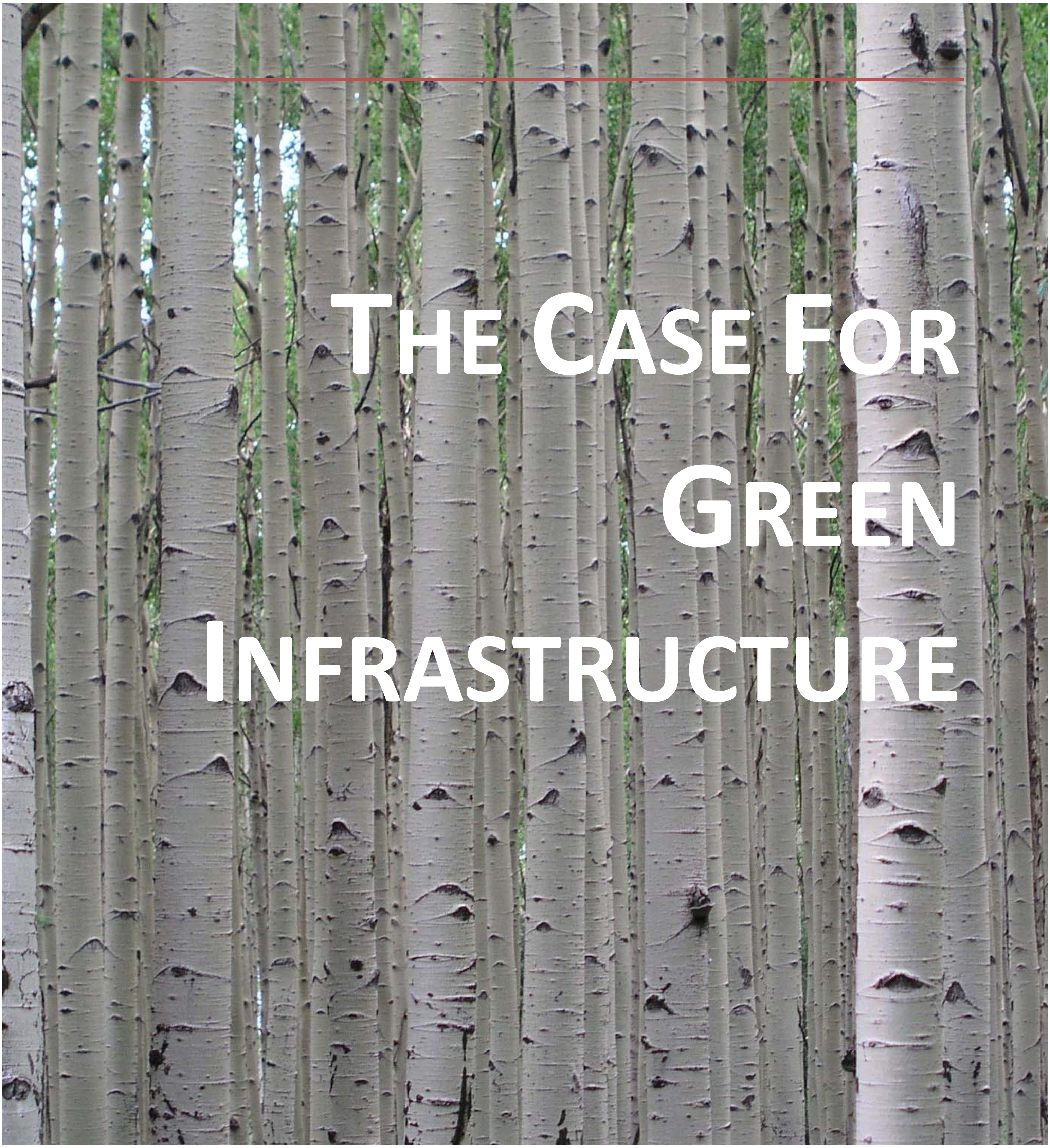
The Case For Green Infrastructure



Green Infrastructure (GI) was investigated as part of a joint-industry program that aims to find ways to increase the resilience to external economic and environmental stressors. For the purposes of this study, GI was defined as planned and managed natural and semi-natural systems which provide additional products and services, when compared to traditional *gray* infrastructure, with environmental, social, and economic benefits.

