery*

22. *EUROPA – natural gas at consumer*

23. *EUROPA - Drinking water from surface water and drinking water from groundwater*

24. *Calculated based on Life-Cycle Energy and Emissions for Municipal Water and Wastewater Services: Case-Studies of Treatment Plants in US Malavika Tripathi, Center for Sustainable Systems, University of Michigan Report No. CSS07-06, April 17, 2007*

25. *EUROPA – Inert waste disposal*

26. *Values from EUROPA inert waste disposal plus an arbitrary additional 10 percent to account additional practices required of a hazardous waste disposal facility*

27. *Based on U.S. CARBON DIOXIDE EMISSIONS AND INTENSITIES OVER TIME: A DETAILED ACCOUNTING OF INDUSTRIES, GOVERNMENT AND HOUSEHOLDS, APRIL 2010. Approximately 1 lb of CO₂ is emitted per dollar of gross domestic product. In the absence of other information, it is assumed that the laboratory also has an emission profile of approximately 1 lb of CO₂ emitted per dollar of sample cost. Conversion factor estimates assume that 50 percent of this 1 lb of CO₂ per dollar of sample cost results from electricity use (U.S. average fuel blend) and 50 percent is due to diesel use. A dollar of sample cost can then be converted into electricity and diesel use. The conversion factors result from this electricity and diesel use using the average electricity fuel blend for the United States and the diesel conversion factors provided here.*

EXHIBIT 3.14 – SUGGESTED CONVERSION FACTORS (continued)

28. NREL – life cycle of electricity from bituminous coal minus the emissions from combusting coal
29. NREL – life cycle of electricity from natural gas minus the emissions from combusting natural gas
30. NREL – life cycle of electricity from nuclear
31. NREL – life cycle of electricity from residual oil minus the emissions from combusting residual oil
32. U.S. Dept. of Energy (GridWorks: Overview of the Electric Grid <http://sites.energetics.com/gridworks/grid.html>).

NREL = National Renewable Energy Laboratory, Life Cycle Inventory, provided by the National Renewable Energy Laboratory and operated by Alliance for Sustainable Energy, LLC under contract to the U.S. Department of Energy. www.nrel.gov/lci

EUROPA = European Reference Life Cycle Database (ELCD core database), version II compiled under contract on behalf of the European Commission - DG Joint Research Centre - Institute for Environment and Sustainability with technical and scientific support by JRC-IES from early 2008 to early 2009. (<http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm>)

EXHIBIT 3.15 – ESTIMATING AIR POLLUTANT EMISSIONS

FROM ONSITE SOURCES

Some treatment processes (such as air strippers used in P&T systems) and some remedies (such as SVE systems) involve discharge of process air to the atmosphere. It is common to include off-gas treatment to mitigate discharge of pollutants to the atmosphere, but in some cases off-gas treatment is not provided. The following equations provide assistance in calculating the emission rate in pounds per year from air strippers and SVE systems.

Estimating Air Emissions from Air Stripper Off-Gas

$$E = \frac{Q \times C \times 3.785 \times 1440 \times 365 \times 2.2 \times \eta_s \times (1 - \eta_t)}{10^9}$$

E = Emission rate (pounds per year)
 Q = process water flow rate (gpm)
 C = concentration ($\mu\text{g/L}$)
 η_s = air stripper efficiency (assume 100%)
 η_t = off-gas treatment efficiency (varies)
 3.785 = liters per gallon
 1440 = minutes per day
 365 = days per year
 2.2 = pounds per kilogram

Estimating Air Emissions from SVE Systems

$$E = \frac{Q \times C \times 0.0283 \times 1440 \times 365 \times 2.2 \times (1 - \eta_t)}{10^9}$$

E = Emission rate (pounds per year)
 Q = process water flow rate (cfm)
 C = concentration ($\mu\text{g/m}^3$)
 0.0283 = cubic meters per cubic foot
 1440 = minutes per day
 365 = days per year
 2.2 = pounds per kilogram
 η_t = off-gas treatment efficiency (varies)

Estimating Air Emissions from Soil during Construction Activities

The 2002 EPA guidance document titled *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (OSWER 9355.4-24) provides a number of equations that can be used to estimate pollutant emissions from soil and dust generation from construction activities. Dust generation can be a significant source of PM10 emissions.

EXHIBIT 3.16 – ESTIMATING CARBON STORED IN PLANTED TREES

Carbon Stored in Planted Trees

$$C_s = e^{-2.2+2.4 \ln(bhd)} \times (1 + e^{(-1.63+.0.74 / bhd)}) \times 0.46 \times 1.69$$

$$=$$

C_s = carbon dioxide stored

bhd = breast-height diameter of tree in (cm), assume 1 cm/yr growth rate for up to 40 years and a slower rate thereafter

Values represent average parameters for willow, poplar, oak, birch, and cypress trees

REFERENCES:

Biomass calculated based on equations from Jenkins, Jennifer C.; Chojnacky, David C.; Heath, Linda S.; Birdsey, Richard A., National scale biomass estimators for United States tree species, Forest Science. 49: 12-35, 2003

Willow - http://na.fs.fed.us/pubs/silvics_manual/volume_2/salix/nigra.htm
species group (aa) according to Jenkins 2003

Bald Cypress - http://na.fs.fed.us/pubs/silvics_manual/Volume_1/taxodium/distichum.htm
species group (cl) according to Jenkins 2003

Poplar - http://na.fs.fed.us/pubs/silvics_manual/volume_2/liriodendron/tulipifera.htm
species group (aa) according to Jenkins 2003

River Birch - http://na.fs.fed.us/pubs/silvics_manual/volume_2/betula/nigra.htm
species group (mb) according to Jenkins 2003

Water Oak - http://na.fs.fed.us/pubs/silvics_manual/volume_2/quercus/nigra.htm
species group (mo) according to Jenkins 2003

EXHIBIT 3.17 – USING DATA FROM ELECTRIC SERVICE PROVIDERS TO DETERMINE FOOTPRINT CONVERSION FACTORS

The methodology involves the use of footprint conversion factors to convert electricity use into energy use and CO₂e, NO_x, SO_x, PM, and HAP emissions. When possible, the fuel blend from the electric service provider should be used to determine this information because it is likely more specific to the site and has likely been updated more recently than eGRID. This fuel blend may be referred to as a “generation mix” or provided on a “Power Content Label”. If this information is not available, then the data for the state where the site is located can be obtained from the most recent year indicated in Table 5 of the state electricity profile obtained from www.eia.gov. Note that information for electricity service providers is available through eGRID (www.epa.gov/egrid) but should not be used for this methodology unless the information is consistent with that obtained directly from the electric service provider. Note that although renewable components of grid electricity are considered when establishing conversion factors for the electricity, the renewable components are not included in the renewable energy metrics (E-2). This is because renewables in the basic grid electricity is not considered a “voluntary” renewable. See Section 2.3 of the methodology for additional information.

Example Power Content from Electric Service Provider	
Energy Source	Percentage of Power Mix Delivered to
Natural gas	39%
Nuclear	22%
Renewable (30% total)	4.8%
- Geothermal (16%)	4.5%
- Biomass/waste (15%)	18.9%
- Hydroelectric (63%)	1.8%
- Wind (6%)	<1%
Coal	8%
Other	1%

Converting Resource Mix to Footprint Conversion Factors and Portion of Energy Derived from Renewable Resources													
Type	%	Energy (MMbtu/MWh)		CO ₂ e (lbs/MWh)		NO _x (lbs/MWh)		SO _x (lbs/MWh)		PM		HAPs	
	o	F ull	Adj . by	F ull	Adj . by	F ull	Adj . by	F ull	A dj.	F ull	A dj.	F ull	A dj.
<i>Conventional Energy</i>													
Coal		6.9		22		6		15		.09		0.	
Natural Gas		6.9		13		1.1		0.0		0.0		0.025	
Oil		6.9		18		2.2		2.8		0.1		0.066	
Nuclear		6.9		0		0		0		0		0	
<i>Renewable Energy</i>													
Biomass		6.9		0	0	1.4		0.6		0.0		5.3E-	0
Geothermal		6.9		0	0	0	0	0	0	0	0	0	0
Hydro		6.9		0	0	0	0	0	0	0	0	0	0
Solar		6.9		0	0	0	0	0	0	0	0	0	0
Wind		6.9		0	0	0	0	0	0	0	0	0	0
Total													

Full load emission values for each fuel type obtained from www.nrel.gov/lci.

All values do not include energy and emissions for resource extraction or for transmission losses, which are counted in Scope 3b.

Energy conversion factors exclude the energy contained in the MWh of electricity used by the remedy to avoid double counting of Scope 1 energy use.

For simplicity, energy conversion factors are assumed to be 6.9 MMBtu per MWh (equivalent to 33% efficiency) for all energy sources, which is typical for thermoelectric facilities but may under or over estimate the energy footprint from other sources.

Appendix B:

Suggested Formats for Presenting the Results of the Footprint Analysis

FLOW OF INFORMATION FOR TABLES B-1 THROUGH B-6

TABLE B-1. SUGGESTED FORMAT FOR SUMMARIZING AND PRESENTING THE ENVIRONMENTAL FOOTPRINT ANALYSIS RESULTS

TABLE B-2. SUGGESTED FORMAT FOR PRESENTING MATERIALS METRICS

TABLE B-3. SUGGESTED FORMAT FOR PRESENTING WASTE METRICS

TABLE B-4. SUGGESTED FORMAT FOR PRESENTING ONSITE WATER METRICS

TABLE B-5A. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING ONSITE (SCOPE 1) ENERGY AND AIR METRICS

TABLE B-5B. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING ELECTRICITY GENERATION (SCOPE 2) ENERGY AND AIR METRICS

