SPE52676

Greenhouse Gas (GHG) Mitigation and Monitoring Technology Performance: Activities of the GHG Technology Verification Center

Sushma Masemore
Southern Research Institute
6320 Quadrangle Drive, Suite 100
Chapel Hill, North Carolina 27514

David A. Kirchgessner
United States Environmental Protection Agency
National Risk Management Research Laboratory
Mail Drop 63
Research Triangle Park, North Carolina 27711

This paper was prepared for presentation in the 1999 SPE/EPA Exploration and Production Environmental Conference held in Austin, Texas, 1-3 March 1999.

Abstract

The Greenhouse Gas (GHG) Technology Verification Center (the Center) is a public/private partnership between the Southern Research Institute (SRI) and the U.S. Environmental Protection Agency's (EPA's) Office of Research and Development. It provides independent third party testing of the performance of GHG mitigation and monitoring technologies, and was established in response to the belief that there are many viable environmental technologies available which are not being utilized for the lack of credible third party performance testing and reporting. The Center is part of EPA's Environmental Technology Verification (ETV) Program, which has established 12 verification centers to evaluate a wide range of technologies in various environmental media and technology areas. The Center has published the results of its first verification: use of a phosphoric acid fuel cell to produce electricity from landfill gas. It has also initiated three new field verifications, two on technologies which reduce methane emissions from natural gas transmission compressors, and one on a new microturbine electricity production technology.

Introduction and Overview

Since the early 1990s, numerous government and private groups have identified the lack of an organized and ongoing program to produce independent, credible performance data as a major impediment to the development and use of innovative environmental technologies. Technology buyers and permitters both need such data at home and abroad, to make informed technology purchase decisions. Because of this broad support, the President's environmental technology strategy, Bridge to a Sustainable Future(1), and the Vice President's National Performance Review Report(2) contain initiatives for an EPA program to accelerate the development of environmental technology through objective verification and reporting of technology performance.

In 1994, EPA's Office of Research and Development formed a workgroup to plan the implementation of the ETV Program. This workgroup guided the initial stages of the program that began in 1995, but more recently, a 1997 strategy document(3) was prepared which describes the verification program strategy based on the evolution of the program over its first 2 years. It outlines the operating principles and implementation activities that are shaping the program, as well as the challenges that are emerging and the decisions that must be addressed in the future. The overriding objectives of the program are to: 1) establish a fully functioning universe of third party verification organizations covering all appropriate classes of technology; 2) verify 300 technologies in 10 years; and 3) reach a point where the vast majority of funding is derived from technology vendors because of the general acceptance of the program's outputs.

While each of the 12 verification organizations has a unique focus and operation, they share several important aspects. The first order of business for newly established programs is to select a group of stakeholders to: 1) oversee the programs; 2) offer advice on technology areas and specific technologies most appropriate for testing; 3) review test plans and verification reports; and, in some cases, 4) help disseminate results. In narrowly focused programs, a single stakeholder group is adequate; while, in more diverse programs such as the Greenhouse Gas Technology Verification program, a hierarchy of stakeholders representing many different industries and organizations is more appropriate. At the top of that hierarchy is the Executive Stakeholder Group, a broad based group which provides overall guidance to the GHG Center.

Once the basic building blocks of the program are in place, actual verification activities begin. Verification activities in each technology area are announced in the Commerce Business Daily and other appropriate publications to encourage maximum participation by technology developers and to ensure fairness. Test plans are developed with the participation of vendors and stakeholders, and tests are conducted by independent third parties: either the verification organization or other testing organizations approved and overseen by the verification organization. Appropriate quality assurance procedures are incorporated into all aspects of the project, and reports are peer reviewed. Verification Statements of three to five pages, based on the performance data contained in the reports, are issued by EPA and appear on the ETV Web site (http://www.epa.gov/etv) and the Center's Web site (http://www.sri-rtp.com/index.html). Outreach activities to disseminate the results to interested parties are conducted by EPA, SRI, and relevant stakeholders.

