# CASCADE

## COMPRESSOR / STORAGE REFUELING STATION SIMULATION PROGRAM

**Version 3.1**

**USER'S MANUAL**

**GAS TECHNOLOGY INSTITUTE**

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### REFUELING STATION
### SIMULATION PROGRAM

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GAS TECHNOLOGY INSTITUTE
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## Copyright Notice

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**REFUEL STATION**

The ability of a refueling station to deliver gas fuel to a vehicle in compressed form is loosely termed the station delivery capacity. This capacity is influenced by a variety of factors such as the fleet size, refill time, vehicle fuel capacity, vehicle fuel efficiency, vehicle daily mileage, and operating time per day. The delivery capacity required for any given fleet can be calculated using this information. Refueling station delivery capacity can be met in one of two ways: through straight compression capacity, or compression assisted by ground storage of compressed fuel gas.

Ground storage makes it possible to use a smaller compressor to service a larger fleet by allowing the compressor to run between vehicle refuels, thereby reducing its required peak flow rate. However, one negative aspect of ground storage is its inability to operate satisfactorily after depletion, which occurs after a number of successive vehicle refuelings. The objective of a refueling station designer is to match the ability of a storage/compression combination to continuously refuel a number of vehicles to the fleet operation's successive refueling requirements. Ground storage complicates the analysis of a refueling station, especially in cases of cascade operation.

Cascade storage involves individually accessed storage vessels controlled by valves that are switched in sequence. Cascade storage works on the principle that banks of vessels at different pressures can more efficiently fill a vehicle than bulk storage, or operation of the total storage capacity as a unit at a common pressure. In a cascade storage operation the compressor fills the ground storage vessels, which in turn fill the vehicles' storage.

A fleet refueling station is considered to be a good candidate for ground storage when it possesses certain characteristics. Generally, fleets with fewer vehicles, longer shift periods, and greater vehicle range are more attractive. In addition, fleets that demand more rapid refueling of each vehicle are good candidates for ground storage. Most importantly, a fleet must experience some delay, on average, between vehicle refuels. While ground storage can be designed to meet a certain number of successive refuels, prolonged continuous refueling of vehicles will always eliminate ground storage from consideration. The reason for this lies in the fact that ground storage vessels will become depleted unless a delay in refueling occurs to allow the compressor to recharge the cascade.

The necessity of a computer simulation program arose due to the difficulty in assessing the performance of a cascade-type ground storage system.

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**CASCADE SOFTWARE**

The Gas Technology Institute developed CASCADE software to help in assessing the performance of a cascade-type ground storage system for any set of fleet vehicle conditions. It is most effectively used as a tool to determine the performance of different refueling configurations. By setting all fleet parameters at a constant value and changing only the number of ground storage vessels and the compressor size, the user can easily observe the performance of the station at varying increments of compression and storage capacity. This will allow the refueling station designer to minimize compression requirements while still attaining the necessary refueling performance. Both English and Metric engineering units are used in the program.

**SOFTWARE REQUIREMENTS**

For CASCADE version 3.1, the operating system requires Windows 2000/XP/Vista system.

CASCADE version 3.1 requires the presence of Microsoft Data Access Components (MDAC) Version 2.6 or higher to run on your system. If MDAC is not present, the CASCADE setup program will install it automatically. Make sure to reboot your computer after installing the program.

**Registration for Unlimited Use License**

Please register your copy of CASCADE . By registering, you can obtain License Number and activate the software for unlimited use on your computer. You can register by e-mailing the registration form to support@interenergysoftware.com, or faxing it to 1-847-768-0916.  The registration form is provided with the software and can be accessed by clicking on "Print Registration Form" button. You can also register directly on the INTERENERGY/GTI web site at www.interenergysoftware.com.

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Software license for unlimited use of the product on single computer can be transferred from another licensed computer. After transferring the license to new computer, you will not be able to use/run the program on the old computer. Therefore, please make sure that is what you want before transferring the license. If you would like to run program on both computers you need to buy a new license.

To transfer the license from old to new computer, please do the following;

- **New computer** you are transferring license to.
1) Install the software on your new computer.
2) Run the software. When the initial form appears on the new computer, click Transfer License button.
3) Insert a **blank** floppy disk (a license transfer disk) into drive A* of this computer.
4) Click **Start Transfer** button to initiate the license transfer process.
5) When finished, remove the disk from the new computer.