TABLE B-5C. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING TRANSPORTATION (SCOPE 3A) ENERGY AND AIR METRICS

TABLE B-5D. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING OFFSITE (SCOPE 3B) ENERGY AND AIR METRICS

TABLE 6. SUGGESTED FORMAT FOR SUMMARIZING ENERGY AND AIR METRICS

SUGGESTED FORMAT FOR ILLUSTRATING CONTRIBUTIONS TO A METRIC

FLOW OF INFORMATION FOR TABLES B-1 THROUGH B-6

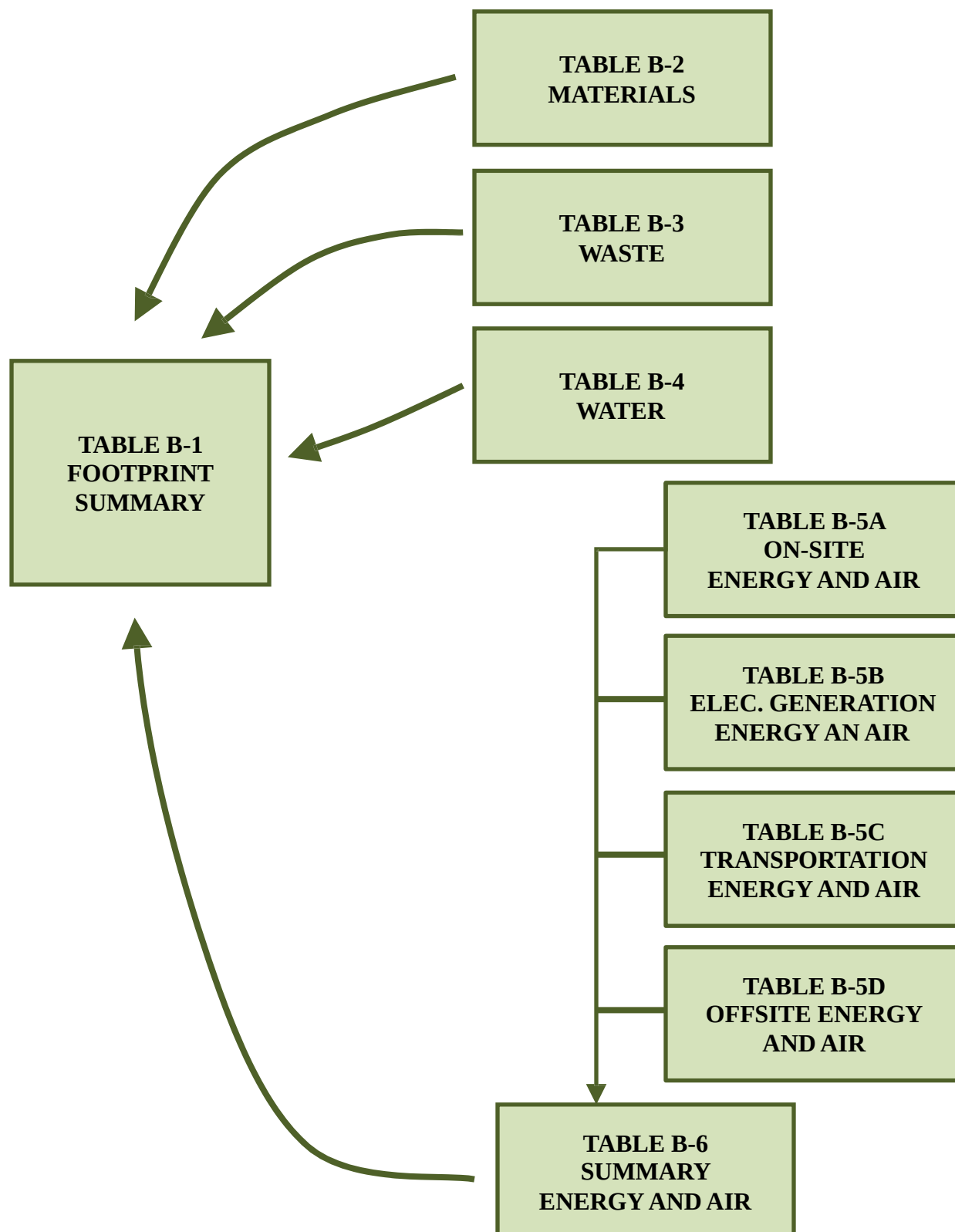


TABLE B-1. SUGGESTED FORMAT FOR PRESENTING THE ENVIRONMENTAL FOOTPRINT

ANALYSIS RESULTS

Core	Metric		Unit of	Value
Materials & Waste	M&	Refined materials used on site	tons	Obtain value from Table B-2, Item
	M&	percent of refined materials from recycled or waste	percent	Obtain value from Table B-2, Item
	M&	Unrefined materials used on site	tons	Obtain value from Table B-2, Item
	M&	percent of unrefined materials from recycled or waste	percent	Obtain value from Table B-2, Item I
	M&	Onsite hazardous waste generated	tons	Obtain value from Table B-3, Item
	M&	Onsite non-hazardous waste generated	tons	Obtain value from Table B-3, Item
	M& W-7	percent of total potential onsite waste that is recycled or reused	percent	Obtain value from Table B-3, Item
Water		Onsite water use (by source)		
	W-1	- Source, use, fate combination #1	millions of	Obtain value from Table B-4,
	W-2	- Source, use, fate combination #2	millions of	Obtain value from Table B-4,
	W-3	- Source, use, fate combination #3	millions of	Obtain value from Table B-4,
	W-4	- Source, use, fate combination #4	millions of	Obtain value from Table B-4,
Energy	E-1	Total energy use	MMBtu	Obtain value from Table B-6, Item
	E-2	Total energy voluntarily derived from renewable resources		
	E-2	- Onsite generation or use and biodiesel use	MMBtu	Obtain value from Table B-6, Item
	E-2	- Voluntary purchase of renewable electricity	MWh	Obtain value from Table B-6, Item
	E-2	- Voluntary purchase of RECs	MWh	Obtain value from Table B-6, Item
Air	A-1	Onsite NOx, SOx, and PM emissions	lbs	Obtain value from Table B-6, Item
	A-2	Onsite HAP emissions	lbs	Obtain value from Table B-6, Item
	A-3	Total NOx, SOx, and PM emissions	lbs	Obtain value from Table B-6, Item
	A-4	Total HAP emissions	lbs	Obtain value from Table B-6, Item
	A-5	Total GHG emissions	tons CO ₂ e	Obtain value from Table B-6, Item

Land &		Qualitative description.

The above table presents the results for the footprint analysis metrics. The following tables are support tables that present the information and calculations used to obtain the metrics.

(Values calculated in highlighted cells are transferred to the summary table (Table
D
) B-1). Items in parentheses are for explanatory purposes only.

$$C=A+B$$

$$E=B/C$$

$$H=F+G$$

$$C=D/2000$$

$$I=G/H$$

TABLE B-3. SUGGESTED FORMAT FOR PRESENTING WASTE METRICS

Waste or Spent Material	Quantit	% of Total
Recycled/Reused Waste (tons)		
Used On Site		
Used On Site Subtotal:	(A)	
Recycled or Reused Off Site		
Recycled/Reused Off Site Subtotal:	(B)	
Recycled/Reused Waste Total:	(C)	(D)
Waste Disposal (tons)		
Hazardous Waste		
Hazardous Waste Subtotal:	(E)	
Non-Hazardous Waste		
Non-Hazardous Waste Subtotal:	(F)	
Waste Disposal Total:	(G)	
Total Potential Waste*:	(H)	100%

* Includes waste that is recycled or reused as well as waste that is disposed of in landfills, incinerators, or other forms of disposal that do not allow for recycling or reuse.

(
D
)

Values calculated in highlighted cells are transferred to the summary table (Table B-1). Items in parentheses are for explanatory purposes only.

C=A+B

D=C/H

G=E+F

H=C+G

TABLE B-4. SUGGESTED FORMAT FOR PRESENTING ONSITE WATER METRICS

Water Resource	Description of Quality of Water Used	Volume Used (Millions of	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location:				
Extracted groundwater #2 Location:				
Extracted groundwater #3 Location:				
Surface water #1				
Surface water #2				
Reclaimed water				
Collected/diverted stormwater				
Other resource #1				
Other resource #2				

Column 1

Column 2

Column 3

Column 4

Column 5

*Descriptions from Columns 1, 4, and 5 are used to define the water metric in Table B-1.
Values from Column 3 are the values of those metrics.*

TABLE B-5A. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING ONSITE (SCOPE 1) ENERGY AND AIR METRICS

Contributors to Footprints	Units	Us	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMB	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Onsite Renewable Energy														
Electricity generated on site by renewable resources	MW		10.											
Landfill gas combusted on site	ccf		0.1		13.1		0.0		0.000		0.00		8.4E-0	
Biodiesel used on site	gal		0.1		22.3		0.2		0		0.00		NP	
Other onsite renewable energy use #1	TBD		TB		TBD		TB		TBD		TBD		TBD	
Other onsite renewable energy use #2	TBD		TB		TBD		TB		TBD		TBD		TBD	
Onsite Renewable Energy Subtotals				(A)										
Other Onsite Energy														
Grid electricity	MW		3.4											
Onsite diesel use	gal		0.1		22.5		0.1		0.005		0.00		0.000	
Onsite gasoline use	gal		0.1		19.6		0.1		0.004		0.00		0.000	
Onsite natural gas use	ccf		0.1		13.1		0.0		0.000		0.00		8.4E-0	
Other forms of onsite energy use #1	TBD		TB		TBD		TB		TBD		TBD		TBD	
Other forms of onsite energy use #2	TBD		TB		TBD		TB		TBD		TBD		TBD	
Other Onsite Energy Subtotals														
Other Onsite Emissions Contributions														
Onsite HAP process emissions	lb												1	
Onsite GHG emissions	lb				1									
Onsite carbon storage	lb				(1)									
GHG reductions by combusting onsite landfill	lb				(20)									
Other onsite contributions	TBD				TBD		TB		TBD		TBD		TBD	
Other Onsite Subtotals														
Onsite Totals				(B1)		(B2)		(B3)		(B4)		(B5)		(B6)

TBD = to be determined. Values in parentheses are negative values. Energy for electricity is only that energy of that electricity and not the energy required to generate the electricity. ccf CH₄ = 100 cubic feet of methane. Obtained by multiplying total volume of landfill gas in ccf by the percentage of the gas that is methane. Energy associated with onsite generation of electricity is assumed to be 10.3 MMBtu/MWh (3.413 MMBtu/MWh for usable electricity plus 6.9 MMBtu/MWh for energy loss due to an assumed 33 percent efficiency). 33 percent efficiency is consistent with Exhibit 3.17. Energy associated with onsite use of grid electricity is 3.413 MMBtu/MWh of electricity because the energy loss associated with 33 percent efficiency is counted in Scope 2 energy calculations. If fuel is a blend of conventional fuel and renewable resource fuel, enter the amount of fuel from conventional sources into appropriate conventional fuel categories and enter amount of fuel from renewable resources into appropriate renewable fuel categories (e.g., for 100 gallons of B20 biodiesel blend, 20 gallons would be entered under biodiesel and 80 gallons would be entered under diesel).

1. Enter use into blue cells in “Use” column in indicated units.
2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factors. Enter result into blue cells in parameter columns.
3. Sum Onsite Renewable Energy results for each parameter and enter in green “Onsite Renewable Energy Subtotals” cells.
4. Sum Other Onsite Energy results for each parameter and enter in green “Other Onsite Energy Subtotals” cells.
5. Sum Other Onsite Contributions results for each parameter and enter in green “Other Onsite Subtotals” cells.
6. Sum green cells for each parameter and enter result in green “Onsite Totals” cells.

Use × Conversion factor = Footprint

This table is for calculation purposes only.
Items (A) and (B1) through (B6) are transferred to Table B-6.

TABLE B-5B. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING ELECTRICITY GENERATION (SCOPE 2) ENERGY AND AIR METRICS

Contributors to Footprints	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MM	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Grid electricity use	MWh		TB	(A1)	TB	(A2)	TB	(A3)	TB	(A4)	TB	(A5)	TB	(A6)
Green pricing or green marketing product purchases	MWh	(B												
REC purchase	MWh	(C												

See Exhibit 3.17 for how to determine the conversion factors for grid electricity.

1. Enter grid electricity use in MWh into blue cell in “Use” column.

2. Convert MWh use into indicated units of each parameter by multiplying use by the indicated conversion factors. Enter result into blue cells in parameter columns.

3. Enter quantity of voluntary purchased renewable electricity in the form of green pricing and green marketing products into the associated blue cell, and document information regarding that product in the table below.

4. Enter quantity of voluntary purchased renewable electricity in the form of RECs into the associated blue cell, and document information regarding that product in the table below.
-

$$Use \times Conversion\ factor = Footprint$$

Description of purchased green pricing or green marketing product	Provider:
	Type of product:
	Type of renewable energy source:
	Date of renewable system installation:
Description of purchased RECs	Provider:
	Type of renewable energy source:
	Date of renewable system installation:

This table is for calculation purposes only.
Items (A1) through (A6), (B), and (C) are transferred to Table B-6.

TABLE B-5C. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING TRANSPORTATION (SCOPE 3A) ENERGY AND AIR METRICS

Category	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Con v.	lbs	Conv. Factor	lbs
Conventional Energy														
Diesel use	gal		0.139		22.5		0.17		0.0054		0.003		0.0000	
Gasoline use	gal		0.124		19.6		0.11		0.0045		0.000		0.0000	
Natural gas use	ccf		0.103		13.1		0.01		0.0000		0.000		0.0000	
Conventional Energy Subtotals														
Renewable Energy														
Biodiesel use	gal		0.127	(A)	22.3		0.20		0		0.000		NP	
Transportation Totals				(B1)		(B2)		(B3)		(B4)		(B5)		(B6)

1. Enter uses of each material or service into “Use” column in indicated units.
2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factor. Enter result into blue cells in parameter columns.
3. Sum Conventional Energy results for each parameter and enter in green “Conventional Energy Subtotals” cells.
4. Sum Conventional Energy Subtotals and biodiesel use results for each parameter and enter in green “Transportation” cells.

Use × Conversion factor = Footprint

*This table is for calculation purposes only.
Items (A) and (B1 through (B6) are transferred to Table B-6.*

TABLE B-5D. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING OFFSITE (SCOPE 3B) ENERGY AND AIR METRICS

Category	Units	Use	Energy		GHGs		NO _x		SO _x		PM		HAPs	
			Con v.	MMBt	Con v.	lbs CO ₂	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
<u>Construction Materials</u>														
Cement	dry-lb		0.002		0.9		0.001		0.0010		0.0000		0.0000	
Concrete	lb		0.000		0.171		0.000		0.0002		0.0000		0.0000	
Gravel/sand/clay	lb		0.000		0.0034		0.000		0.0000		0.0000		2.1E-1	
HDPE	lb		0.031		1.9		0.003		0.0041		0.0006		0.0000	
Photovoltaic system (installed)	W		0.034		4.5		0.015		0.032		0.0006		0.0000	
PVC	lb		0.022		2.6		0.004		0.0076		0.0012		0.0004	
Stainless Steel	lb		0.012		3.4		0.007		0.012		0.0044		0.0001	
Steel	lb		0.004		1.1		0.001		0.0017		0.0005		0.0000	
Other refined construction	lb		0.014		1.98		0.003		0.0053		0.0014		0.0001	
Other unrefined construction	lb		0.000		0.0033		0.000		0.0000		0.0000		2.1E-1	
<u>Treatment Materials and</u>														
Cheese Whey	lb		0.002		0.031		0.000		0.0000		0.0000		NP	
Emulsified vegetable oil	lb		0.007		3.44		0.006		0.0019		0.0000		NP	
Molasses	lb		0.004		0.48		0.001		0.0002		0.0000		NP	
Treatment materials and	lb		0.015		1.7		0.003		0.0065		0.0006		0.0000	
Virgin GAC (coal based)	lb		0.015		5.8		0.014		0.034		0.0007		0.0012	
<u>Fuel Processing</u>														
Biodiesel Produced	gal		0.029		-16.8		0.018		0.033		0.0008		NP	
Diesel Produced	gal		0.019		2.7		0.006		0.013		0.0003		0.0001	
Gasoline Produced	gal		0.021		4.4		0.008		0.019		0.0005		0.0001	
Natural Gas Produced	ccf		0.005		2.2		0.003		0.0046		0.0000		0.0000	
<u>Public water</u>	gal x		0.009		5		0.009		0.0059		0.016		0.0000	
<u>Offsite Services</u>														
Offsite waste water treatment	gal x		0.015		4.4		0.016		0.015		NP		NP	
Offsite Solid Waste Disposal	ton		0.16		25		0.14		0.075		0.4		0.0014	
Offsite Haz. Waste Disposal	ton		0.176		27.5		0.154		0.0825		0.44		0.0015	
Offsite Laboratory Analysis	\$		0.006		1		0.004		0.0036		0.0004		0.0001	

TABLE B-5D. SUGGESTED FORMAT FOR CALCULATING AND PRESENTING OFFSITE (SCOPE 3B) ENERGY AND AIR METRICS (continued)

Category	Units	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
<i>Resource Extraction for Electricity</i>														
Coal extraction and processing	MWh		3.1		180		0.77		0.15		0.018		NP	
Natural gas extraction and	MWh		1.6		270		0.18		13		0.0071		NP	
Nuclear fuel extraction and	MWh		0.16		25		0.15		0.5		0.0015		NP	
Oil extraction and processing	MWh		2.3		270		1.7		0.069		0.042		NP	
<i>Electricity Transmission</i>														
Transmission and distribution	MWh		10.3											
Offsite Totals				(A1)		(A2)		(A3)		(A4)		(A5)		(A6)