In September 1995, EPA initiated four pilot ETV verification organizations: 1) the Small Package Drinking Water Systems Pilot; 2) the Pollution Prevention and Waste Treatment Systems Pilot; 3) the Site Characterization and Monitoring Technologies Pilot; and 4) the Indoor Air Products Pilot. In addition, the Agency solicited proposals for a fifth pilot to test the option of a private sector, non-technology specific, independent entity. In fiscal 1996, technology categories selected for the new pilots were: Advanced Monitoring Systems to encourage regulatory reinvention; Air Pollution Control Technologies; Innovative Coatings for Pollution Prevention; and Wet Weather Flow Technologies. One new pilot, focusing on GHG technologies, became operational near the end of the 1997 calendar year. The GHG Technology Verification Center, operated by SRI, was approved for ETV funding by the U.S. EPA in March 1997. It is coordinated, organized, and directed by EPA's National Risk Management Research Laboratory, through the Atmospheric Protection Branch of its Air Pollution Prevention and Control Division. SRI's Research Triangle Park, North Carolina, office directs the day-to-day activities of the Center.

The GHG Technology Verification Center

Background. It is well known that carbon dioxide (CO_2) emissions account for about 60% of human-induced GHG warming, and that methane, halocarbons, and nitrous oxide, although significant, account for only 18, 13, and 4%, respectively. This makes a compelling case for the verification program to focus primarily on sources of CO_2, since it accounts for much of the GHG emissions, and since the opportunities for reducing emissions would appear to be significant. However, in the absence of GHG regulations, market and other forces continue to play a dominant role in the development and implementation of commercial GHG mitigation and monitoring technologies. Technologies that have low capital requirements and strong potentials for profitable economic performance will continue to have a great commercialization potential in the next 2 to 5 years.

Since opportunities for the development and use of GHG mitigation and monitoring technologies are increasing, and will likely continue to increase in the future, dependable information on technology performance, cost, and reliability is needed to help industry and others make sound technology purchase decisions. The Center has established and tested a process to identify the technologies most in need of performance verification, to encourage vendors of those technologies to participate in the ETV program, and to produce high quality verification reports.

Identification of Candidate Technologies. SRI conducted a broad national screening study for technologies that might be appropriate for testing. The strategy identified GHG mitigation technologies which have all of the following features: 1) clear market potential (application will save money for the user and/or will solve a significant problem); 2) a large number of potential users; 3) performance questions (technical or economic) which inhibit a broader application; and 4) no existing verification services available. The study screened 151 technologies and determined that 37 may be suitable for verification testing in eight different technology areas (e.g., natural gas industry, perfluorocompound use, and electricity end-use devices). The eight technology areas were then presented to the Executive Stakeholder Group to obtain feedback on which technology areas they thought SRI should pursue. The Executive Stakeholder Group selected the oil and gas industries as the technology area with the greatest promise for immediate testing. SRI then conducted a focused study on which technologies in the oil and gas industries should be targeted, and the results of this study were presented at an Oil and Gas Industries Stakeholder Group meeting in June 1998.

The Oil and Gas Industries Stakeholder Group met for the first time on June 23 and 24, 1998, in Houston, Texas. The objectives of the meeting were to: 1) gauge the need for verification testing in these industries, 2) identify technology testing priorities, 3) identify broadly acceptable testing strategies, and 4) recruit oil and gas industries stakeholders. Industry representatives identified seven high priority technologies in need of verification, voiced support for the Center's mission, identified broadly acceptable verification strategies, and emphasized that the verification of cost drivers is critical for industry acceptance of new products. Since the Houston meeting, an Oil and Gas Industries Stakeholder Group was formed, vendors of GHG mitigation devices were solicited in several top-rated technology areas, and verification testing was started on two compressor leak mitigation devices. Vendors expressed strong interest in the ETV Program, and identified several market barriers that ETV may be able to address.