- **Old computer**, which has original license.
1) Run the program on your old computer.
2) Put the license transfer disk with an initiation file created from the new computer into drive A* of this computer.
3) Click on the **Transfer License** via File pull-down menu at the top of main screen.
4) After the transferred license file is copied to the disk, take the disk out.
   Now, the license on the old computer is disabled. You should uninstall the software from this machine.


- Go back to the **new computer**.
1) Put the license transfer disk back to the new computer drive A*.
2) Click on the **Activate Transferred License** button to finish the transfer process.


The license should be now transferred to the new computer. The program will stop running after the license is transferred. Just re-start the program.


**Note: The program uses the drive A as the default floppy disk drive of computers. If your computer does not have a floppy disk drive, please use the menu button of Select Floppy/Disk Drive to select any drives of the devices with removable storages (CD, flash memory, or others.).**

**TECHNICAL SUPPORT**

Technical support is available at:

- Internet - http://www.interenergysoftware.com

- E-mail - support@interenergysoftware.com

- Fax – 847-768-0510

**SOFEWARE OPERATION**

## 1. Input Information



User Input Screen

To begin the analysis of a fleet refueling station, the user must enter information in six areas:

**Fuel -** selection of fuel type and input of fuel equivalency ratio value.

**Fleet / Vehicle characteristics** - input of vehicle fuel efficiency, daily route mileage, and number of vehicles in the fleet.

**Vehicle storage characteristics** - input of the storage cylinder volume, rated pressure at 70°F ambient temperature, and maximum pressure of the cylinder.

**Ground storage characteristics** - input of the storage volume, operating pressure, and number of ground storage cylinders desired by the fleet operator

**Refueling characteristics** - input of time required for switching or moving vehicles to refueling dispensers, and shift operating time (number of hours per day the fleet will be in operation).

**Temperature** - input of vehicle storage temperature and ground storage temperature.

**Data Field Definitions:**

The following describes each item in detail.

**Equivalency Ratio** is the number of standard cubic feet that contain the same amount of energy as one gallon of gasoline. Alternatively, it can be based on observed fuel economy values. Gasoline typically has an energy content of 110,000 to 115,000 Btu/gal. For natural gas of mean U.S. composition, a value of 124 scf/gge (928 sl/liter) can be used, while for Hydrogen, a value of 416scf/gge (3112 sl/liter) is applicable.

**Vehicle Fuel Efficiency** is the efficiency of the vehicle when running on compressed fuel gas. This value must be at least 1 mpg-equivalent or 1 liter/100-km-equivalent.

**Daily Vehicle Route Mileage** is the average mileage that the vehicle travels during an average working day. This value is used to determine the amount of fuel gas to be replenished at the end of the day. The value entered must be at least 1 mile or 1 km.

**Fleet Size** is the total number of vehicles that must be filled each day (or each working day). This does not include any vehicles not in service or partially utilized. The fleet must have at least 1 vehicle and no more than 999 vehicles.

**Dual Fuel Operation** indicates that the vehicle is capable of running on both fuel gas and some other fuel. The advantages of using a dual-fuel vehicle is the capability of switching to the alternate or backup fuel when the fuel gas tanks are exhausted. If dual-fuel operation is indicated, the program will calculate the vehicle range to tank exhaustion and assume the vehicle will make it safely back to the refueling station on the alternate fuel.

**Vehicle Total Storage Volume** is the total water volume in cubic feet of the cylinder(s) used to store the compressed fuel gas. The program treats on-board storage as a single vessel. The total volume must be at least 1 cubic foot (1728 cubic inch or 28.4 liter) and no more than 1000 cubic feet water volume (1728000 cubic inch or 28300 liter).

**Vehicle Rated Storage Pressure** is the vehicle storage cylinder rated pressure that the fuel gas is at when the cylinder(s) are completely filled. For natural gas, it must be at least 1000 psig and no greater than 3600 psig at temperature 70 °F (between 70 and 250 bar at temperature 21 °C). For hydrogen, it must be at least 1000 psig and no greater than 9500 psig at temperature 70 °F (between 70 and 650 bar at temperature 21 °C).

**Vehicle Maximum Allowable Storage Pressure** is the vehicle storage cylinder maximum pressure allowable for the cylinder construction.