NP = not provided

1. Enter uses of each material or service into "Use" column in standard units.
 2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factor. Enter result into blue cells in parameter columns.
 3. Fuel processing refers to all fuel used, including that for onsite equipment use and transportation.
 4. Electricity from various resources is obtained from generation mix that is used in Exhibit 3.17 and the resource extraction conversion factors from Exhibit 3.14.
 5. For electricity transmission, enter 10 percent of the grid electricity used for calculating energy and emissions from electricity generation. The conversion factors are the same as those used for electricity generation, but the energy conversion factor is 10.3 MMBtu/MWh (3.413 MMBtu/MWh for usable electricity plus 6.9 MMBtu/MWh for energy loss due to an assumed 33 percent efficiency at the power plant).
 6. Resource extraction conversion factors are calculated using values in Exhibit 3.14 and the specified fuel blend for electricity generation.

$$Use \times Conversion\ factor = Footprint$$

*This table is for calculation purposes only.
Items (A1) through (A6) are transferred to Table B-6.*

TABLE B-6. SUGGESTED FORMAT FOR SUMMARIZING ENERGY AND AIR METRICS

Category	Total	GHGs	NOx	SOx	PM	NOx+SOx+P	HAPs
	MMbtus	lbs CO ₂ e	lbs	lbs	lbs	lbs	lbs
Onsite (Scope 1)						(D)	(E)
Electricity Generation (Scope 2)							
Transportation (Scope 3a)							
Other Offsite (Scope 3b)							
Remedy Totals	(A)	(B)				(F)	(G)
GHG Footprint in Tons (1 ton = 2,000 lbs)		(C)					

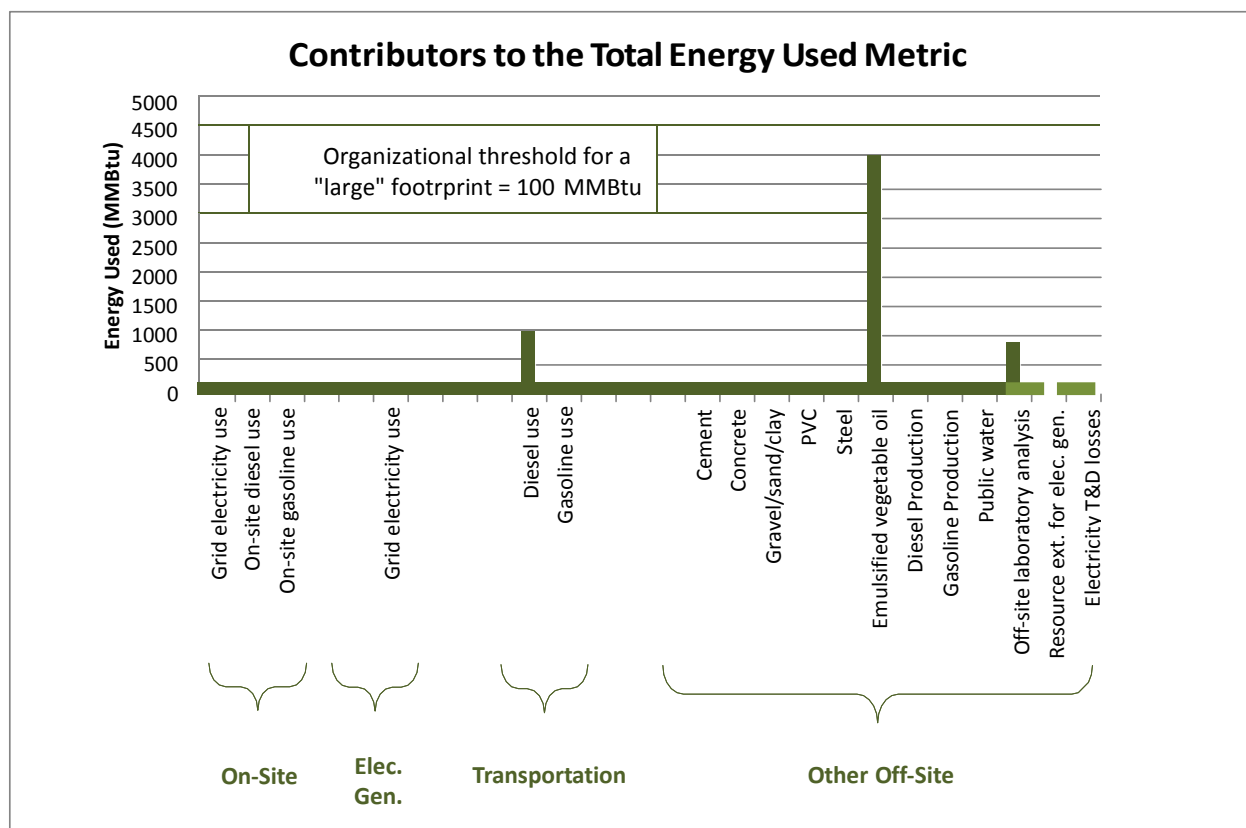
1. Values for “On Site (Scope 1)” are items B1 through B6 from Table B-5A.
2. Values for “Electricity Generation (Scope 2)” are items A1 through A6 from Table B-5B.
3. Values for “Transportation (Scope 3a)” are items B1 through B6 from Table B-5C.
4. Values for “Other Offsite (Scope 3b)” are items A1 through A6 from Table B-5D
5. Sum Scope 1 through Scope 3b values in each column to obtain “Remedy Totals”
6. Divide item B by 2000 to obtain GHG metric in tons
7. Sum NOx, SOx, and PM10 values in each row to obtain “NOx+SOx+PM10”

Voluntary Renewable Energy Use	Unit	Quantity
Onsite generation or use	MMBtu	(H)
Onsite biodiesel use	MMBtu	(I)
Biodiesel use for transportation	MMbtu	(J)
Onsite generation or use and biodiesel use	MMBtu	(K)
Renewable electricity purchase	MWh	(L)
REC purchases	MWh	(M)

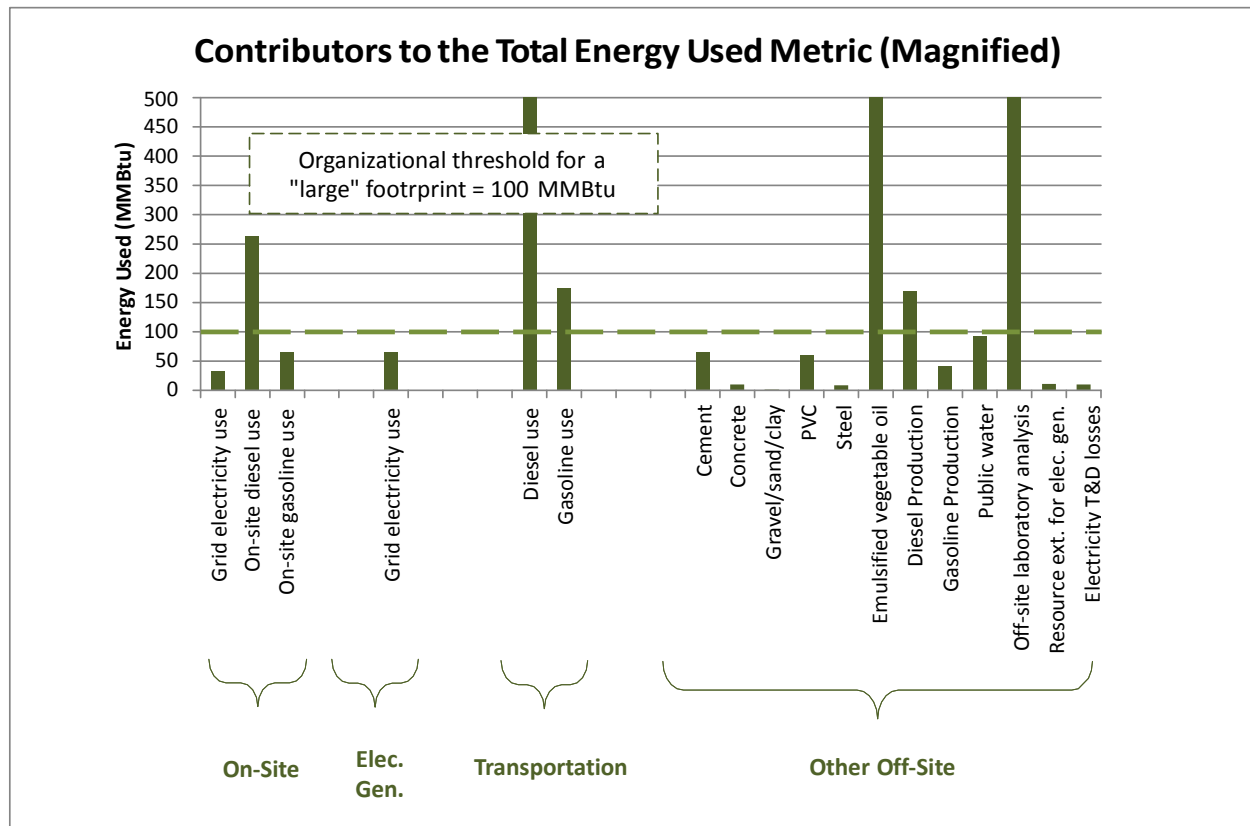
1. Value for “Onsite energy generation or use” is item A from Table B-5A.
2. Value for “Onsite biodiesel use” is from Table B-5A.
3. Value for “Biodiesel use for transportation” is item A from Table B-5C
4. Value for “Onsite generation or use and biodiesel use” (K) is calculated as follows: $K = H + I + J$.
5. Value for “Renewable electricity purchase” is item B from Table B-5B.
6. Value for “REC purchases” is item C from Table B-5B.

SUGGESTED FORMAT FOR ILLUSTRATING CONTRIBUTIONS TO A METRIC

Project teams may find it helpful to graph the contributions to each metric to identify the values of the contributions next to each other or next to some guide or threshold value. The following example figure depicts the contributions to the *total energy used* metric from Energy and Air Scenario #1. The *total energy used* metric was chosen as an example. Figures might be generated for other metrics as well. The organization operating the remedy has determined that any activity that uses more than 100 MMBtu should be targeted for potential footprint reduction. The figure illustrates this 100 MMBtu guide.



Some contributions (e.g., diesel for transportation, emulsified vegetable oil, and laboratory analysis) are significantly higher than this 100 MMBtu target. These contributions are clear targets for applying footprint reduction practices or BMPs. The figure is also regenerated on the following page with a different vertical axis to visualize some of the smaller footprint contributions relative to the 100 MMBtu guide.



This figure shows that onsite diesel use, gasoline use for transportation, diesel production (e.g., at a refinery), and public water use are all contributions that are close to or larger than the 100 MMBtu guide. The project team might consider use of biodiesel blends, carpooling, and use of alternate water supplies as potential practices for reducing these footprints.

Appendix C: Footprint Reduction Scenarios

Eight hypothetical cleanup scenarios are presented in this appendix to illustrate how the results of methodology application could be screened to find potential strategies for reducing the project's environmental footprint. The footprint reduction scenarios are categorized as follows:

- **Materials and Waste**
- **Water**
- **Energy and Air**

These scenarios are categorized for illustrative purposes and are independent of one another. As such, the site conditions or other influential factors in each scenario are not necessarily common among the three categories.

Scenarios in this appendix are provided for illustrative purposes only and do not constitute a recommendation by EPA.

**Footprint Reduction Scenarios:
Materials and Waste**

MATERIALS AND WASTE SCENARIO #1

MATERIALS AND WASTE SCENARIO #2

MATERIALS AND WASTE SCENARIO #3

MATERIALS AND WASTE FOOTPRINT REDUCTION SCENARIO #1

Background:

A P&T system is under design to treat arsenic through co-precipitation. The 50 percent design extraction rate is 700 gpm, and the system is anticipated to operate for 30 years. The process water is oxidized with hydrogen peroxide. Ferric chloride is added to provide iron to adsorb the arsenic, and sodium hydroxide is added to neutralize the water. Polymer is added to assist with flocculation. Precipitated metals are dewatered and disposed of off site as listed hazardous waste. No other significant waste streams are associated with the site.

The following items will be constructed:

- Ten 6-inch extraction wells, each to 60 feet deep with 20-foot screens
- 3,000 feet of 6-inch HDPE piping with electrical conduit and wiring
- 80-foot x 100-foot building that is 30 feet high
- 200-foot x 200-foot reinforced fly-ash concrete pad and containment area (20,000 ft³ of concrete)
- 50,000 pounds of primary treatment equipment

Screening:

The largest contributor to refined materials is expected to be the sodium hydroxide (over 6,000,000 lbs of pure sodium hydroxide) over a 30-year period. The largest contributor for unrefined materials is expected to be the aggregate in the concrete for the building foundation (about 1,200 tons). No specific appreciable non-hazardous waste streams have been identified. The dewatered sludge from metals removal is expected to be 2,600 tons. The project team has chosen a percent-based screening limit of 1 percent for refined and unrefined materials and magnitude based limits of 1,000 lbs for refined materials and 1 ton for unrefined materials and wastes. The limits are therefore as follows:

Categ	Large st	Large st	Selecte d % of Largest	Perce nt-	Magnitu de-	Applic able
Refi ned	Sodiu m	6,000,000 lbs	1%	60,000 lbs	1,000 lbs	60,000 lbs
Unrefi ned	Concr ete	1,200 tons	1%	12 tons	1 tons	12 tons
Non-hazar dous	Gener al waste	Unknown	1%	Unkno wn	1 ton	1 ton

Hazar dou	Dewate red	2,600 tons	1%	26 tons	1 ton	26 tons

The data quality for the remedy information is considered poor to moderate. The extraction rate is subject to change due to additional modeling and capture zone evaluation during startup. The chemical dosing is highly dependent on actual influent chemical loading, and the remedy duration was loosely estimated for cost estimating purposes. The footprint results are expected to be highly sensitive to these relatively uncertain parameters. Because the metrics are direct presentation of expected materials use and waste,

there is little or no added uncertainty associated with converting remedy information and engineering estimates into the metrics as there would be for energy and air metrics.