The Executive Stakeholder Group also felt that perfluorocompound (PFC) use in the microelectronics and aluminum industries, residential electricity use, municipal solid waste landfill technologies, commercial lighting, and distributed power systems were all areas that should be examined for verification opportunities. In the solid waste landfill area, vendors of leachate evaporators and internal combustion engines contacted the Center. In both cases, it was concluded that verification testing would be too costly to achieve, and/or would yield little value to the vendors. Assessments of verification opportunities in the PFC/SF_6 area, electricity end-use area, and distributed power area are still underway.

Currently 35 stakeholders are involved in this pilot. There are 13 executive stakeholders, 19 oil and gas industries stakeholders, and 3 microelectronics industry stakeholders. The Oil and Gas Industries Stakeholder Group was the first technology-specific stakeholder group formed. Tables 1 and 2 provide an organizational breakdown for two of the primary stakeholder groups formed so far.

Outreach Activities. To promote the Center and solicit broad vendor and stakeholder participation, the Center has participated in five national and international GHG conferences and verification expert workshops, published announcements in three trade journals, and developed and promoted a new GHG verification Web site. The Center is an active member of the GHG Emissions Trading Policy Forum, the UN-sponsored Working Group on the Clean Development Mechanism, and several UN-sponsored verification experts groups. SRI has published notices promoting the Center and soliciting vendor participation in several issues of Environmental Manager, the Oil and Gas Journal, and Pipeline & Gas Industry.

SRI plans to continue aggressive outreach activities in 1999, and active participation in the national and international GHG verification activities described above. In addition, wide distribution of Verification Statements and the Center-sponsored newsletter *Greenhouse Gas Verification News* will begin, enhancing the benefits provided to participating vendors.

The Verification Process. The verification process consists of: 1) inviting vendors to submit pre-test applications; 2) conducting engineering evaluations to determine their readiness for testing; 3) locating host test sites and preparing initial test plans based on input from the stakeholders, vendors, and host; 4) negotiating and signing testing commitment letters; 5) preparing test and quality assurance plans; 6) performing verification tests; and 7) reporting and distributing performance results. Figure 1 is a flowchart of the procedure employed.

Verification results are reported in two formats: a Verification Report, a mandatory requirement for participating; and a Verification Statement, a vendor marketing tool. In addition to the one test already completed, the Center is currently testing two new technologies, and is planning to start two additional verifications in 1999. The Center will continue to identify additional technologies for verification over the next 3 to 5 years.

Verification Activities To Date

Phosphoric Acid Fuel Cell Verification. For several years, International Fuel Cells (IFC) Corporation has employed the commercially available phosphoric acid fuel cell (PC25^{TM}) to generate electricity from natural gas. This fuel cell can also be used at municipal solid waste landfills to convert landfill gas (LFG) into electric power. This application requires a supplemental gas pretreatment unit (GPU) to remove sulfur and halide compounds present in the LFG. The combined GPU and PC25^{TM} fuel cell system provides a means for utilizing waste LFG, thus reducing methane emissions and other landfill air pollutants.

The gas purity requirements of the fuel cell, and the composition and physical properties of the incoming LFG dictate the design of the GPU. The waste is cleaned by the GPU then converted into electric power for on-site use, or for distribution to an electric grid. In the GPU, hydrogen sulfide (H_2S) is first removed via adsorption on an impregnated carbon bed, which is used to catalyze the conversion of H_2S into elemental sulfur. Additional water, heavy hydrocarbons, halides, and other contaminants are removed using a dryer bed, a low temperature cooler, an additional carbon bed, and a particulate filter. A heat exchanger is used to ensure that the gas temperature meets fuel cell inlet requirements.

The PC25^{TM} fuel cell consists of a fuel processing system power section (fuel cell stack), an electrical conversion system (power conditioner), and a thermal management system. In the fuel processing section, treated LFG is converted to hydrogen and CO_2 for introduction into the fuel cell stack. The fuel treatment process consists of a low temperature fuel preprocessor that removes the residual contaminants from the treated gas, a fuel reformer, and a low temperature shift converter where the exhaust from the reformer is further processed. The hydrogen from the process fuel stream is then combined electrochemically with oxygen from the air to produce electricity in the fuel cell stacks. The direct current produced is converted into alternating current in a power-conditioning package. The PC25^{TM} is designed to produce 200 kW of electric power.