The hypothesis of the study was:

> GI can provide more opportunities than gray infrastructure to increase the resilience of an organization

The focus of this study was to investigate the ability of GI solutions to increase the resilience of an organization to external stressors, to enhance the economic protection of business assets and infrastructure and to reduce the resource intensity in the context of the globally applicable food-energy-water nexus.

The GI team, composed of scientists and engineers from The Dow Chemical Company, Shell, Swiss Re, and Unilever, working with The Nature Conservancy and an academic resiliency expert, evaluated a number of business case studies from their respective organizations and from literature. The team interviewed the project leaders to assess the level of resilience each project had to acute, chronic and social stressors as well as a comparison to the traditional gray alternative. Where data was not available for direct comparison, informed judgments from Subject Matter Experts were used. This Whitepaper includes distilled findings from the interviews and subsequent analysis of the hypothesis as stated above.

Key conclusions:

Five key conclusions from this study are given here and will be elaborated on in the remainder of this document.

- GI solutions form an essential element in a portfolio of solutions to increase the resilience of industrial business operations, but do not provide resilience against every potential stressor and therefore benefit from thorough site investigation and management of location specific risks
- GI solutions often demonstrate financial advantages compared to *gray* infrastructure due to a reduction of initial capital expenses and ongoing operational expenses and can be used to strategically recapitalize ageing assets
- GI solutions offer opportunities, often overlooked in current project assessments, to effectively manage socio-political risks through innovative collaboration with key stakeholders
- GI solutions often leverage existing natural resources. Their regenerative processes consume less energy and are thus less sensitive to power loss and fluctuations in the cost of energy, as compared to *gray* infrastructure
- Both *green* and *gray* infrastructure resist shocks, but in different ways. Hybrid approaches, utilizing a combination of green and gray infrastructure, may provide an optimum solution to shocks and improve the overall resilience of an organization

Key recommendations:

Four key recommendations from this study are given here and will be elaborated on in the remainder of this document:

- Organizations should employ a more comprehensive economic and environmental footprint analysis to more accurately compare green versus gray infrastructure and to investigate, and when relevant, appropriately assess the co-benefits of GI solutions
- GI solutions benefit from pilot projects and engagement of external partners to glean expertise, experiences and innovative approaches that can de-risk the GI technology and accelerate implementation
- Organizations are currently not staffed with the requisite skills nor supported by the culture necessary to bring GI solutions to scale. Leadership emphasis and change management is required for successful implementation
- Organizations are advised to build a fit-for-purpose set of capabilities integrating the areas of strategy, innovation, new business development, project economics, engineering and environmental sustainability

INTRODUCTION AND OBJECTIVE

The global economy is a tightly wound system, extremely interconnected and efficient, with increasing risks to organizations due to the rapid propagation of disruptive events. Ecosystem services, the goods and services humans receive from nature, underpin the global economy and provide tremendous value to people and organizations. Receiving services from nature is often more cost effective and sustainable than generating them with man-made materials like steel and concrete. The hypothesis is that working together with natural systems, and hence GI, enables organizations to better manage disruptive events, such as power interruption, raw material price increases and mechanical failure which often impair traditional *gray* solutions.

The remainder of the document highlights the pros and cons of green (natural) and gray (man-made) solutions and proposes innovative approaches to balance the different trade-offs involved when designing resilient infrastructure.

GREEN INFRASTRUCTURE CONCEPT AND DEFINITION

GI systems are defined, for the purpose of this study, as planned and managed natural and semi-natural systems which provide additional products and services, when compared to traditional gray infrastructure, with environmental, social, and economic benefits. GI can enhance or even replace a functionality that is traditionally provided by man-made structures.

GI aims to build upon the success that nature has had in evolving systems that are inherently sustainable and resilient. GI solutions employ ecosystem services to create more resource efficient systems involving water, air and land use. GI solutions are designed to fulfill a specific need, such as water purification or carbon sequestration, while offering location-specific and valuable co-benefits, such as enhanced habitat for wildlife.

The GI team investigated the GI concept and the ability of GI to increase the resilience of an organization to external stressors. The GI team analyzed several business case studies from their respective organizations and from literature. The team interviewed fourteen project leaders to assess the increased level of resilience each project had to acute, chronic and social stressors when compared to traditional *gray* infrastructure. Where data was not available for direct comparison, informed judgments from Subject Matter Experts were used.