MATERIALS AND WASTE SCENARIO #1 (continued)

Estimated Materials Footprint over 30-Year Operation Period

Material and Use	Uni	Quanti	Conve rsion Factor	% Recycl ed or	Quantity	
					Virgin	Rec
Refined Materials (lbs)						
Wells – PVC casing and grout		Expected to be less than screening limit				
Wells – screen		Expected to be less than screening limit				
Piping and conduit	ft	3,000	7.5 lbs/ft		22,500	
Building steel	ft ³	240,0	1	55%	108,00	132,
Concrete reinforcing steel	ft ²	40,00	1.3	55%	23,400	28,6
Cement portion of concrete	ft ³	20,00	22	20%	352,00	88,0
Process equipment		Expected to be less than screening limit				
Process controls		Expected to be less than screening limit				
Hydrogen peroxide (50%)	gal	295,6	4.96	0%	1,467,	0
Ferric chloride (37%)	gal	1,368	4.33	0%	5,928,	0
Sodium hydroxide (20%)	gal	3,011	2.04	0%	6,144,	0
Polymer (specific gravity =	gal	120,4	8.7	0%	1,047,	0
Refined materials Total (lbs):					15,091	248,
Refined materials Total (lbs):					15,340,500	
Refined Materials Total (tons = lbs / 2000):					7,670	
Percent of Refined Materials that is Recycled or Reused Content					<2%	
Unrefined Materials (tons)						
Wells –sand pack		Expected to be less than screening limit				
Aggregate for concrete	ft ³	20,000	115 lbs/ft ³		1,150	
			2000			
Unrefined Materials Total (tons):					1,150	0
Unrefined Materials Total (tons):					1,150	
Percent of Unrefined Materials that is Recycled or Reused Content:					0%	

NOTE: polymer quantity includes unknown water content of aqueous solution

* Values for piping/conduit and concrete reinforcing steel are shown in the above table because the project team determined that professional judgment alone was not sufficient to assume they were below the screening limit. Because the project team invested the time and resources to estimate the values for the screening process, the contributions from these items are retained in the analysis.

Values provided in the “Quantity” Column are obtained from engineering estimates during design.

Conversion factors in above tables obtained from Exhibit 3.3 through Exhibit 3.8.

MATERIALS AND WASTE SCENARIO #1 (continued)

Estimated Waste Footprint		
Waste or Used Material	Quantit	% of Total
Recycled/Reused Waste (tons)		
Used On Site		
None.		
Used On Site Subtotal:	0	0%
Recycled or Reused Off Site		
None.		
Recycled/Reused Off Site Subtotal:	0	0%
Recycled/Reused Waste Total:	0	0%
Waste Disposal (tons)		
Hazardous Waste		
2,600 tons of dewatered precipitated metals sludge	2,600	100%
Hazardous Waste Subtotal:	2,600	100%
Non-Hazardous Waste		
None.		
Non-Hazardous Waste Subtotal:	0	0%
Waste Disposal Total:	2,600	100%
Total Potential Waste*:	2,600	100%

* Includes waste that is recycled or reused as well as waste that is disposed of in landfills, incinerators, or other forms of disposal that do not allow for recycling or reuse.

Findings:

Overall materials use is dominated by the treatment chemicals. Efforts for footprint reduction can be focused on identifying a potential waste stream of iron hydroxides that may help reduce some of the sodium hydroxide and ferric chloride use. Use of this waste stream would also increase the percentage of materials from recycling/reuse. The waste footprint is dominated by the precipitated sludge. The waste is not characteristically hazardous. Delisting the waste may allow for non-hazardous waste disposal, which would lower the hazardous waste footprint and increase the non-hazardous waste footprint. Effort will also be placed on optimizing the extraction rate because the extraction rate directly influences treatment chemical use and waste disposal.

MATERIALS AND WASTE SCENARIO #2

Background:

A biobarrier that involves routine injections of emulsified vegetable oil is designed to control groundwater plume migration. A total of 20 permanent injection wells each with 20-foot screen intervals will be used. Of the 20 wells, 10 will be 60 feet deep and 10 will be 40 feet deep. The wells will be constructed with 2-inch PVC casing. A total of 400,000 lbs of emulsified vegetable oil will be injected over events spanning 10 years. Drill cuttings (approximately 9 tons) are disposed of off site at a landfill as non-hazardous waste.

Screening:

The largest contributor to refined materials is expected to be the emulsified vegetable oil. The largest contributor for unrefined materials is expected to be the sand (about 4 tons) for the sand packs of the injection wells. The drill cuttings are the only anticipated waste stream. The project team has chosen a percent-based screening limit of 1 percent for refined and unrefined materials and magnitude based limits of 1,000 lbs for refined materials and 1 ton for unrefined materials and wastes. The limits are therefore as follows:

Catego	Large st	Large st	Selecte d % of Largest	% - bas	Magnitu de-	Applic able
Refin ed	Emulsi fied	400,000 lbs	1%	4,000 lbs	1,000 lbs	4,000 lbs
Unrefi ned	Sand	4 tons	1%	0.04 tons	1 ton	1 ton
Non-hazard ous	Drill cuttings	9 tons	1%	0.09 tons	1 ton	1 ton
Hazard ous	None expected					

The data quality for the remedy information is considered moderate. The design for the injection well network is finalized and is conservative. No additional wells are expected. The amount of emulsified vegetable oil to be added in the first event has also been determined, but the frequency of maintenance injections and the amount of oil to be injected in each maintenance injection event are estimates to be refined during remedy implementation. The footprint results are expected to be highly sensitive to parameters of the reinjection events. Because the metrics are direct presentation of expected materials use and waste, there is little or no added uncertainty associated with converting remedy information and engineering estimates into the metrics as there would be for energy and air metrics.

MATERIALS AND WASTE SCENARIO #2 (continued)

Estimated Materials Footprint

Material and Use	U	Quan	Conver sion Factor	% Recycl ed or	Quantity	
					Virgin	Rec
Refined Materials						
Injection well PVC		Expected to be less than screening limit				
Injection well grout	f	800	13	0%	10,400	0
Emulsified vegetable oil	l	400,	1	0%	400,00	0
Other items		Expected to be less than screening limit				
Refined materials Total (lbs):					410,40	0
Refined materials Total (lbs):					410,400	
Refined Materials Total (tons = lbs/2000):					205	
Percent of Refined Materials that is Recycled or Reused Content					0%	
Unrefined Materials						
Injection wells – sand pack	f	400	0.01	0%	4	0
Unrefined Materials Total (tons):					4	0
Unrefined Materials Total (tons):					4	
Percent of Unrefined Materials that is Recycled or Reused Content:					0%	

Values provided in the “Quantity” Column are obtained from engineering estimates during design.

Conversion factors in above tables obtained from Exhibit 3.3 through Exhibit 3.8.

Estimated Waste Footprint

Waste or Used Material	Quantit	Percent of Total
Recycled/Reused Waste (tons)		
Used On Site		
None.		
Used On Site Subtotal:	0	0%
Recycled or Reused Off Site		
None.		
Recycled/Reused Off Site Subtotal:	0	0%
Recycled/Reused Waste Total:	0	0%
Waste Disposal (tons)		
Hazardous Waste		
None.	0	0%
Hazardous Waste Subtotal:	0	0%
Non-Hazardous Waste		
Drill cuttings	9	100%
Non-Hazardous Waste Subtotal:	9	100%
Waste Disposal Total:	9	100%
Total Potential Waste*:	9	100%

** Includes waste that is recycled or reused as well as waste that is disposed of in landfills, incinerators, or other forms of disposal that do not allow for recycling or reuse.*

MATERIALS AND WASTE SCENARIO #2 (continued)

Findings:

Overall materials use is dominated by the emulsified vegetable oil. Efforts for footprint reduction can be focused on identifying a potential off-spec food grade amendment that will otherwise be considered a waste product. This may modify the total amount of materials used but will also increase the percentage of materials from recycled/reused material. Performance monitoring data will be reviewed closely to evaluate quantity and frequency of maintenance injections so that remedy protectiveness is maintained without using much more vegetable oil than expected. The drill cuttings are not hazardous, and it may be possible to use them as fill elsewhere on site to reduce the quantity of waste for offsite disposal and increase the total potential waste that is recycled or reused.

MATERIALS AND WASTE SCENARIO #3

Background:

Contaminated soil is being consolidated on site and covered with a Resource Conservation and Recovery Act (RCRA) Subtitle C cap. The total cap surface area is approximately 100,000 square feet. No waste is being transported off site for disposal, so there is no waste footprint. The cap components are as follows:

- 24 inches of earthen material (200,000 ft³ or 7,400 cy = 9,000 tons)
- 12 inches of sand (100,000 ft³ or 3,700 cy = 5,600 tons)
- 40-mil HDPE membrane (40 mils = 0.040 inches, total volume = 333 ft³ = 19,900 lbs)
- 24 inches of compacted clay (200,000 ft³ or 7,400 cy = 11,100 tons)
- 12 inches of native soil/sand as a foundation for the cap (100,000 ft³ or 3,700 cy = 5,600 tons)

The 12 inches of native soil/sand are used from an onsite borrow pit that will be converted to a required stormwater retention basin. The 24-inch thick layer of earthen material will be a combination of onsite soil (75 percent) and mulch/compost (25 percent) generated from onsite vegetation. The 12-inches of sand for the drainage layer, the 24-inches of clay, and the HDPE are brought from offsite sources. The design has been finalized, and little change is expected in these parameters.

Screening:

The largest contributor to refined materials is expected to be the HDPE liner. The largest contributor for unrefined materials is the clay. The native soil is considered a reused product because the excavated area will be converted to a stormwater retention basin. The mulch/compost is also considered a reused or recycled material because it is generated from cleared vegetation that would otherwise need to be hauled off site. No waste streams have been identified. The project team has chosen a percent-based screening limit of 1 percent for refined and unrefined materials and magnitude based limits of 1,000 lbs for refined materials and 1 ton for unrefined materials and wastes. The limits are therefore as follows:

Catego	Large st	Large st	Selected % of Largest	Perce nt-	Magnitude-b ased	Applic able
Refin ed	HDPE	19,900 lbs	1%	190 lbs	1,000 lbs	1,000 lbs
Unrefi ned	Clay	11,100 tons	1%	110 tons	1 ton	110 tons
Non-hazard ous		None expected				

Hazardous		None expected

The data quality for the remedy information is considered good. The design has been completed and construction is underway. No significant changes in materials use are anticipated. Because the metrics are direct presentation of expected materials use and waste, there is little or no added uncertainty associated with converting remedy information and engineering estimates into the metrics as there would be for energy and air metrics.

MATERIALS AND WASTE SCENARIO #3 (continued)

Estimated Materials Footprint

Material and Use	Unit	Quantity	Conversion	% Recycled or	Quantity	
					Virgin	Recycled
Refined Materials (lbs)						
HDPE – 40 mil thickness (40 mil = 1.3 mm)	ft ³	333	59.6 lbs/ft ³	0%	19,900	0
Refined materials Total (lbs):					19,900	0
Refined materials Total (lbs):					19,900	
Refined Materials Total (tons = lbs/2000):					9.95	
Percent of Refined Materials that is Recycled or Reused Content					0%	
Unrefined Materials (tons)						
Clay	cuy	7,400	1.5 tons/cuy	0%	11,100	0
Soil for 12-inch layer	cuy	3,700	1.5 tons/cuy	100%	0	5,600
Soil for 75% of 24-inch layer	cuy	5,550	1.5 tons/cuy	100%	0	8,300
Mulch/compost for 25% of 24- inch layer	cuy	1,850	0.4 tons/cuy	100%	0	700
Sand	cuy	3,700	1.5 tons/cuy	0%	5,600	0
Unrefined Materials Total (tons):					16,700	14,600
Unrefined Materials Total (tons):					31,300	
Percent of Unrefined Materials that is Recycled or Reused Content					47%	

Values provided in the “Quantity” Column are obtained from engineering estimates during design.

Conversion factors in above tables obtained from Exhibit 3.3 through Exhibit 3.8.

Waste Footprint
NONE

Findings:

The materials metrics and waste metrics are the result of careful planning during design to use materials for multiple purposes (e.g., excavated areas for retention basins and cleared vegetation for mulch). No other materials and waste footprint reduction opportunities are expected to be identified for this remedy.

**Footprint Reduction Scenarios:
Water**

WATER SCENARIO #1

WATER SCENARIO #2

WATER SCENARIO #3

WATER SCENARIO #1

Background:

A P&T system at a site in the Eastern United States with non-aqueous phase liquid extracts 50 gpm from a shallow aquifer to contain a continuing source of groundwater contamination and prevent the contamination from discharging to a local creek. The aquifer from which water is extracted is considered a potential source of drinking water by the State, but given the water quality, treatment would be required prior to use. Treatment would include removal of dissolved iron and potentially other forms of treatment. There are no current local users of the aquifer. Public water supply source in the area is either surface water or groundwater from deeper, uncontaminated wells. Water treated by the P&T system is discharged to the creek that is protected by the remedy. The P&T system is expected to operate for more than 30 years.