Tests on the GPU and PC25^{TM} were conducted at two sites where the LFG flow rates, composition, heating value, and containment levels are representative of the U.S. landfill population. The performance of the GPU was evaluated by comparing the sulfur and halogen concentrations in the GPU outlet gas with the levels required to effectively operate the fuel cell. The GPU operating availability was determined by dividing the length of time the unit was available by the total operating time of the GPU. The emissions characteristics of the GPU flare, which is used to combust the contaminants collected by the GPU, were measured to evaluate hazardous air pollutants emitted to the atmosphere. The performance of the fuel cell was evaluated by demonstrating the LFG-to-energy conversion process, and by quantifying the power output. The energy conversion efficiency and fuel cell exhaust emissions were also measured.

The first verification test was executed at the Penrose Landfill in Los Angeles, California. The system was then relocated to the Groton Landfill in Connecticut where its performance was verified under different operating conditions. At both sites, the GPU provided LFG purification that was a factor of about 10 better than its design specifications required. The GPU availability at Penrose was 87%, and after initial start-up problems were resolved at Groton, availability was found to be 70%. The adjusted availability for the fuel cell, which compensates for shutdowns not caused by the fuel cell, was over 96% at both test sites. The fuel cell system energy conversion efficiency, based on lower heating values, was determined to be 37.1% at Penrose and 38.0% at Groton. The electricity produced at both sites was directed to the grid and sold to utility companies. The emissions from the fuel cell exhaust are consistent with the data measured from 16 other PC25™ units operating on natural gas. The average emissions were measured as (dry gas, corrected to 15% O_2): NO_x = 0.12 ppmv or 0.29 g/hr, SO_2 = nondetectable (0.23 ppmv detection limit) or <0.78 g/hr, and CO = 0.77 ppmv or 1.15 g/hr. Details of the verification have been published[(4)]. A Verification Statement may be downloaded from either of the Web sites mentioned earlier.

Natural Gas Compressor Leak Capture and Utilization System. The first technology tested for the oil and gas industries is offered by A&A Environmental Seals, Inc., of La Marque, Texas. The technology, referred to as the Seal Assist System (SAS), captures methane from leaking compressor rod seals, then routes the captured gas into the compressor engine fuel line. With over 13,000 natural gas compressors operating in the United States alone, compressor rod seal leaks represent a major source of methane emissions, and a significant loss of economic and natural resources.

The Center, in cooperation with Enron Gas Pipeline Group, has started a long-term performance testing of the SAS at a Transwestern Pipeline gas transmission station in Arizona. The SAS will be tested continuously for 8 months, during which a Phase I Report containing initial installation data and gas reduction measurements, and a Phase II Report containing longer-term technical and economic performance data will be issued. The specific verification goals associated with the Phase I and Phase II verification efforts are outlined below.

- Phase I SAS Evaluation:
  - Verify initial leak capture performance
  - Verify initial gas recovery and use performance
  - Verify initial baseline methane emissions and emission reduction
  - Document installation and shakedown requirements
  - Document capital and installation costs

- Phase II SAS Evaluation:
  - Verify long-term leak capture performance
  - Verify long-term gas recovery and use performance
  - Estimate annual baseline methane emissions and emission reduction
  - Document long-term SAS operational requirements
  - Calculate SAS payback period

A key verification goal is to calculate SAS economic performance using verified data. Industry engineers need verified economic performance data to support technology purchase decisions, and to justify those decisions to their managers.

SAS installation and shakedown were completed in January 1999, and testing started that month. The Phase I Report should be published in June 1999, and will contain controlled and uncontrolled methane emission rates, along with capital and installation costs. The Phase II Report should be published in January 2000, and will contain estimates of the annual emission reduction achieved, annual operating and maintenance requirements, device availability, and economic payback period.