**Minimum Pressure Difference** is the minimum pressure difference between a vehicle's tank and the connected cascade bank that can still produce an acceptable fuel gas flow rate through the dispenser for fueling the vehicle. It should be between 50 and 500 psi (between 3.5 and 30 bar).

**Time for Switching Between Vehicles** is the time required to disconnect one vehicle and connect the next. During this time, no vehicle filling occurs; however, the compressor continues to fill the ground storage cylinders, if required. The minimum acceptable time for this is 0 minutes (instantaneous switching between vehicles) with a maximum of 99 minutes. This feature can also be used to approximate the demands of periodic vehicle refueling. For example, a fleet in which vehicles are available for refueling an average of every 30 minutes would have 25 minutes switching time, given a refueling time of 5 minutes.

**Refueling Operation Time** is the total amount of time in hours per day that can be given to the refueling of the fleet. It is not necessarily equal to the actual time required to complete fueling the fleet, which is computed by the program. It must be at least 1 hour and not more than 24 hours.

**Compressor Running During Refueling** permits the option of running the compressor while vehicle refueling takes place, or only when the cascade banks are depleted and need to be recharged. An answer of No to this question can also be used to assess the performance of refueling stations which possess no on-line compression capacity.

**Dispenser Rating Point Pressure and Flow Rate** are the rated dispenser inlet pressure and rated flow through the dispenser. The dispenser flow rate, at any instant of time, to the vehicle cylinder is computed by considering the combined restriction of the dispenser and the vehicle's connection receptacle, as being an orifice. The flow rate to the vehicle is computed based on this user information, and the instantaneous cascade bank and vehicle cylinder pressures. Choked flow occurs through this simulated dispenser/receptacle orifice when the vehicle cylinder pressure is below the critical pressure at any instant during the fill.

**Number of Storage Banks** is the total number of cylinder banks in the refueling station. Having more than 1 cylinder bank allows the compressor to refill one bank while the others are used to fill the vehicle.  The number of cylinder banks can vary between 1 and 3.

**Ground Storage Bank Volume** is the size of a switchable bank in the refueling station. The compressor fills and the vehicle depletes the same bank if there is no switching control to establish multiple banks.  If the station has more than 1 bank, each bank may be a different size, with the total capacity equal to the sum of the individual banks.  Each bank can have one or more cylinders.  Each bank must be at least 1 cubic foot (1728 cubic inch or 28.4 liter) and no more than 1000 cubic feet water volume (1728000 cubic inch or 28300 liter).

**Ground Maximum Storage Pressure** is the pressure of the fuel gas when the ground storage vessels are filled to a rated capacity at 70$^o$F (21 °C) ambient temperature. It must be at least the minimum pressure difference above the vehicle's pressure. For natural gas, it should be at least 1000 psig and no greater than 5000 psig (between 70 and 340 bar).  For hydrogen, it should be at least 1000 psig and no greater than 10000 psig (between 70 and 690 bar).

**Vehicle Storage Temperature** is the temperature of the fuel gas in the vehicle storage tank.  It must be at least –40 °F (-40°C) and no more than 150 °F (65 °C).

**Ground Storage Temperature** is the temperature of the fuel gas in the ground storage vessels.  It must be at least be at least –40 °F (-40°C) and no more than 150 °F (65 °C).

<u>**Commands**</u>

**File Menu**
> **Save Input File** command (File menu): Use the **Save Input File** command to save all the user input information on the screen in a text file.
> **Open Input File** command (File menu): Use the **Open Input File** command to open an existing input file to input the information required on this screen automatically.
> **Exit** command (File menu): Use the **Exit** command to exit CASCADE application.

**Next Menu/Command**
> Use **Next** Command/Menu to go to next page that shows the intermediate results based on the values the user input here.

**Help Menu**
> **Contents** command (Help menu): Use the **Contents** command to call up CASCADE Online Help Index. Using this index as a starting point, you can

quickly find any Help topic of interest. Once in online Help, you can always return to the main window by clicking the Contents button in the upper left corner of the Help window.

**Disclaimer** command (Help menu): Use the **Disclaimer** command to review all information on Terms and Conditions to use CASCADE.

**About** command (Help menu): Use the **About** command to find the version number and other pertinent information about CASCADE.

**Help** command

Use **Help** command to show the on-line help information for this form.