An optimization evaluation team suggested constructing a slurry wall and impermeable cap around the contaminant source to reduce the required pumping rate to 10 gpm from 50 gpm. The slurry wall would be 3,000 feet long, with an average depth of 30 feet, and a minimum width of 3 feet. Construction of the slurry wall requires approximately 2 million gallons of extracted groundwater to prepare the slurry. Treated water would be discharged to the same creek. The stormwater diverted by the cap (approximately 1 million gallons per year) eventually discharges to the creek.

Screening:

Given the extraction rates and remedy duration for the existing and optimized remedy configurations, extracted groundwater for treatment is expected to range between 157 and 800 million gallons. The amount of extracted groundwater required for slurry wall construction (2 million gallons) is considered negligible by comparison. No appreciable public water is used for the remedy.

Estimated Onsite Water Footprint:

See tables on following pages.

Findings:

The existing remedy configuration has the largest total water footprint, but the majority of the water use is from the extraction and treatment of shallow groundwater that would otherwise discharge to a local creek. The extracted water is treated and discharged to the same creek such that local water resources are not significantly affected. The existing remedy and optimization configurations both have marginal effects on

local water resources, but other green remediation metrics may be substantially affected. The diverted stormwater could be used to help construct wetlands to increase ecosystem services in the area.

WATER SCENARIO #1 – Existing Remedy Configuration - Onsite Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: within 100 feet of creek Aquifer: shallow	Shallow groundwater that discharges to creek in relatively short distance. Groundwater classified as drinking water by State. Requires treatment prior to use. Other water resources available	790	Extracted for treatment	Discharged to creek
Surface water #1 Intake Location: not				
Collected/diverted stormwater				

WATER SCENARIO #1 – Optimization Consideration (Slurry Wall) Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: within 100 feet of creek Aquifer: shallow	Shallow groundwater that discharges to creek in relatively short distance. Groundwater classified as drinking water by State. Requires treatment prior to use. Other water resources available	160	Extracted for treatment	Discharged to creek
Surface water #1 Intake Location: not				
Collected/diverted stormwater	Rain water quality	30	Prevented from recharging shallow groundwater near	Eventually discharged to nearby creek.

*For the above tables, orange shading indicates areas of potential improvement in the water footprint. Yellow shading indicates no net or significant effect on the water footprint.
Green shading indicates examples of water best management practices.*

WATER SCENARIO #2

Background:

Note that this scenario purposely includes similar features to Scenario #1, with the exception of the quality and local use of groundwater that is extracted and treated as part of the remedy. The water footprint differs significantly from that of Scenario #1 based on the quality of the water and its local use.

A P&T system in the Midwestern United States with non-aqueous phase liquid extracts 200 gpm from an aquifer used as a local potable water supply. Water treated by the P&T system is discharged to surface water. The P&T system is expected to operate for more than 30 years.

An optimization team has suggested two potential modifications to the existing remedy that are not mutually exclusive:

Slurry wall and impermeable cap – A slurry wall and impermeable cap could be constructed around the contaminant source to reduce the required pumping rate to 40 gpm from 200 gpm. The slurry wall would be 3,000 feet long, with an average depth of 30 feet, and a minimum width of 3 feet. Construction of the slurry wall will require approximately 2 million gallons of water to prepare the slurry. Water treated by the P&T system is discharged to surface water. The P&T system is expected to operate for more than 30 years. The stormwater diverted by the cap (approximately 1 million gallons per year) is directed to a nearby infiltration basin.

Beneficial reuse – The treated water can be used for irrigation during the growing season. Approximately 40 percent of the extracted water could therefore be used beneficially.

Screening:

Given the extraction rates and remedy duration for the existing and optimized remedy configurations, extracted groundwater for treatment is expected to range between 630 million gallons and more than 3 billion gallons. The amount of extracted groundwater for slurry wall construction (2 million gallons) is considered negligible by comparison. No appreciable public water is used for the remedy.

Estimated Onsite Water Footprint:

See tables on following pages.

Findings:

The existing remedy configuration has the largest total onsite water footprint. The two optimization suggestions both improve the onsite water footprint, and the two suggestions implemented together improve the footprint further. The substantial volume of extracted water may also serve a beneficial purpose if it can be used for heat transfer in a geothermal heat pump application. Water that is not used for a beneficial purpose can be reinjected to maintain the water resource.

WATER SCENARIO #2 – Existing Remedy Configuration – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply. Limited alternative potable water resources available.	3,200	Extracted for treatment	Discharged to surface water (not reusable)
Collected/diverted stormwater				

WATER SCENARIO #2 – Optimization Suggestion (Slurry Wall) – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply. Limited alternative potable water resources available.	630	Extracted for treatment	Discharged to surface water (not reusable)
Collected/diverted stormwater	Rain water quality	30	Diverted from source area	Allowed to recharge aquifer in unimpacted area.

WATER SCENARIO #2 – Optimization Suggestion (Beneficial Reuse) – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply. Limited alternative potable water resources available.	1,920	Extracted for treatment	Discharged to surface water (not reusable)
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply. Limited alternative potable water resources available.	1,280	Extracted for treatment	Used beneficially. No net loss of water resource due to groundwater extraction and treatment.
Collected/diverted stormwater				

WATER SCENARIO #2 – Optimization Suggestion (Slurry Wall and Beneficial Reuse) – Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply. Limited alternative potable water resources available.	378	Extracted for treatment	Discharged to surface water (not reusable)
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply. Limited alternative potable water resources available.	252	Extracted for treatment	Used beneficially. No net loss of water resource due to groundwater extraction and treatment.
Collected/diverted stormwater	Rain water quality	30	Diverted from source area	Allowed to recharge aquifer in unimpacted area.

For the above tables, orange shading indicates areas of potential improvement in the water footprint. Yellow shading indicates no net or significant effect on the water footprint. Green shading indicates examples of water best management practices.

WATER SCENARIO #3

Background:

This scenario compares two similar remedies considered at two different sites to illustrate how location and local water resources affect the onsite water footprint.

Example #1 - A soil remedy for a site in the arid Western United States involves the excavation, land farming, and backfill of treated soil. Up to 40 acres is expected to be disturbed by heavy equipment. The underlying aquifer is a crucial local water resource for potable water and irrigation. No other viable sources of potable water are available in the area. Over 2 million gallons of extracted groundwater is anticipated to be used for dust control over the duration of the remedy. Over 4 million gallons of extracted groundwater is anticipated to be used to foster degradation of contaminants during landfarming over the duration of the remedy.

Example #2 - A soil remedy for a site in the Northern Central United States involves the excavation, land farming, and backfill of treated soil. Up to 40 acres is expected to be disturbed by heavy equipment. The underlying aquifer is not used for potable water or irrigation. Surface water resources are the predominant sources of water in the area. No water is anticipated to be needed for dust control over the duration of the remedy. Approximately 750,000 gallons of extracted groundwater and 250,000 gallons of collected stormwater, which would otherwise discharge to surface water downgradient of the local reservoir, are anticipated to be used to foster degradation of contaminants during landfarming over the duration of the remedy.

Screening:

There are no other appreciable water resource uses other than those specified.

Estimated Onsite Water Footprint:

See tables on following pages.

Findings:

Water use for a the same soil remedy is substantially higher in the arid Western United States than it is the Northern Central United States due to the need for dust control and the high evaporation potential in west. In addition, the water resource in the Western United States is of greater local value due to its use and the absence of other potential sources of water. Timing some of the work associated for Example #1 with or following precipitation events may help reduce the amount of water that needs to be extracted for dust control. However, this could adversely affect schedule. Groundwater use for Example #2 is lower for the same remedy as Example #1. In addition, groundwater is the not the primary water resource used in the area and stormwater is an available resource.

WATER SCENARIO #3 – Example #1 (Arid Western United States) - Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply and irrigation. Limited alternative potable water resources	2	Dust control	Evaporated to atmosphere
Extracted groundwater #1 Location: on site	Groundwater used for local potable water supply and irrigation. Limited alternative potable water resources	4	Landfarming	Evaporated to atmosphere or microbial metabolism
Surface water #1 Intake Location: not				
Collected/diverted stormwater				

WATER Scenario #3 – Example #2 (Northern Central United States) - Water Footprint Analysis

Water Resource	Description of Quality of Water Used	Volume Used	Uses	Fate of Used Water
Public water supply				
Extracted groundwater #1 Location: on site	Groundwater not used for local potable water supply or irrigation.	0.75	Landfarming	Evaporated to atmosphere or microbial metabolism
Surface water #1 Intake Location: not				
Collected/diverted stormwater	Stormwater that would otherwise discharge to local creek	0.25	Landfarming	Evaporated to atmosphere or microbial metabolism

*For the above tables, orange shading indicates areas of potential improvement in the water footprint. Yellow shading indicates no net or significant effect on the water footprint.
Green shading indicates examples of water best management practices.*

**Footprint Reduction Scenarios:
Energy and Air**

ENERGY AND AIR SCENARIO #1

ENERGY AND AIR SCENARIO #2

ENERGY AND AIR SCENARIO #1

Background:

Design of an *in situ* bioremediation remedy for chlorinated volatile organic compounds (VOCs) is underway.

Remedy information is as follows:

- Restoration of 200-foot x 200-foot area of shallow aquifer (25 feet to 50 feet deep)
- Construction of 80 permanent 2-inch PVC wells, 50 feet deep with 20-foot screen intervals
- Drill cuttings left at well locations
- Injection of 500,000 pounds of emulsified vegetable oil (5 percent solution) over three injection rounds
- Extracted groundwater used for chemical blending and injection
- Quarterly sampling at 30 points for 5 years, semi-annual sampling at 30 points for additional 5 years, annual sampling at 30 points for 10 additional years
- All samples analyzed for VOCs only
- Purge water disposed to ground surface

Screening:

This step identifies the largest contributors to the energy and onsite air metrics and develops screening limits for use in identifying important potential contributors to the footprint and providing the rationale for excluding minor contributors.

Onsite NO_x+SO_x+PM Emission Screening

The only sources of onsite emissions are expected to be the drill rig operation and the low-flow sampling equipment. Both are expected to be above the screening limits.

Onsite HAP Emission Screening

No additional sources beyond those counted in the NO_x+SO_x+PM screening.

Total Energy Screening

The screening limit is based on the higher of a magnitude based limit of 100 screening units or a percentage-based limit equal to 1 percent of the largest contributor to the total energy footprint. Because no appreciable renewable energy is used, it is assumed that the total energy screening process reasonably screens items/activities for the total air emissions metrics. Based on professional judgment, the two most

likely candidates for the largest total energy contributor are the 500,000 pounds of emulsified vegetable oil and the well installation. Based on Exhibit 3.2, the 500,000 pounds of emulsified vegetable oil equates to 500,000 screening units ($500,000 \times 1$), and the well installation equates to 200,000 screening units ($4,000 \times 50$). The emulsified vegetable oil is the largest contributor. Therefore, the percentage based screening unit is 5,000 ($500,000 \times 1$ percent). Items or activities associated with the remedy that would equate to less than 5,000 screening units will be omitted.

ENERGY AND AIR CASE STUDY #1 (continued)

The following table presents the primary items/activities associated with the remedy and preliminary engineering estimates regarding the quantities of those items/activities. Screening unit conversions from Exhibit 3.2 are applied to calculate the number of screening units, and a decision to include or exclude each item/activity is stated. Items exceeding the screening limit of 5,000 will be quantified more accurately during footprint calculation. As noted, some items that are available from the materials or waste footprint or for the onsite emissions footprint are included even if the values are below the screening limit because the information is already available.

Item	Quantity	Screening	Limit = 5,000
Vegetable oil	500,000 lbs	500,00	Include
Drill rig operation	Used for onsite NOx+SOx+PM footprint		Include
PVC, Grout, and Steel for wells	Available from materials footprint		Include
Sand for wells	Available from materials footprint		Include
Concrete for wells	Available from materials footprint		Include
Drill rig transport	<1,000 miles	<2,000	Exclud
Oversight transport	<1,000 miles	<500	Exclud
Well materials transport	<10,000 ton-miles	<3,300	Exclud
Vegetable oil transport	>100,000 ton-miles	>33,00	Include
Laboratory analysis	>\$100,000	>100,0	Include
Electricity	>5,000 kWh	>5,000	Include
Injection team travel	>10,000 miles	>5,000	Include
Sampling travel	~5,000 miles	<5,000	Exclud
Sampling equipment	Used for onsite NOx+SOx+PM footprint		Include
Sampling materials	<5,000 lbs	<5,000	Exclud

Footprint Calculation:

This part of the footprint calculation follows Step 5: Quantify Energy and Air Metrics. Step 5 is comprised of 3 parts.

Part 1: Inventory Remedy Travel, Equipment Use,

Materials, and Offsite Services

The following construction materials are available from the materials footprint (not shown)

- 2,700 pounds of PVC (estimated as noted in Exhibit 3.6)

- 30,400 lbs of sand/gravel (estimated as noted in Exhibit 3.6)
- 31,200 lbs of cement for grout (estimated as noted in Exhibit 3.6)
- Bentonite negligible relative to other materials
- 2,000 lbs of steel for well covers (estimated)
- 12 tons of concrete for surface finish (estimated)

Based on Exhibit 3.11B, drilling of 4,000 vertical feet might involve 40 days with a 150 HP rig operating a 75 percent load.