Gas recovery and use by the SAS will be measured continuously throughout the 8-month measurement or study period. However, to calculate the payback period, estimates of gas recovery over periods longer than 8 months will be needed. This necessitates the use of gas recovery extrapolation/projection techniques. A key factor influencing payback period is the amount of gas recovered, and Figure 2 illustrates the two strategies that will be used to calculate a range of payback periods. Figure 2 shows that monitoring will be conducted over about one-third of the anticipated 2-year payback period, requiring that projections of gas recovery be estimated for the remaining two-thirds of the payback period (i.e., just before and just after the study period). Strategies for projecting gas recovery both before and after the study or measurement period have been developed, and as Figure 2 shows, one represents a conservative or low emission recovery case, and the other represents an extrapolation using the data collected throughout the 8-month period. A measurement Test Plan has been prepared and can be downloaded from the Center's Web site.

Natural Gas Compressor Static Seals. Compressors that remain pressurized with natural gas when off-line can leak significant quantities of gas from the rod seals. The second device being verified for the oil and gas industries is the Static Pac®, a device that reduces or eliminates methane leaking from off-line compressor rod seals. Static Pacs are manufactured by C. Lee Cook of Louisville, Kentucky and, according to the manufacturer, is most applicable to reciprocating compressors in the gas transmission sector that perform some peak shaving duty. The device's performance will be verified on a peak shaving reciprocating compressor that is operated by ANR Pipeline Company.

Testing is scheduled to begin in March 1999, to correspond to the time when standby compressor operations begin to increase in frequency. As with the SAS device described earlier, Static Pacs will be tested over a several month period but, unlike the SAS test, continuous measurements will not be made. Instead, discrete spot measurements will be collected during standby operations to verify emission reduction performance and to quantify baseline emissions. The Center will issue a Phase I Report containing initial installation data and measured gas savings. A Phase II Report will be issued later, after multiple start-up and shutdown tests have been completed, and the report will contain longer-term technical and economic performance data. The specific goals of the Phase I and Phase II verification efforts are outlined below.

- Phase I Static Pac® Evaluation:
  - Verify initial rod seal leak prevention performance (emissions after Static Pac installation)
  - Verify initial baseline methane emissions and emission reduction
  - Document installation and shakedown requirements
  - Document capital and installation costs

- Phase II Static Pac® Evaluation:
  - Verify long-term rod seal leak prevention performance
  - Estimate annual baseline methane emissions and emission reduction
  - Document long-term operational requirements
  - Calculate gas savings and payback period

Microturbine Power Generator Systems. Allied Signal Power Systems, Inc. of Torrance, California and SONAT Power Systems, Inc. of Birmingham, Alabama in cooperation with Enron Gas Pipeline Group of Houston, Texas, are supporting an independent performance verification of a 75 kW Turbogenerator™. The test will be conducted at an Enron operated gas transmission station in Melbourne, Florida. Microturbines are a relatively new technology and, although based on well-established turbine technology designs, have been applied at natural gas transmission stations on a limited basis.

The test is scheduled to begin in the summer of 1999, and will address a range of technical, economic, emissions, and operational performance characteristics. A phased approach will be used to initially verify the performance of a single commercial unit (Phase I). If the Phase I results meet site acceptance criteria established jointly by the Center, the vendor, and the host site, then several new microturbines will be installed as needed to supply the entire station's electricity demand (four units are likely), and the Phase II verification monitoring will begin. The four units are expected to meet the baseload demand of 250 kW, and also be capable of meeting peak load demand (300 kW).

The primary objectives of the Phase I test are to verify: 1) energy production and conversion efficiency performance, 2) capital, installation, and operation and maintenance (O&M) costs, 3) emission rates of several criteria pollutants and GHG species, 4) installation and start-up requirements, and 5) compatibility with existing electrical systems. The Phase I and Phase II efforts have similar objectives, but a more long-term perspective will be provided and overall economic performance will be assessed. The following is a list of key variables that will be quantified.