## 2. Intermediate Results and Compressor Size Input



Intermediate Results and Compressor Size Input Screen

After the user inputs the required information in the five areas, the program will calculate a variety of intermediate measures such as full fill pressure and temperature of vehicle, capacity of the vehicle and ground storage cylinders, required refuel interval per vehicle, end-of-day gas supply and pressure for vehicles, average number of vehicles refueled per hour, and total daily station demand. Two very important measures which are calculated include the "Minimum Required Flow Rate per Vehicle" and the "Average Required Flow Rate per Shift". These values give the required flow rate to meet the demands of refueling one vehicle within the allowable time, and refueling all fleet vehicles within the shift operating period, respectively. It should be noted that the required flow rates are adjusted for the amount of fuel remaining in the vehicle, so the assumption of daily refueling is made. The user is then asked for the **Compressor size** to be used for the analysis.

## Data Field Definitions:

The following describes each item in detail.

**Vehicle Storage Full Fill Pressure** is the required full-fill pressure within the cylinder at its rated mass content and full-fill temperature. GTI's patented dispenser control algorithm, Accufill [2,3,4] is used to compute the required full-fill pressure within the vehicle cylinder at its rated mass content.

**Vehicle Storage Full Fill Temperature** is the temperature of the gas at the required full-fill pressure within the cylinder. As a vehicle cylinder is filled with gas, either Hydrogen or Natural Gas, the temperature of the gas within the cylinder rises. This rise in temperature is a result of complex mixing and compression thermodynamic processes within the gas as its pressure rises during the fill.

**Vehicle Storage Cylinder Capacity** is the total amount of fuel gas, in standard cubic feet, that is stored on the vehicle when it is filled to rated capacity. This is based on the water volume and the rated pressure at $70^{o}$F ambient temperature.

**End-of-Day Vehicle Gas Volume** and **End-of-Day Gas Pressure** define the state of the vehicle's storage tank at the end of the average day if it started full. These are the conditions the refueling station sees when the vehicle is first connected.

**Required Refuel Interval per vehicle** is the period, in days, that the vehicle can run on fuel gas. If it is less than 1 day and the fleet vehicles can only run on fuel gas, the rest of the program will not be run because the end-of-the-day state of the vehicle's tank cannot be determined. If the vehicle has a dual-fuel capability, the program will assume the vehicle was driven on fuel gas until the tank pressure reached 50 psig.

**Ground Storage Cylinder Capacity** is the rated amount of fuel gas, in standard cubic feet, contained in each refueling station cylinder bank; based on the rated pressure and the water volume.

**Total Ground Storage Capacity** is the sum of the storage capacity of all cylinder banks.

**Average Number of Vehicles Refueled per Hour** is the rate at which vehicles need to be refueled to completely refuel the fleet during shift operating time.

**Total Daily Station Demand** is the amount of fuel gas that is required to fill the fleet, with all vehicles starting at the end-of-day conditions.

**Maximum Flow per Vehicle** is the maximum flow rate at which a vehicle can be filled using selected fueling station components (cascade, dispenser, compressor).

**Average Required Flow per Shift** is the average flow rate that must be sustained throughout the shift to refuel all fleet vehicles completely.  The length of the shift is determined by user input for **Refueling Operation Time** in hours.

**Compressor Size** is the user-entered size of the compressor in scf/min or liter/min.  It insures that the compressor feeds the cascade bank at the same rate as the vehicle depletes it.  A larger size causes the compressor to idle during some of the operating time.  A smaller size allows the station to take advantage of the cascade storage.

## Commands

**Next Menu/Command:**
> **Next (Simulation)** Menu/Command: Use **Next (Simulation)** Menu/Command to go to next page to simulate and display the process of operation of refueling process.
> **Next (Results)** Menu/Command: Use **Next (Results)** Menu/Command to directly go to see the refueling simulation results (reports and charts).