The following are items associated with system operation that passed the screening process:

ENERGY AND AIR CASE STUDY #1 (continued)

- 500,000 pounds (250 tons) of emulsified vegetable oil injected over three events, shipped from approximately 1,000 miles away, empty return trip not required
- 10,000,000 gallons of water extracted, blended, and reinjected
- Average injection rate (multiple wells simultaneously) is 100 gpm
- Consultants and contractors visit site 200 times over three years
 - Travel in three light-duty trucks
 - Roundtrip daily commute is 40 miles
 - Total is $3 \times 40 \times 200 = 24,000$ miles
- Mixers and pumps powered by onsite electricity for 1,800 hours total
 - Four 0.75 HP extraction pumps
 - Two 0.5 HP mixers
 - Two 1 HP transfer pumps
- Local fuel blend for electricity generation is as follows:
 - 40 percent natural gas
 - 15 percent coal
 - 20 percent hydro
 - 20 percent nuclear
 - 2 percent biomass
 - 3 percent wind

The following are items associated with monitoring that passed the screening process:

- 1,200 samples collected and analyzed for VOCs at \$100/sample is \$120,000
- Sampling requires a total of 2,500 hours of two 2.5 HP gasoline compressors (12,500 HP-hrs)

Part 2: Energy Inventory

This step converts the above transportation and equipment use into fuel use and converts electrical equipment use into electricity use. For scenario expediency, energy inventory for three tasks are combined. A formal analysis might split the inventory into three tasks: construction, operations and maintenance (O&M), and long-term monitoring.

Fuel Use for Personnel Transportation

Personnel or Equipment	T	Round trip Distan	Tota l Dist	Vehicle	Fuel Efficie	Fuel Us
<i>Gasoline</i>						

Injection contractor	2	40	8,00	Truck	17 mpg	470
Injection contractor	2	40	8,00	Truck	17 mpg	470
Injection consultant	2	40	8,00	Truck	17 mpg	470
				Total Gasoline		1,410

**Driller and drill rig transport, drilling oversight, and sampling technician transportation to site excluded based on screening.*

ENERGY AND AIR CASE STUDY #1 (continued)

Fuel Use for Equipment Use

Equipment Type	HP	Hou	BFSC	PLF	Fuel Use
<i>Diesel</i>					
Drill rig	150	320	0.052	0.75	1,90
<i>Gasoline</i>					
Sampling compressors	2 x	2,50	0.057	0.75	530

Fuel Use for Equipment, Materials, and Waste Transport

Equipment	Tons	Travel Dista	Vehicle	Fuel Efficiency	Fuel Use
<i>Diesel (transport)</i>					
Drill rig	Excluded				
Well PVC and Steel					
Sand, cement,					
Sand, cement,					
Vegetable Oil	250	1,000	Truc	0.029 gptm	7,25
				Total	7,25

gptm = gallons per ton-mile

Onsite Electricity Use

Equipment	H	% Fu	Motor	k	Hou	kW
Two 0.5 HP mixers	1	80%	65%	0.9	1,800	1,66
Four 0.75 HP extraction	3	80%	65%	2.7	1,800	4,95
Two 1 HP transfer pumps	2	80%	75%	1.6	1,800	2,88
				Total		~9,5

1 HP = 0.746 kW, See Exhibit 3.13 for calculations and assumptions.

Part 3: Convert to Energy and Air Metrics

See accompanying tables

Findings:

The largest contributor to the energy and air metrics is the production of the emulsified vegetable oil, but the following items and activities are also significant contributors that merit additional focus when attempting to reduce the energy and air metrics:

ENERGY AND AIR CASE STUDY #1 (continued)

- Transportation of the emulsified vegetable oil
- Laboratory analysis
- Drill rig operation
- Generators for low-flow sampling

The conversion factor to estimate energy use and emissions from laboratory analysis is generic and derived without specific consideration of what occurs within a laboratory. This additional uncertainty in the laboratory footprint should be considered when interpreting the footprint results. The materials for well installation were generally insignificant with respect to the calculated energy and air metrics.

ENERGY AND AIR SCENARIO #1 – DETERMINING FOOTPRINT CONVERSION FACTORS FOR GRID ELECTRICITY BASED ON UTILITY OR LOCATION

Power Content from Electric Service Provider	
Energy Source	Percentage of Power Mix Delivered
Coal	15%
Natural gas	40%
Oil	0%
Nuclear	20%
Hydroelectric	20%
Biomass	2%
Geothermal	0%
Wind	3%
Solar	<1%

Converting Resource Mix to Footprint Conversion Factors													
Type	%	Energy (MMBtu/M		CO ₂ e		NO _x (lbs/MWh)		SO _x (lbs/MWh)		PM		HAPs	
	o	Ful	Adj. by	Ful	Adj. by	Ful	Adj. by	Ful	Adj	Ful	Adj	Ful	Adj
<i>Conventional Energy</i>													
Coal	1	6.9	1.035	22	330	6	0.	15	2.3	0.0	0.014	0.66	0.0
Natural Gas	4	6.9	2.76	13	520	1.1	0.	0.0	0.0	0.0	0.032	0.025	0.0
Oil	0	6.9	0	18	0	2.2	0	2.8	0	0.1	0	0.066	0
Nuclear	2	6.9	1.38	0	0	0	0	0	0	0	0	0	0
<i>Renewable Energy</i>													
Biomass	2	6.9	0.138	0	0	1.4	0.028	0.6	0.0	0.0	0.001	5.3E-6	1.1
Geothermal	0	6.9		0	0	0	0	0	0	0	0	0	0
Hydroelectric	2	6.9	1.38	0	0	0	0	0	0	0	0	0	0
Solar	0	6.9		0	0	0	0	0	0	0	0	0	0
Wind	3	6.9	0.207	0	0	0	0	0	0	0	0	0	0
Total	1		6.9		850		1.		2.4		0.048		0.1

Full load emission values for each fuel type obtained from www.nrel.gov/lci.
All values do not include energy and emissions for resource extraction or for transmission losses, which are counted in offsite (Scope 3b).
Energy conversion factors exclude the energy contained in the MWh of electricity used by the remedy to avoid double counting of onsite energy use.
For simplicity, energy conversion factors are assumed to be 6.9 MMBtu per MWh (equivalent to 33 percent efficiency) for all energy sources.

ENERGY AND AIR SCENARIO #1 – CALCULATING AND PRESENTING ONSITE (SCOPE 1) ENERGY AND AIR METRICS

Contributors to Footprints	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMB	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Onsite Renewable Energy														
Electricity generated on site by renewable resources	M	0	10.3	0										
Landfill gas combusted on site	ccf	0	0.103	0	13.1	0	0.01	0	0.0000	0	0.00076	0	8.4E-0	0
Biodiesel used on site	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Other onsite renewable energy use #1		0		0		0		0		0		0		0
Other onsite renewable energy use #2		0		0		0		0		0		0		0
Onsite Renewable Energy Subtotals				0		0		0		0		0		0
Other Onsite Energy														
Grid electricity	M	9.	3.413	32.4										
Onsite diesel use	gal	1,	0.139	264.1	22.5	42,75	0.17	323	0.0054	10.26	0.0034	6.46	0.0003	0.57
Onsite gasoline use	gal	5	0.124	65.72	19.6	10,38	0.11	58.3	0.0045	2.385	0.00054	0.2862	0.0003	0.159
Onsite natural gas use	ccf	0	0.103	0	13.1	0	0.01	0	0.0000	0	0.00076	0	8.4E-0	0
Other forms of onsite energy use #1		0		0		0		0		0		0		0
Other forms of onsite energy use #2		0		0		0		0		0		0		0
Other Onsite Energy Subtotals				362		53,13		381.3		12.645		6.7462		0.729
Other Onsite Emissions Contributions														
Onsite HAP process emissions	lb	0											1	0
Onsite GHG emissions	lb	0			1	0								
Onsite carbon storage	lb	0			(1)	0								
GHG reductions by combusting onsite landfill	lb	0			(20)	0								
Other onsite contributions		0				0		0		0		0		0
Other Onsite Subtotals						0		0		0				0
Onsite Totals				362		53,13		381.3		12.645		6.7462		0.729

TBD = to be determined. Values in parentheses are negative values. Energy for electricity is only that energy of that electricity and not the energy required to generate the electricity. ccf CH₄ = 100 cubic feet of methane. Obtained by multiplying total volume of landfill gas in ccf by the percentage of the gas that is methane. Energy associated with onsite generation of electricity is assumed to be 10.3 MMBtu/MWh (3.413 MMBtu/MWh for usable electricity plus 6.9 MMBtu/MWh for energy loss due to an assumed 33 percent efficiency). 33 percent efficiency is consistent with Exhibit 3.17. Energy associated with onsite use of grid electricity is 3.413 MMBtu/MWh of electricity because the energy loss associated with 33 percent efficiency is counted in Scope 2 energy calculations If fuel is a blend of conventional fuel and renewable resource fuel, enter the amount of fuel from conventional sources into appropriate conventional fuel categories and enter amount of fuel from renewable resources into appropriate renewable fuel categories (e.g., for 100 gallons of B20 biodiesel blend, 20 gallons would be entered under biodiesel and 80 gallons would be entered under diesel).

1. Enter use into blue cells in “Use” column in indicated units.
2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factors. Enter result into blue cells in parameter columns.
3. Sum Onsite Renewable Energy results for each parameter and enter in green “Onsite Renewable Energy Subtotals” cells.
4. Sum Other Onsite Energy results for each parameter and enter in green “Other Onsite Energy Subtotals” cells.
5. Sum Other Onsite Contributions results for each parameter and enter in green “Other Onsite Subtotals” cells.
6. Sum green cells for each parameter and enter result in green “Onsite Totals” cells.

Use × Conversion factor = Footprint

ENERGY AND AIR SCENARIO #1 – CALCULATING AND PRESENTING ELECTRICITY GENERATION (SCOPE 2) ENERGY AND AIR METRICS

Contributors to Footprints	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MM	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Grid electricity use	MWh	9.	6.9	65.6	850	8,075	1.4	13.3	2.4	22.8	0.04	0.456	0.1	0.99
Green pricing or green marketing product purchases	MWh	0												
REC purchase	MWh	0												

See Exhibit 3.17 for how to determine the conversion factors for grid electricity.

1. Enter grid electricity use in MWh into blue cell in “Use” column.

2. Convert MWh use into indicated units of each parameter by multiplying use by the indicated conversion factors. Enter result into blue cells in parameter columns.

3. Enter quantity of voluntary purchased renewable electricity in the form of green pricing and green marketing products into the associated blue cell, and document information regarding that product in the table below.

4. Enter quantity of voluntary purchased renewable electricity in the form of RECs into the associated blue cell, and document information regarding that product in the table below.
-

$$Use \times Conversion\ factor = Footprint$$

Description of purchased green pricing or green marketing product	Provider:
	Type of product:
	Type of renewable energy source:
	Date of renewable system installation:
Description of purchased RECs	Provider:
	Type of renewable energy source:
	Date of renewable system installation:

ENERGY AND AIR SCENARIO #1 –CALCULATING AND PRESENTING TRANSPORTATION (SCOPE 3A) ENERGY AND AIR METRICS

Category	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Con v.	lbs	Conv. Factor	lbs
Conventional Energy														
Diesel use	gal	7,250	0.139	1008	22.5	163125	0.17	1233	0.0054	39	0.003	25	0.0000	0.038
Gasoline use	gal	1,410	0.124	175	19.6	27636	0.11	155	0.0045	6	0.000	1	0.0000	0.055
Natural gas use	ccf	0	0.103	0	13.1	0	0.01	0	0.0000	0	0.000	0	0.0000	0.000
Conventional Energy Subtotals				1,183		190,76		1,388		45		25		0.093
Renewable Energy														
Biodiesel use	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.000	0	NP	
Transportation Totals				1,183		190,76		1,388		45		25		0.093

1. Enter uses of each material or service into “Use” column in indicated units.
2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factor. Enter result into blue cells in parameter columns.
3. Sum Conventional Energy results for each parameter and enter in green “Conventional Energy Subtotals” cells.
4. Sum Conventional Energy Subtotals and biodiesel use results for each parameter and enter in green “Transportation” cells.