- Energy Conversion Performance: determined by measuring electric power output at on-site voltage and frequency conditions, gas supply quality, and other variables collected under a suite of different turbine loads.
- Criteria Pollutant Emission Performance and GHG Reduction: including nitrogen oxides, carbon monoxide, oxygen, total hydrocarbons, sulfur dioxide, carbon dioxide, and methane in the turbine exhaust. GHG emission reductions will be calculated as the sum of the estimated emissions contributed by power plants serving the transmission station, minus the CO_2 emissions produced by the on-site turbines that produced an equal amount of delivered power.
- Operational Feasibility: net system availability, excluding downtimes that are unrelated to turbine failure. Operational feasibility will also consist of documenting installation costs, reasons for downtime, O&M requirements, health and safety data, and compatibility with the existing electrical system.
- Economic Performance: including estimating technology payback period (years) and electricity cost savings ($/kW-hr).

The duration of the Phase I test is estimated to be from 2 to 3 months, while Phase II is estimated to be 4 months (excluding installation, start-up, and shakedown activities).

At the time this paper was prepared, the Center was planning a second test of a microturbine capable of using waste methane at gas production and processing facilities. Capstone Turbine Corporation, in Tarzana, California, manufactures the device. The test may verify turbine performance on a low-pressure fuel stream that is saturated with water and heavy hydrocarbons.

Future Technology Verification Plans. In fiscal year 1999, the Center plans to continue the process of seeking verification candidates from the oil and gas industries. In addition, new initiatives will continue in the energy production area (e.g., distributed power systems such as microturbines), GHG monitoring technologies, and microelectronics and aluminum industries.

Summary

The GHG Technology Verification Center is part of the ETV Program operated by the U.S. EPA's Office of Research and Development. The Center has been in existence just over 1 year and has been awarded EPA funding of $3 million through fiscal year 1998, and acquired significant vendor co-funding for all of its upcoming verifications in the natural gas industry. In addition, the Center has published the results of its first verification (fuel cells), and initiated three new field verifications in the gas industry (two compressor seal technologies, and one microturbine technology). The Center will maintain its relationships with the natural gas and fuel cell industries, while extending its working relationships to other potentially viable areas including landfill and other waste disposal industries, the microelectronics and aluminum industries, the energy production industries, and the GHG monitoring industry. This aggressive beginning suggests that the Center will be successful in making a significant impact on the market penetration of GHG mitigation technologies, and will reach its objective of financial self-sufficiency with minimal Agency involvement within 5 years.

References

1. Executive Office of the President, *Bridge to a Sustainable Future: National Environmental Technology Strategy*,(G.P.O. 061-000-00839-0), Washington, D.C., 1995.

2. Office of the Vice President, *From Red Tape to Results -- Creating a Government that Works Better & Costs Less (National Performance Review Report)*, (G.P.O. 040-000-00592-7), Washington, D.C., 1993.

3. U.S. Environmental Protection Agency. *Environmental Technology Verification Program: Verification Strategy,* Report No. EPA/600/K-96/003 (NTIS PB97-160006), 22 pp., Office of Research and Development, Washington, D.C., February 1997.

4. Masemore, S.; Piccot, S. *Electric Power Generation Using a Phosphoric Acid Fuel Cell on a Municipal Solid Waste Landfill Gas Stream*, Report No. EPA-600/R-98-105, 63 pp., U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Research Triangle Park, N.C., August 1998.

Table 1. Makeup of the Executive Stakeholder Group by Organization Type.

Type of Stakeholder	Number of Representatives
Industry or Private Sector	**2**
Federal Agencies	**5**
State Agencies	**1**
International Organizations	**2**
Professional Trade Associations	**2**

Table 2. Makeup of the Oil and Gas Industries Stakeholder Group by Organization Type.