**Exit Menu:** Use the **Exit** command to exit CASCADE application.

**Back Command:** Use the **Back** command to go back the User Input Screen.

**Help Command:** Use **Help** command to show the on-line help information for this screen.

## 3. Refueling Process Simulation Screen
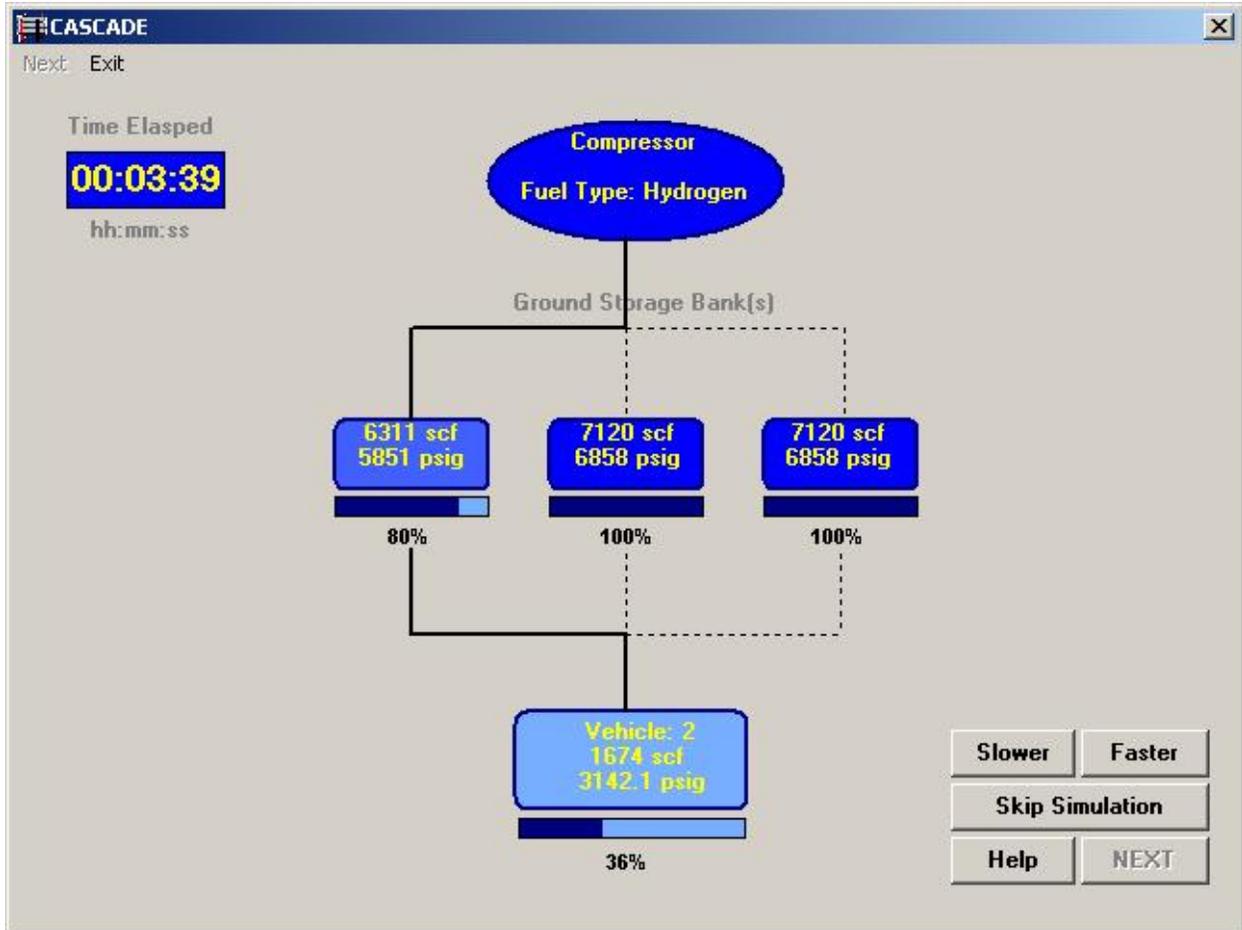


Simulation Screen

CASCADE runs running simulation and displays the fueling progress graphically in simulation screen. The lowest pressure cascade bank fills the vehicle cylinder, up to the minimum delta pressure input between cascade and vehicle. Then the vehicle is fueled from the medium pressure bank, topped off with the highest-pressure bank. The bank are refilled, from compressor output, in reverse order, starting with the highest pressure bank, followed by the medium bank, and then the lowest bank.

**Commands**

**Next Menu/Command:** Use **Next** Command/Menu to go to next page to see the refueling simulation results (reports and charts).