Use × Conversion factor = Footprint

ENERGY AND AIR SCENARIO #1 – CALCULATING AND PRESENTING OFFSITE (SCOPE 3B) ENERGY AND AIR METRICS

Category	Units	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
<u>Construction Materials</u>														
Cement	dry-lb	31,20	0.002	65.52	0.9	28080	0.001	56.16	0.0010	32.76	0.0000	0.0982	0.0000	0.9048
Concrete	lb	24,00	0.000	9.84	0.171	4104	0.000	8.4	0.0002	5.04	0.0000	0.24	0.0000	0.24
Gravel/sand/clay	lb	30,40	0.000	0.8512	0.0034	101.84	0.000	0.5016	0.0000	0.456	0.0000	0.0608	2.1E-1	6.232E
HDPE	lb	0	0.031	0	1.9	0	0.003	0	0.0041	0	0.0006	0	0.0000	0
Photovoltaic system (installed)	W	0	0.034	0	4.5	0	0.015	0	0.032	0	0.0006	0	0.0000	0
PVC	lb	2,700	0.022	59.4	2.6	7020	0.004	12.96	0.0076	20.52	0.0012	3.24	0.0004	1.269
Stainless Steel	lb	0	0.012	0	3.4	0	0.007	0	0.012	0	0.0044	0	0.0001	0
Steel	lb	2,000	0.004	8.8	1.1	2200	0.001	2.8	0.0017	3.4	0.0005	1.12	0.0000	0.134
Other refined construction	lb	0	0.014	0	1.98	0	0.003	0	0.0053	0	0.0014	0	0.0001	0
Other unrefined construction	lb	0	0.000	0	0.0033	0	0.000	0	0.0000	0	0.0000	0	2.1E-1	0
<u>Treatment Materials and</u>														
Cheese Whey	lb	0	0.002	0	0.031	0	0.000	0	0.0000	0	0.0000	0	NP	
Emulsified vegetable oil	lb	500,0	0.007	3850	3.44	17200	0.006	3300	0.0019	950	0.0000	16.5	NP	
Molasses	lb	0	0.004	0	0.48	0	0.001	0	0.0002	0	0.0000	0	NP	
Treatment materials and chemicals	lb	0	0.015	0	1.7	0	0.003	0	0.0065	0	0.0006	0	0.0000	0
Virgin GAC (coal based)	lb	0	0.015	0	5.8	0	0.014	0	0.034	0	0.0007	0	0.0012	0
<u>Fuel Processing</u>														
Biodiesel Produced	gal	0	0.029	0	-16.8	0	0.018	0	0.033	0	0.0008	0	NP	
Diesel Produced	gal	9,150	0.019	169.27	2.7	24705	0.006	58.56	0.013	118.95	0.0003	3.111	0.0001	1.098
Gasoline Produced	gal	1,940	0.021	40.74	4.4	8536	0.008	15.52	0.019	36.86	0.0005	1.0088	0.0001	0.3104
Natural Gas Produced	ccf	0	0.005	0	2.2	0	0.003	0	0.0046	0	0.0000	0	0.0000	0
<u>Public water</u>	gal x	10,00	0.009	92	5	50000	0.009	97	0.0059	59	0.016	160	0.0000	0.15
<u>Offsite Services</u>														
Offsite waste water treatment	gal x	0	0.015	0	4.4	0	0.016	0	0.015	0	NP		NP	
Offsite Solid Waste Disposal	ton	0	0.16	0	25	0	0.14	0	0.075	0	0.4	0	0.0014	0
Offsite Hazardous Waste Disposal	ton	0	0.176	0	27.5	0	0.154	0	0.0825	0	0.44	0	0.0015	0
Offsite Laboratory Analysis	\$	120,0	0.006	780	1	12000	0.004	576	0.0036	432	0.0004	48	0.0001	15.6

ENERGY AND AIR SCENARIO #1 – CALCULATING AND PRESENTING OFFSITE (SCOPE 3B) ENERGY AND AIR METRICS(continued)

Category	Units	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Con v.	lbs CO ₂	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Resource Extraction for Electricity														
Coal extraction and processing	MWh	1.425	3.1	4.35	180	256.	0.77	1.0972	0.15	0.2137	0.018	0.0256	NP	
Natural gas extraction and processing	MWh	3.8	1.6	6.20	270	1026	0.18	0.684	13	49.4	0.0071	0.0269	NP	
Nuclear fuel extraction and	MWh	1.9	0.16	0.30	25	47.5	0.15	0.285	0.5	0.95	0.0015	0.0028	NP	
Oil extraction and processing	MWh	0	2.3	0	270	0	1.7	0	0.069	0	0.042	0	NP	
Electricity Transmission	MWh													
Transmission and distribution losses	MWh	0.95	10.3	9.785	850	807.	1.4	1.33	2.4	2.28	0.048	0.0456	0.1	0.095
Off Site Totals				5,097		1,966,884		4,131		1,712		233		20

NP = not provided

1. Enter uses of each material or service into “Use” column in indicated units.

2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factor. Enter result into blue cells in parameter columns.

3. Fuel processing refers to all fuel used, including that for onsite equipment use and transportation.

4. Electricity from various resources is obtained from generation mix that is used in Exhibit 3.17 and the resource extraction conversion factors from Exhibit3.14.

5. For electricity transmission, enter 10 percent of the grid electricity used for calculating energy and emissions from electricity generation. The conversion factors are the same as those used for electricity generation, but the energy conversion factor is 10.3 MMBtu/MWh (3.413 MMBtu/MWh for usable electricity plus 6.9 MMBtu/MWh for energy loss due to an assumed 33 percent efficiency at the power plant).

6. Resource extraction conversion factors are calculated using values in Exhibit 3.14 and the specified fuel blend for electricity generation.

Use × Conversion factor = Footprint

ENERGY AND AIR SCENARIO #1 – SUMMARY OF METRICS

Category	Total	GHGs	NOx	SOx	PM	NOx+SOx+	HAPs
	MMbtus	lbs CO ₂ e	lbs	lbs	lbs	lbs	lbs
Onsite (Scope 1)	362	53,138	381	12.6	6.7	400.5	0.73
Electricity Generation (Scope 2)	65.6	8,075	13.3	22.8	0.46	36.56	0.99
Transportation (Scope 3a)	1,183	190,761	1,388	45	25	1,459	0.093
Other Offsite (Scope 3b)	5,097	1,966,84	4,131	1,712	233	6,076	20
Remedv Totals	6,708	2,218,81	5,913	1,792	265	7,971	22
GHG Footprint in Tons (1 ton = 2,000 lbs)		1,109					

Voluntary Renewable Energy Use	Unit	Quantity
Onsite energy generation or use	MMBtu	1,229
Onsite biodiesel use	MMBtu	0
Biodiesel use for transportation	MMBtu	0
Onsite generation or use and biodiesel use	MMBtu	0
Renewable electricity purchase	MWh	0
REC purchases	MWh	0

ENERGY AND AIR SCENARIO #2

Background:

This scenario involves quantifying the energy and air metrics over a 30-year period for an operating P&T system (i.e., construction of the system is not included in the footprint analysis):

- O&M of P&T system that is containing VOC and semi-volatile organic compound (SVOC) plume
- VOC influent is 1,000 micrograms per liter ($\mu\text{g/L}$), SVOC influent is 600 $\mu\text{g/L}$
- Combined extraction rate of 200 gpm from three extraction wells
- Onsite photovoltaic system generates 12,000 kWh per year (360,000 kWh over 30 years) of renewable energy that is used on site
- 50 feet to water table
- Treatment with air stripping, GAC treatment of air stripper off-gas, and GAC treatment of air stripper effluent
- GAC is 95 percent efficient for VOC removal and untreated VOCs are HAPs (according to Exhibit 3.15, approximately 26,000 pounds of HAPs are emitted on site over 30 years)
- Treated water is reinjected
- Semi-annual sampling at 50 points for 30 years
- All samples analyzed for VOCs and SVOCs
- Estimated remedy duration of 30 years

Screening:

The step identifies the largest contributors to the energy and onsite air metrics and develops screening limits for use in identifying important potential contributors to the footprint and providing the rationale for excluding minor contributors.

Onsite NO_x+SO_x+PM Emission Screening

The only source of onsite emissions is expected to be the low-flow sampling equipment.

Onsite HAP Emission Screening

No additional sources beyond those counted in the NO_x+SO_x+PM screening.

Total Energy Screening

The screening limit is based on the higher of a magnitude based limit of 100 screening units or a percentage-based limit equal to 1 percent of the largest contributor to the total energy footprint. Because no appreciable renewable energy is used, it is assumed that the total energy screening process reasonably screens items/activities for the total air emissions metrics. Based on professional judgment, the largest total energy contributor is the electricity (204,000 kWh per year for 30 years, which translates to 6,120,000 kWh). Accounting for the electricity generated from the onsite photovoltaic system, this translates to $(6,120,000 \text{ kWh} - 360,000 \text{ kWh} = 5,760,000 \text{ kWh})$. According to Exhibit 3.2, this translates

to 5,760,000 screening units. Therefore, the percentage based screening unit is 57,600 ($57,600,000 \times 1$ percent). Items or activities associated with the remedy that would equate to less than 61,200 screening units will be omitted.

The following table presents the primary items/activities associated with the remedy and preliminary engineering estimates regarding the quantities of those items/activities. Screening unit conversions from Exhibit 3.2 are applied to calculate the number of screening units, and a decision to include or exclude each item/activity is stated. Items exceeding the screening limit of 57,600 will be quantified more accurately during footprint calculation. As noted below, some items that are available from the materials or waste footprint or for the onsite emissions footprint are included even if the values are below the screening limit because the information is already available.

Item	Quantity	Screening	Limit = 57,600
Electricity	5,760,000 kWh	5,760,	Include
Laboratory analysis (GW	>\$100,000	>100,0	Include
Laboratory analysis (process)	>\$100,000	>100,0	Include
GAC	>100,000 lbs	>100,0	Include
GAC transport	>100,000 ton-miles	>33,00	Include
Operator and sampling tech.	>100,000 miles	>50,00	Include
Sampling equip.	Used for onsite NO _x +SO _x +PM		Include
Sampling materials	<1,000 lbs	<1,000	Exclud

The engineering estimates for GAC transport and personnel transport were not sufficiently detailed to confirm they would be below the screening limit. Therefore, they are included in the footprint calculation step, and will be included in the footprint analysis.

Footprint Calculation:

This part of the footprint calculation follows Step 5: Quantify Energy and Air Metrics. Step 5 is comprised of 3 parts.

Part 1: Inventory Remedy Travel, Equipment Use,

Materials, and Offsite Services

The following are items associated with remedy operation that passed the screening process:

- 7,000 pounds of GAC per year for 30 years (210,000 pounds or 105 tons)
 - 1,000 miles round-trip distance from regeneration facility to local warehouse

- 100 miles round-trip distance from warehouse to site, two trips per year (60 trips total)
- Estimated 2000 operator/technician/oversight visits over next 30 years
 - Travel in light-duty trucks
 - Roundtrip daily commute is 40 miles
- Pumps and blowers powered by onsite electricity for 250,000 hours over next 30 years
 - Typical electrical bill is 204,000 kWh per year
 - Three 3 HP extraction pumps with VFDs
 - One 3 HP transfer pump with VFD
 - One 3 HP effluent pump with VFD
 - One 10 HP blower with VFD

ENERGY AND AIR CASE STUDY #2 (continued)

- Site located in Colorado, generation mix not available from utility, use eGRID Subregion RMPA fuel blend for electricity generation is as follows:
 - 71.7 percent coal
 - 19.5 percent natural gas
 - 7.4 percent hydro
 - 1.4 percent wind
- Renewable Energy Certificates each year to offset all grid electricity use
 - RECs purchased from wind facility located in RMPA (Colorado – Eastern Wyoming) Subregion constructed in 2005
- Process sampling, 3 samples for VOCs (\$100 /sample) and SVOCs (\$200/sample) each month for 30 years

The following are items associated with long-term monitoring that passed the screening process:

- 500 trips to site by sampling team in one light-duty truck (100 miles round trip)
- 3,000 samples collected and analyzed for VOCs at \$100 per sample and SVOCs at \$200 per sample (includes cost of QA samples)
- Sampling requires a total of 6,000 hours of 2.5 HP gasoline compressors
- Purge water disposed of in treatment plant

Part 2: Energy Inventory

This step converts the above transportation and equipment use into fuel use and converts electrical equipment use into electricity use. For scenario expediency, energy inventory for three tasks are combined. A formal analysis might split the inventory into three tasks: construction, O&M, and long-term monitoring.

Fuel Use for Personnel Transportation

Personnel	T	Round trip Dist	Total Dist	Vehicle	Fuel Efficiency	Fuel Use
<i>Diesel</i>						
None						
<i>Gasoline</i>						
Operator	2	40	80,0	Truck	17 mpg	4,706
Sampling	5	100	50,0	Truck	17 mpg	2,941

				Total Gasoline	7,647

ENERGY AND AIR CASE STUDY #2 (continued)

Fuel Use for Equipment Use

Equipment Type	Hours	Fuel Consumption Rate (gal/hr)	Fuel Use
<i>Diesel</i>			
None			
<i>Gasoline</i>			
Sampling compressors	6000	0.14	840

Fuel Use for Materials, Equipment, and Waste Transport

Equipment	T	Travel Distance	Vehicle	Fuel Efficiency	Fuel Use
<i>Diesel</i>					
GAC facility to	1	1,000	Truck	0.029 gptm	3,04
GAC warehouse to site	1	60 x	Truck	6 mpg	1,00
				Total	4,04

gptm = gallons per ton-mile

Onsite Electricity Use

Equipment	H	% Fuel	Motor	k	Hours	kWh
Extraction pumps	9	80%	75%	9.6	250	2,160
Two process pumps	6	80%	75%	6.4	250	5,760
One air stripper blower	10	80%	75%	10.	250	3,780
				Calculated		6,675
				Total from Electric Bills		6,120

Calculated and actual values are close. Use actual value from electric bills and use calculated values to help understand breakdown of electricity use.

Part 3: Convert to Energy and Air Metrics

See accompanying tables

Findings:

Electricity generation accounts for approximately 40 percent of the total energy use but approximately 70 percent of the GHG emissions because a large percentage of the electricity is generated from the

ENERGY AND AIR CASE STUDY #2 (continued)

combustion of coal. Resource extraction for electricity generation and electricity transmission losses are also large contributors to energy use and air emissions. The onsite generation and use of renewable energy provides a favorable metric related to the voluntary use of renewable energy and avoids some of the emissions associated with the electricity generation. The purchase of RECs provides another favorable metric related to voluntary use of renewable energy. Although this methodology focuses on air emissions before potential reductions from REC purchases, some EPA programs and federal guidance supports air emission reductions associated with a REC purchase.

Other significant contributors to the energy and air emissions metrics are laboratory analysis, GAC manufacturing, and various aspects of transportation. Footprint reduction would likely focus on reducing electricity use, potentially identifying an alternative source of electricity, optimization of GAC use, and GAC transportation.