Type of Stakeholder	Number of Representatives
Industry or Private Sector	**14**
Federal Agencies	**2**
Consultants	**4**
Vendor Community	**15**

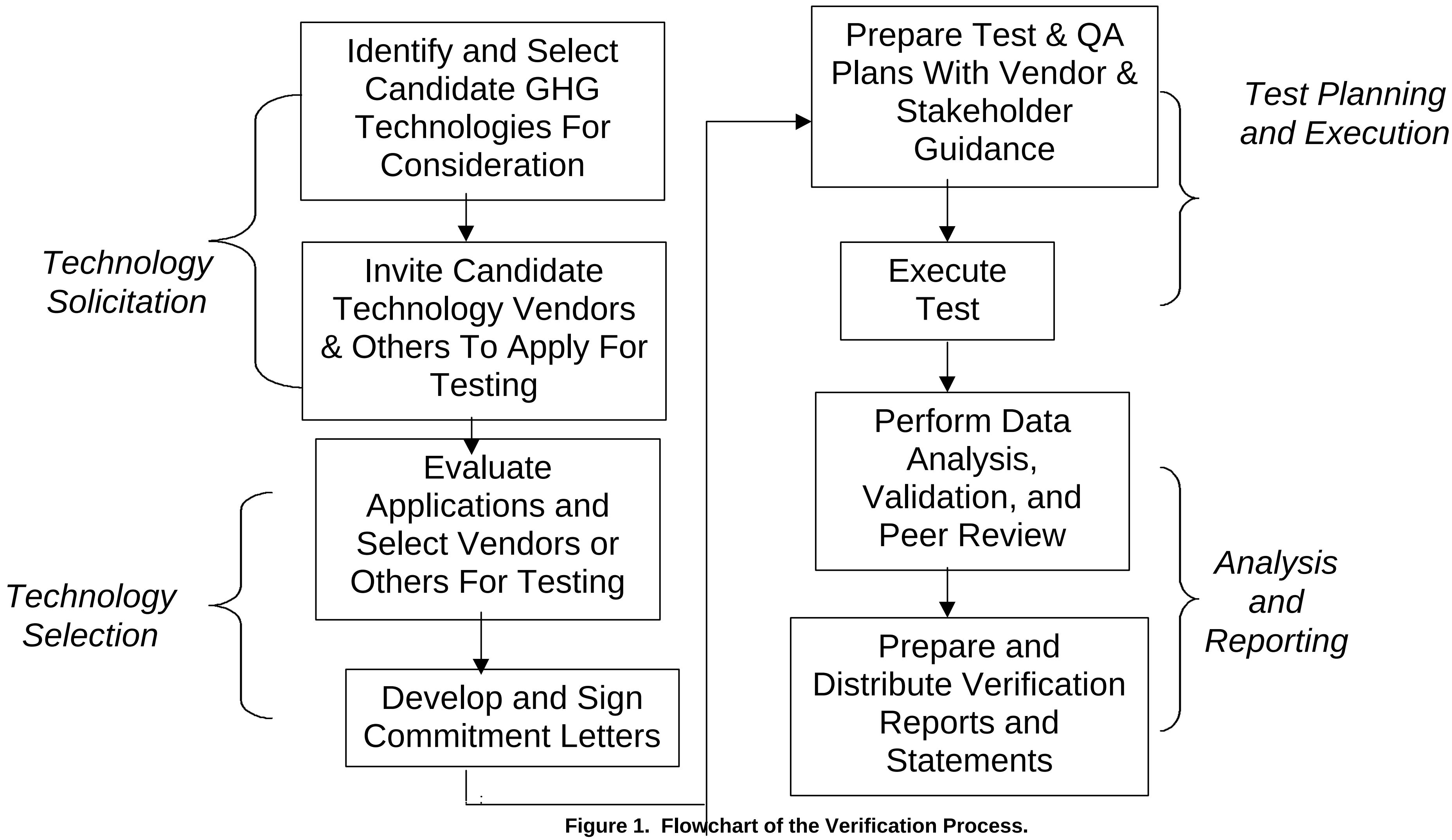

Figure 1. Flowchart of the Verification Process.