**Exit Menu:** Use **Exit** command to exit CASCADE application.
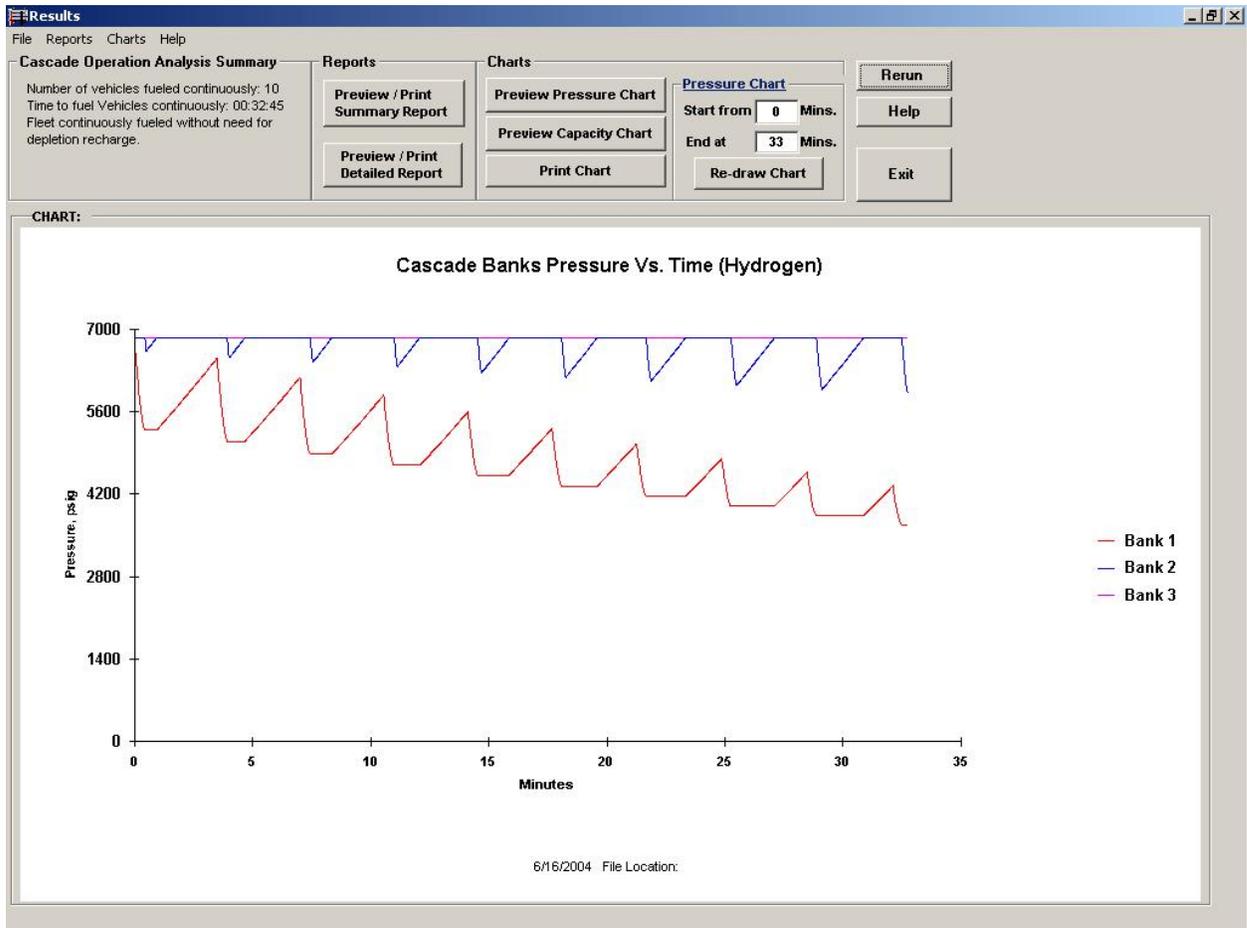
**Slower Command:** Use **Slower** command to slow down the simulation.

**Faster Command:** Use **Faster** command to speed up the simulation.

**Skip Simulation Command:** Use **Skip Simulation** command to skip the simulation process and see the refueling simulation results directly.

**Help Command:** Use **Help** command to show the on-line help information for this screen.

# 4. Results



Analysis Result Screen

The primary output of the CASCADE program is the number of vehicles, which can be refueled continuously (in a row). The program also calculates the continuous refueling time, and total fleet refueling time. If the simulation indicates that the compressor is too small to maintain continuous refueling, the program displays the vehicle that would not have been totally filled, then backs up to the point just before filling started. It computes the amount of fuel gas required to bring the cascade banks back to full capacity and the time this would take. Knowing the number of vehicles that can be continuously refueled before recharging the cascade banks, the program quickly steps through the remaining part of the demonstration. Figure 4 shows the cascade analysis result screen. The user has options to print the summary page, the detail pages, and/or charts.