ENERGY AND AIR SCENARIO #2 – DETERMINING FOOTPRINT CONVERSION FACTORS FOR GRID ELECTRICITY
BASED ON UTILITY OR LOCATION

Power Content from eGRID RPMA Subregion		Converting Utility Resource Mix to Footprint Conversion Factors													
Energy Source	Percentage of Power Mix Delivered	Type	%	Energy (MMbtu/M		CO ₂ e		NO _x (lbs/MWh)		SO _x (lbs/MWh)		PM		HAPs	
			o	Ful	Adj. by	Ful	Adj. by	Ful	Adj. by	Ful	Adj.	Ful	Adj.	Ful	Adj.
Coal	71.7%	<i>Conventional Energy</i>													
Natural gas	19.5%	Coal	7	6.9	4.947	22	157	6	4.	15	10.	0.0	0.065	0.66	0.4
Oil	0%	Natural Gas	1	6.9	1.346	13	254	1.1	0.	0.0	0.0	0.0	0.015	0.025	0.0
Nuclear	0%	Oil	0	6.9	0	18	0	2.2	0	2.8	0	0.1	0	0.066	0
Hydroelectric	7.4%	Nuclear	0	6.9	0	0	0	0	0	0	0	0	0	0	0
Biomass	0%	<i>Renewable Energy</i>													
Geothermal	0%	Biomass	0	6.9	0	0	0	1.4	0	0.6	0	0.0	0	5.3E-6	0
Wind	1.4%	Geothermal	0	6.9	0	0	0	0	0	0	0	0	0	0	0
Solar	0%	Hydroelectric	7.	6.9	0.511	0	0	0	0	0	0	0	0	0	0
		Solar	0	6.9	0	0	0	0	0	0	0	0	0	0	0
		Wind	1.	6.9	0.096	0	0	0	0	0	0	0	0	0	0
		Total	1		6.9		183		4.		10.		0.081		0.4
Full load emission values for each fuel type obtained from www.nrel.gov/lci . All values do not include energy and emissions for resource extraction or for transmission losses, which are counted in Scope 3. Energy conversion factors exclude the energy contained in the MWh of electricity used by the remedy to avoid double counting of Scope 1 energy use. For simplicity, energy conversion factors are assumed to be 6.9 MMBtu per MWh (equivalent to 33 percent efficiency) for all energy sources.															

ENERGY AND AIR SCENARIO #2 – CALCULATING AND PRESENTING ONSITE ENERGY AND AIR METRICS

Contributors to Footprints	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMB	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Onsite Renewable Energy														
Electricity generated on site by renewable resources	M	360	3.413	1,229										
Landfill gas combusted on site	ccf	0	0.103	0	13.1	0	0.01	0	0.0000	0	0.00076	0	8.4E-0	0
Biodiesel used on site	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.00099	0	NP	
Other onsite renewable energy use #1		0		0		0		0		0		0		0
Other onsite renewable energy use #2		0		0		0		0		0		0		0
Onsite Renewable Energy Subtotals				1,229		0		0		0		0		0
Other Onsite Energy														
Grid electricity	M	5,760	3.413	19,659										
Onsite diesel use	gal	0	0.139	0	22.5	0	0.17	0	0.0054	0	0.0034	0	0.0003	0
Onsite gasoline use	gal	840	0.124	104.16	19.6	16464	0.11	92.4	0.0045	3.78	0.00054	0.4536	0.0003	0.252
Onsite natural gas use	ccf	0	0.103	0	13.1	0	0.01	0	0.0000	0	0.00076	0	8.4E-0	0
Other forms of onsite energy use #1		0		0		0		0		0		0		0
Other forms of onsite energy use #2		0		0		0		0		0		0		0
Other Onsite Energy Subtotals				19,763		16464		92.4		3.78		0.4536		0.252
Other Onsite Emissions Contributions														
Onsite HAP process emissions	lb	26,000											1	26,00
Onsite GHG emissions	lb	0			1	0								
Onsite carbon storage	lb	0			-1	0								
GHG reductions by combusting onsite landfill	lb	0			-20	0								
Other onsite contributions		0				0		0		0		0		0
Other Onsite Subtotals				0		0		0		0		0		0
Onsite Totals				20,992		16,46		92		3.8		0.45		26,00

TBD = to be determined. Values in parentheses are negative values. Energy for electricity is only that energy of that electricity and not the energy required to generate the electricity. ccf CH₄ = 100 cubic feet of methane. Obtained by multiplying total volume of landfill gas in ccf by the percentage of the gas that is methane. Energy associated with onsite generation of electricity is assumed to be 10.3 MMBtu/MWh (3.413 MMBtu/MWh for usable electricity plus 6.9 MMBtu/MWh for energy loss due to an assumed 33 percent efficiency). 33 percent efficiency is consistent with Exhibit 3.17. Energy associated with onsite use of grid electricity is 3.413 MMBtu/MWh of electricity because the energy loss associated with 33 percent efficiency is counted in Scope 2 energy calculations If fuel is a blend of conventional fuel and renewable resource fuel, enter the amount of fuel from conventional sources into appropriate conventional fuel categories and enter amount of fuel from renewable resources into appropriate renewable fuel categories (e.g., for 100 gallons of B20 biodiesel blend, 20 gallons would be entered under biodiesel and 80 gallons would be entered under diesel).

1. Enter use into blue cells in “Use” column in indicated units.
2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factors. Enter result into blue cells in parameter columns.
3. Sum Onsite Renewable Energy results for each parameter and enter in green “Onsite Renewable Energy Subtotals” cells.
4. Sum Other Onsite Energy results for each parameter and enter in green “Other Onsite Energy Subtotals” cells.
5. Sum Other Onsite Contributions results for each parameter and enter in green “Other Onsite Subtotals” cells.
6. Sum green cells for each parameter and enter result in green “Onsite Totals” cells.

Use × Conversion factor = Footprint

ENERGY AND AIR SCENARIO #2 – CALCULATING AND PRESENTING ELECTRICITY GENERATION ENERGY AND AIR METRICS

Contributors to Footprints	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MM	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
Grid electricity use	MWh	5,	6.9	39,74	183	10,546	4.5	25,92	10.	62,20	0.08	467	0.47	2,707
Green pricing or green marketing product purchases	MWh	0												
REC purchase	MWh	5,												

See Exhibit 3.17 for how to determine the conversion factors for grid electricity.

1. Enter grid electricity use in MWh into blue cell in “Use” column.

2. Convert MWh use into indicated units of each parameter by multiplying use by the indicated conversion factors. Enter result into blue cells in parameter columns.

3. Enter quantity of voluntary purchased renewable electricity in the form of green pricing and green marketing products into the associated blue cell, and document information regarding that product in the table below.

4. Enter quantity of voluntary purchased renewable electricity in the form of RECs into the associated blue cell, and document information regarding that product in the table below.

$Use \times Conversion\ factor = Footprint$

Description of purchased green pricing or green marketing product	Provider:
	Type of product:
	Type of renewable energy source:
	Date of renewable system installation:
Description of purchased RECs	Provider: REC Seller, LLP
	Type of renewable energy source: Wind
	Date of renewable system installation: 2005

ENERGY AND AIR SCENARIO #2 –CALCULATING AND PRESENTING TRANSPORTATION ENERGY AND AIR METRICS

Category	Unit	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Conv. Factor	lbs	Conv. Factor	lbs	Conv. Factor	lbs	Con v.	lbs	Conv. Factor	lbs
Conventional Energy														
Diesel use	gal	4,045	0.139	562	22.5	91013	0.17	688	0.0054	22	0.003	14	0.0000	0.021
Gasoline use	gal	7,647	0.124	948	19.6	149881	0.11	841	0.0045	34	0.000	4	0.0000	0.298
Natural gas use	ccf	0	0.103	0	13.1	0	0.01	0	0.0000	0	0.000	0	0.0000	0.000
Conventional Energy Subtotals				1,510		240,89		1,529		56		18		0.319
Renewable Energy														
Biodiesel use	gal	0	0.127	0	22.3	0	0.20	0	0	0	0.000	0	NP	
Transportation Totals				1,510		240,89		1,529		56		18		0.319

1. Enter uses of each material or service into “Use” column in indicated units.
2. Convert uses into indicated units of each parameter by multiplying use by the indicated conversion factor. Enter result into blue cells in parameter columns.
3. Sum Conventional Energy results for each parameter and enter in green “Conventional Energy Subtotals” cells.
4. Sum Conventional Energy Subtotals and biodiesel use results for each parameter and enter in green “Transportation” cells.

Use × Conversion factor = Footprint

ENERGY AND AIR SCENARIO #2 –CALCULATING AND PRESENTING OFFSITE ENERGY AND AIR METRICS

Category	Units	Use	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMBt	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
<u>Construction Materials</u>														
Cement	dry-lb	0	0.002	0	0.9	0	0.001	0	0.0010	0	0.0000	0	0.0000	0
Concrete	lb	0	0.000	0	0.171	0	0.000	0	0.0002	0	0.0000	0	0.0000	0
Gravel/sand/clay	lb	0	0.000	0	0.0034	0	0.000	0	0.0000	0	0.0000	0	2.1E-1	0
HDPE	lb	0	0.031	0	1.9	0	0.003	0	0.0041	0	0.0006	0	0.0000	0
Photovoltaic system (installed)	W	0	0.034	0	4.5	0	0.015	0	0.032	0	0.0006	0	0.0000	0
PVC	lb	0	0.022	0	2.6	0	0.004	0	0.0076	0	0.0012	0	0.0004	0
Stainless Steel	lb	0	0.012	0	3.4	0	0.007	0	0.012	0	0.0044	0	0.0001	0
Steel	lb	0	0.004	0	1.1	0	0.001	0	0.0017	0	0.0005	0	0.0000	0
Other refined construction	lb	0	0.014	0	1.98	0	0.003	0	0.0053	0	0.0014	0	0.0001	0
Other unrefined construction	lb	0	0.000	0	0.0033	0	0.000	0	0.0000	0	0.0000	0	2.1E-1	0
<u>Treatment Materials and</u>														
Cheese Whey	lb	0	0.002	0	0.031	0	0.000	0	0.0000	0	0.0000	0	NP	
Emulsified vegetable oil	lb	0	0.007	0	3.44	0	0.006	0	0.0019	0	0.0000	0	NP	
Molasses	lb	0	0.004	0	0.48	0	0.001	0	0.0002	0	0.0000	0	NP	
Treatment materials and chemicals	lb	21000	0.015	3150	1.7	35070	0.003	630	0.0065	1365	0.0006	128.1	0.0000	3.36
Virgin GAC (coal based)	lb	0	0.015	0	5.8	0	0.014	0	0.034	0	0.0007	0	0.0012	0
<u>Fuel Processing</u>														
Biodiesel Produced	gal	0	0.029	0	-16.8	0	0.018	0	0.033	0	0.0008	0	NP	
Diesel Produced	gal	4,045	0.019	74.832	2.7	10921.	0.006	25.888	0.013	52.585	0.0003	1.3753	0.0001	0.4854
Gasoline Produced	gal	8,487	0.021	178.22	4.4	37342.	0.008	67.896	0.019	161.25	0.0005	4.4132	0.0001	1.3579
Natural Gas Produced	ccf	0	0.005	0	2.2	0	0.003	0	0.0046	0	0.0000	0	0.0000	0
<u>Public water</u>	gal x	0	0.009	0	5	0	0.009	0	0.0059	0	0.016	0	0.0000	0
<u>Offsite Services</u>														
Offsite waste water treatment	gal x	0	0.015	0	4.4	0	0.016	0	0.015	0	NP		NP	
Offsite Solid Waste Disposal	ton	0	0.16	0	25	0	0.14	0	0.075	0	0.4	0	0.0014	0
Offsite Haz. Waste Disposal	ton	0	0.176	0	27.5	0	0.154	0	0.0825	0	0.44	0	0.0015	0
Offsite Laboratory Analysis	\$	1,100,	0.006	7150	1	11000	0.004	5280	0.0036	3960	0.0004	440	0.0001	143

ENERGY AND AIR SCENARIO #2 –CALCULATING AND PRESENTING OFFSITE ENERGY AND AIR METRICS (continued)

Category	Units	Us	Energy		GHGs		NOx		SOx		PM		HAPs	
			Con v.	MMB	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs	Con v.	lbs
<i>Resource Extraction for Electricity</i>														
Coal extraction and processing	MWh	4,130	3.1	12,803	180	743,38	0.77	3,180	0.15	619	0.01	74	NP	
Natural gas extraction and processing	MWh	1,123	1.6	1,797	270	303,26	0.18	202	13	14,602	0.0071	8	NP	
Nuclear fuel extraction and	MWh	0	0.16	0	25	0	0.15	0	0.5	0	0.0015	0	NP	
Oil extraction and processing	MWh	0	2.3	0	270	0	1.7	0	0.06	0	0.04	0	NP	
<i>Electricity Transmission</i>	MWh													
Transmission and distribution losses	MWh	576	10.3	5,933	1831	1,054,	4.5	2,592	10.8	6,221	0.08	47	0.47	271
Off Site Totals				31,086		3,619,		11,978		26,981		703		419

ENERGY AND AIR SCENARIO #2 – SUMMARY OF METRICS

Category	Total	GHGs	NOx	SOx	PM	NOx+SOx+	HAPs
	MMbtus	lbs CO ₂ e	lbs	lbs	lbs	lbs	lbs
Onsite (Scope 1)	20,992	16,464	92	3.8	0.45	96	26,000
Electricity Generation (Scope 2)	39,744	10,546,560	25,920	62,208	467	88,595	2,707
Transportation (Scope 3)	1,510	240,894	1,529	56	18	1,603	0.319
Other Offsite (Scope 3)	31,086	3,619,224	11,978	26,981	703	39,662	419
Remedy Totals	93,332	14,423,142	39,519	89,249	1,188	129,956	29,126
GHG Footprint in Tons (1 ton = 2,000 lbs)		7,212					

Voluntary Renewable Energy Use	Unit	Quantity
Onsite energy generation or use	MMBtu	1,229
Onsite biodiesel use	MMBtu	0
Biodiesel use for transportation	MMBtu	0
Onsite generation or use and biodiesel use	MMBtu	1,229
Renewable electricity purchase	MWh	0
REC purchases	MWh	5,760