GREEN INFRASTRUCTURE SOLUTIONS; EXAMPLES

The GI case studies varied from a private entity solving a water treatment challenge within its fence-line, to a multi-stakeholder organization working together with a city to create a storm water management program, to a conservation organization working with governments and communities on coastal erosion control. Two GI solutions, describing the recurring benefits and challenges inherent to GI, are described below. They set the stage for subsequent discussions on the trade-offs involved when designing green or hybrid infrastructure solutions.

Union Carbide Corporation, subsidiary of The Dow Chemical Company:
Seadrift, TX Wetlands for Wastewater Treatment

Project description: 110-acre engineered wetland in lieu of an industrial wastewater treatment plant

In 1995, the Seadrift water treatment facility was seeking a solution to consistently meet regulatory requirements for water discharge. An innovative GI solution consisting of a constructed wetland was installed and has been successfully operating since day 1 and for the last 15 years. The constructed wetland design offered the following advantages and disadvantages:

<u>Advantages</u>

- **Capital expense savings**: $1.2-1.4 Million versus $40 Million for the *gray* infrastructure alternative proposed
- **Operating expense savings**: no energy, additives, or oxygen; no biosolids disposal; minimal maintenance
- **Lower environmental footprint**: eliminated the need for the construction and operation of an energy-intensive wastewater treatment facility

- **Labor reduction**: Operational support drastically different; a wetland requires minimal support from operations and maintenance as opposed to the grey alternative requiring 24/7 support
- **Operational performance**: 100% compliant from day zero and for over 15 years
- **Construction benefits**: project Implementation time reduced by half (fully operational in 18 months)

Disadvantages

- **Large project land footprint**: 110 acres as opposed to 4-5 acres for a *gray* infrastructure alternative
- **1-2 years pilot period:** required to de-risk the GI technology and find the optimum design
- **Criteria for application of this solution**: compliance with applicable regulations related to water quality
- **Biotic stresses** (nutria, alligators, etc.): relatively minor disturbances that the system had to overcome

Petroleum Development Oman LLC (PDO): Constructed Wetlands for Produced Water Treatment, Oman

Project description: more than 360 ha engineered wetland in lieu of disposing water in deep aquifers

The need for disposal of large amounts of produced water created a major limiting factor for the oil production from the Nimr fields. These large volumes of produced water would require a water processing infrastructure to treat and inject the water into a deep disposal well. This man-made infrastructure would result in a high cost facility requiring high amounts of electric power and producing GHG emissions.

The PDO team investigated alternative, low cost solutions to treat and dispose of the water. The world's largest commercial wetland treats more than 30vol% (100,000 m^3/d) of the total produced water from the PDO Nimr oilfields in Oman in which The Shell Petroleum Company Ltd is a Joint Venture partner. The four-tier gravity-based wetland design offered the following advantages and disadvantages:

Advantages

- **Capital expense savings:** significant capital cost savings compared to the man-made produced water treatment and injection facility
- **Operating expense savings**: power consumption reduced by approximately 98% due to the elimination of electric powered water treatment and injection equipment
- **Operational performance**: satisfactory water treatment performance ever since the start of the wetland operation (December 2010). The oil content in the produced water is consistently reduced from 400 mg/l to less than 0.5 mg/l when leaving the wetland system
- **Significantly reduced carbon footprint:** CO_2 emissions reduced by approximately 98% due to the elimination of electric powered water treatment and injection equipment
- **Other benefits**: potential for innovative customer value propositions that could offer a variety of environmental and socio-political benefits e.g. through by-product optimization (fresh water, biomass etc)
- **Other benefits**: the new facility enabled an additional crude oil recovery of 100 barrels per day

Disadvantages

- **Large required land footprint**: more than 360 ha to treat 100,000 m^3/d of produced water
- **Long pilot period (>5 years):** required to de-risk the constructed wetland technology and find the optimum wetland design
- **Operational risk of the wetland**: potential risk of not meeting the performance requirements due to external factors (e.g. seasonal temperature swings, biotic stresses)

Identifying areas of opportunity

The key differences between *green* and *gray* infrastructure are summarized in Table 1 and illustrate the trade-offs involved when evaluating *green* versus *gray* solutions. These trade-offs help identify the specific areas of opportunity for optimum resilient infrastructure which are often combinations of new GI solutions integrated into existing facilities, creating so-called *hybrid solutions*.