**Commands**

**File Menu**

        **Save Results** command (File menu): Use the **Save Results** command to allow users save all the input information and analysis results in a very compact format.

        **Open Saved Results** command (File menu): Use the **Open Saved Results** command to allow users open an existing saved file to import all the information including the input and results and see the results directly here with reports and charts.

        **Rerun** Menu/Command: Use **Rerun** Command/Menu to return to the User Input Screens to let the user either accept/save the previously entered values or change them for new case.

        **Exit** menu/command: Use **Exit** command to exit CASCADE application.

**Rerun Analysis** Command: Use **Rerun Analysis** Command to return to the User Input Screens to let the user either accept/save the previously entered values or change them for new case.

**Preview /Print Summary Report** Menu**/**Command**:** Use **Summary Report** command to see the summary report. The summary report documents the user entries and the intermediate calculated results and cascade operation analysis summary results.

**Preview /Print Detailed Report** Menu**/**Command**:** Use **Detailed Report** command to see the detail page report. The detailed report contains the information displayed when CASCADE was simulating the refueling station operation. It indicates the pressures and amounts of fuel gas in each storage vessel / bank, what vehicle is being filled, which bank is filling the vehicle, and which bank is being filled by the compressor. It indicates the time (with respect to the start of the refueling period) at which switching between banks occurs.

**Preview Pressure Chart** Menu**/**command: Use this command to see the chart of banks pressure vs. Time.

**Preview Capacity Chart** Menu**/**command: Use this command to see the chart of banks capacity vs. time

**Print Chart** command: Use this command to print the chart shown on the screen.

**Re-draw Chart** command: Use this command to zoom in the pressure/capacity chart based on the user input time range.

**Help Command:** Use **Help** command to show the on-line help information for this screen.

**Exit** Command**:** Use **Exit** command to exit CASCADE application.

**BACKGROUND**

This section generally describes the logic behind the operation of CASCADE and references modeling algorithms used.

In selecting the bank filling the vehicle, the program determines the bank that is at the lowest pressure above the minimum for filling the vehicle, and simulates its use until the pressure has dropped below that of usability. This is the minimum pressure difference entered by the user. It continues to do this until the vehicle is filled or the cascade banks are exhausted. For the lift truck analysis, once the cascade banks are exhausted (or are incapable of filling the vehicle to the maximum storage pressure), the simulation has the compressor directly connected to the vehicle, bypassing the banks. This permits the compressor to fill up the vehicle to its maximum, even if it is the same maximum as the compressor output.

In selecting which bank the compressor should be filling, the program always searches for the highest pressure bank (below capacity) which is not currently filling a vehicle. This helps to insure that there is at least one bank that can be used to finish filling a vehicle at its maximum pressure, as much as possible. If the other banks are at their maximum, the compressor is attached to the bank currently filling the vehicle. Once attached, it continues until that bank is filled, or the vehicle is switched to that bank.

As a vehicle cylinder is filled with gas, either Hydrogen or Natural Gas, the temperature of the gas within the cylinder rises. This rise in temperature is a result of complex mixing and compression thermodynamic processes within the gas as its pressure rises during the fill[1]. Accufill [2,3,4], GTI's patented dispenser control algorithm, takes into account these processes, as it computes the required full-fill pressure within the cylinder at its rated mass content. Accufill has been shown, via laboratory and field testing, to fully fill all types (1 through 4) of NGV and Hydrogen cylinders to within +/- 2% of their rated gas masses. This accuracy is maintained in vehicles containing single cylinders of 2.5 GGE to 22 GGE volumes, and in parallel vehicle storage arrangements of up to 6 on-board cylinders.

The computations related to full fill gas pressure and temperature within the Accufill algorithm are incorporated in Version 3.1 of CASCADE for Hydrogen and Natural Gas. Instantaneous values of cascade bank pressure and temperature, initial vehicle pressure, and vehicle storage volume are combined within the CASCADE software to compute full-fill vehicle conditions. If the cascade depletes in pressure before the vehicle is completely filled, CASCADE notifies the user via an error message. In addition, if the required full-fill vehicle storage pressure exceeds the user inputted maximum storage pressure, CASCADE fills the vehicle storage cylinder to that maximum pressure, and notifies the user via another error message.