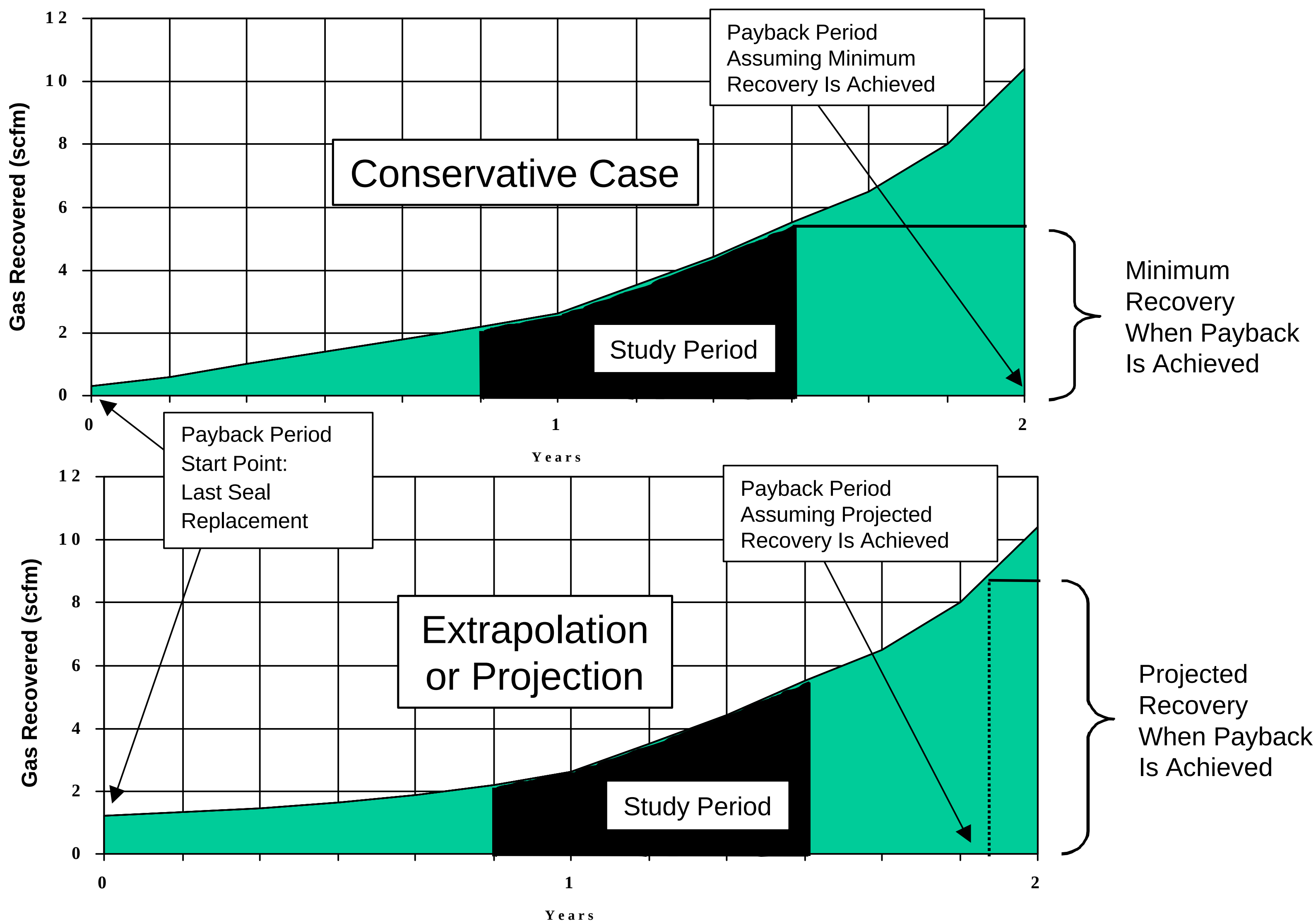

Figure 2. Long-term Gas Recovery Study or Measurement Period and Projection Methods.