Evaluation criteria	Green infrastructure	Gray infrastructure
Stakeholder involvement	Extended stakeholders are often required to support the project and may have an active and ongoing role in the project design and operation	Stakeholders are often engaged with the aim to create local support for the project, but without active involvement in the project design and operation
Engineering approach	GI solutions require a custom-made, location-specific design and do not lend themselves to standardization and replication	Traditional engineering solutions enable standardization and replication which can significantly reduce project costs and delivery times
Physical footprint	A large physical footprint is often required due to low energy density	Usually, only a small physical footprint is required due to high energy density
Environmental footprint	Often reduced environmental footprint due to GI solutions being nature-based and self-regenerating	Often increased environmental footprint due to material and energy intensive processes (manufacturing, distribution, operation)
Speed of delivering the functionality	GI solutions may take time (years) to grow to provide a certain service and capacity	Traditional engineering solutions provide a certain service and capacity from day 1 of operation
Susceptibility to external factors	GI solutions are susceptible to extreme weather conditions, seasonal changes in temperature or rainfall and disease.	Gray infrastructure is susceptible to power loss, mechanical failure of industrial equipment and price volatility.
Operational and maintenance costs	Operating and maintenance costs are often significantly lower (only monitoring and feedback is required)	Operating costs are often significantly higher due to power consumption, operational and maintenance requirements
Risk of price volatility	GI solutions are relatively insensitive to fluctuations in the cost of raw materials, oil, gas and power	Traditional engineering solutions are sensitive to fluctuations in the cost of raw materials, oil, gas and power
Approach to system monitoring and control	GI solutions are living and complex systems that can be monitored and effectively managed by a deep understanding of the key control variables	Traditional engineering solutions are man-made systems that are typically designed with established monitoring techniques to effectively manage and control system performance
Required operating personnel	No need for 24/7 operational supervision	Complex control and safeguarding systems typically require 24/7 operational supervision
Expenses for increasing capacity of system	Relatively inexpensive to extend the capacity of the GI solution, provided there is physical footprint available	Extension of capacity could be relatively inexpensive as long as significant modification or redesign is not required
Need for recapitalization	Recapitalization during the life of the GI project is usually not significant. The end of life replacement/decommissioning will vary greatly depending on the GI technology selected but is usually not necessary as GI solutions are self-sustaining and do not depreciate	Gray solutions are depreciating assets with a finite performance capacity and usually require significant replacement/decommissioning at end of life

TABLE 1: EVALUATION OF GREEN VERSUS GRAY INFRASTRUCTURE

Key observations

The table above shows that both green and gray solutions have benefits and challenges. Both green and gray infrastructure resist shocks, but in different ways. Hybrid approaches, utilizing a combination of green and gray infrastructure, may provide an optimum solution to shocks and improve the overall resilience of an organization. Synergies occur from combining both engineering schemes, each building upon their respective strengths. For example, gray components may support the growth phase of GI projects, or vice versa.

Hybrid solutions enable effective risk management against different types of shocks and stressors in the goal to transition to more resilient facilities. GI solutions offer a fit-for-purpose approach to create more resilient facilities due to its ability to be implemented in a modular way.

The areas of opportunity for Green or hybrid infrastructure solutions often relate to:

a) A means to strategically recapitalize aging industrial infrastructure through the integration of GI solutions into existing facilities that need regular rejuvenation or replacement of existing equipment to provide a functionality
b) An application in areas that are environmentally stressed and would benefit from improved land use, enhanced biodiversity, additional sources of water and flood or erosion protection.

SWOT analysis of Green Infrastructure

GI projects present a different set of risks due to the nature of the solution, the level of interaction with the local environment and the number of stakeholders that may be involved. A SWOT analysis of GI is given in Table 2.

	Green infrastructure
Strengths	Provides nature's inherent resource-efficiency and multi-functionality (water purification, carbon sequestration, flood protection etc.)
	Requires low initial expenses and operating expenses (only monitoring, feedback and control)
	Appreciates over time as it grows more interconnected with the local environment
	Is less sensitive to increases in the cost of raw materials, cost of power, power interruption, etc.
Weaknesses	Often requires a large physical footprint due to low energy density
	Ecosystem services are currently not comprehensively valued or quantified as part of project technical and non-technical evaluations
	Requires time for proper site investigation and performance maturation
	Engineering community has little expertise in designing ecosystems
Opportunities	Offers opportunities for innovative non-technical risk management by active local stakeholder participation in the design and operation of the GI solution
	Offers opportunities to partner with local landowners in the use of land areas
	Offers opportunities to boost the local economy by offering valuable by-products like fresh water and biomass that can be used for local food production
	Offers opportunities to create resource efficient systems with minimal waste streams through by-product optimization
	Offers low-cost risk mitigation opportunities (e.g. living reefs and mangroves mitigate coastal flood risk at very low costs)
Threats	Can be susceptible to seasonal weather changes and extreme weather conditions
	Can be subjected to unforeseen stresses over its lifetime (e.g. biotic stresses like insect invasion)
	There is generally insufficient understanding of the ecosystem control variables
	There is a lack of recognized ecosystem-related industry design standards
	May require time (years) to mature and to provide the required functionality
	Can pose challenges to obtain permits or regulatory approvals

TABLE 2: SWOT ANALYSIS OF GREEN INFRASTRUCTURE SOLUTIONS

Key observations

The SWOT analysis indicates that GI solutions offer a range of environmental, social, and economic benefits. However, GI solutions do not provide resilience against every potential stressor, and therefore benefit from thorough site investigation and management of location-specific risks. GI solutions require time to optimize the design and to reach peak performance

RISK MANAGEMENT OF GI SOLUTIONS

The table below summarizes potential risks, consequences and mitigations for managing the integration of GI solutions in projects and business operations.

Recurring GI related risks	Possible consequences	Proposed mitigation
Technical		
Susceptibility to seasonal weather changes and extreme weather conditions	Not meeting the project performance specifications	Define a pilot project for testing the GI functionality in different seasons and under different weather conditions in order to determine the key control variables and to find the optimal GI solution
Insufficient understanding of ecosystem control variables		
Required time (years) to mature and to provide the required functionality	Not meeting the project start-up date	Consider creating a separate GI pilot project work-stream that comes online independent of the main project start-up date
Economic		
Large physical footprint required	Landowners are not interested to negotiate property leases or community not supportive of land use for this purpose	Early engagement with landowners. Emphasize the co-benefits of the GI solution to the local landowners and community
Unclear permit requirements	Permits not obtained, project delays	Early involvement of regulators. Shape the development of regulations for green or hybrid infrastructure solutions backed up by relevant performance data
Social / political		
Lack of recognized ecosystem-related industry design standards	Trust and reputational damage due to system underperformance	Proactively assess the system performance and address failures through design changes
		Involve regulators, local landowners and communities in the operational phase
Operational		
Unforeseen stresses (e.g. biotic stresses like insect invasion)	Operational disturbances of the GI solution	Develop a location-specific monitoring and feedback system
Organizational		
Engineering community has little expertise designing ecosystems	GI options are not appropriately screened and assessed	Seek collaboration with green engineering / consultancy firms to help design GI solutions
		Onboard the appropriate expertise in the company
		Set up long-term contracts for design, build, own, operate and transfer activities

TABLE 3: TYPICAL RISK REGISTER ELEMENTS OF GI SOLUTIONS

Key observations

GI solutions require innovative approaches to, a) understand the local ecosystem and build fruitful relationships with local stakeholders, b) test and optimize the GI system performance, c) understand and manage GI-related permit requirements, and d) to build in-house expertise in designing and managing GI solutions.

Critical success factors for implementation in corporate environments

Although GI solutions often present a strong business case and typically provide more categories of benefits than gray solutions, they have not yet been adopted into core business practices and capital project evaluations. Critical success factors for implementation of GI are summarized here:

- Employ a more comprehensive economic and environmental footprint analysis to more accurately compare green versus gray infrastructure
- Engage with the engineering community (utilities/process technology/waste stream management, etc.) to build organizational capacity and expertise in green or hybrid infrastructure engineering. Develop learning modules that focus on the identification of GI opportunities and on the evaluation of typical failure modes of GI solutions in order to develop internal skill sets
- Establish an external network from academia, R&D institutes and GI contractors to facilitate knowledge sharing and skill transfer activities
- Engage with the project community early on in the project development process to ensure GI solutions are being considered as part of the early field planning process
- Engage with the new business development community to develop innovative value propositions that emphasize the potential of GI solutions to boost the local economy e.g. through innovative by-product optimization
- Build a fit-for-purpose set of capabilities integrating the areas of strategy, innovation, new business development, project economics, engineering and environmental sustainability