The vehicle fill time is computed based on a summation of a 50 step incremental determination of the time for the vehicle cylinder to be filled to its rated mass of gas. At each increment of vehicle fill, the dispenser flow rate is computed, based on the methodology described above. As a cascade bank becomes depleted, the average pressure at the dispenser

inlet is reduced. This results in longer vehicle fill times relative to those achieved when the cascade bank is completely filled.

**References (Available on CD):**

[1]"Modeling The Fast Fill Process in Natural Gas Vehicle Storage Cylinders", Kenneth J. Kountz, Paper at 207th ACS Meeting, San Diego March 1994
[2] "Apparatus and Method For Controlling the Charging of NGV Cylinders From Natural Gas Refueling Stations", K. Kountz and C. Blazek, U.S. Patents 5,488,978 and 5,551,490, 1996
[3]"System and Method For Charging a Container With Pressurized Gas", K. Kountz and C. Blazek, U.S. Patents 5,641,005 and 5,752,552, 1997 and 1998
[4]"Computer Readable Medium Having a Computer Program For Dispensing Compressed Natural Gas", K. Kountz and W. Liss and C. Blazek, U.S. Patents 5,771,947 and 5,881,779, 1998 and 1999

**REVISION HISTORY**

- **Version 3.1**

CASCADE version 3.1 represents major revision and improvement of vehicle refilling modeling algorithms.

- GTI's patented dispenser control algorithm, Accufill [2,3,4,] is used to compute the required <u>full-fill pressure and temperature</u> within the cylinder at its rated mass content.
- The <u>dispenser flow rate</u>, at any instant of time, to the vehicle cylinder is computed by considering the combined restriction of the dispenser and the vehicle's connection receptacle, as being an orifice. The rated flow through the dispenser is user inputted, together with an associated rated dispenser inlet pressure. The flow rate to the vehicle is computed based on this user information, and the instantaneous cascade bank and vehicle cylinder pressures. Choked flow occurs through this simulated dispenser/receptacle orifice when the vehicle cylinder pressure is below the critical pressure at any instant during the fill.
- The <u>vehicle fill time</u> is computed based on a summation of a 50 step incremental determination of the time for the vehicle cylinder to be filled to its rated mass of gas. At each increment of vehicle fill, the dispenser flow rate is computed, based on the methodology described above. As a cascade bank becomes depleted, the average pressure at the dispenser inlet is reduced. This results in longer vehicle fill times relative to those achieved when the cascade bank is completely filled.

Additional upgrades/revisions include:

- Revised tables of Hydrogen properties.
- User option to disable CASCADE modeling visualization screen to shorten processing time.
- Enhanced customization of output graphs.
- Modeling of Natural Gas and Hydrogen vehicle fuelling stations (Pure Methane option is no longer available)

- **Version 2.0**

CASCADE version 2.0 operates in Microsoft Windows 32 bit environments (Win 95 to Win XP). It has easy to understand and user-friendly graphical interfaces. It also features a new enhanced reporting feature. The user can generate two reports (summary and detailed) and can chart changes in ground storage bank pressure or capacity over time.

User can now simulate hydrogen and pure methane refueling station in addition to natural gas available in previous versions of the software. Properties tables for natural gas, methane,

and hydrogen are imbedded in the program that have been generated by the NIST program STRAPP.

Temperature compensation was added to the ground storage model to reflect actual storage capacity at different temperatures.  Similarly, vehicle storage temperature compensation (dome load valve dispenser control) was added to the model to allow proper calculation of full fill pressure at various ambient conditions.

Other features added to version 2.0 are user abilities to save the input and/or output the program data/configuration for later retrieval. Users can open the saved input file to run the simulation or open the saved result file and directly view the results in the reports and charts. Both English and metric engineering units are provided to let users easily to input the values based on their needs.

- **Version 1.4**

The features added to version 1.4 (1.3 was an internal intermediate version) include the ability to simulate lift truck operation (filling methodology includes direct compressor to vehicle operation), to specify the maximum operating pressure and volume for each of the cascade banks individually, to optionally exit from the program anywhere along the input screen or simulation, to specify the equivalency ratio of natural gas to gasoline, to specify the minimum pressure difference for an acceptable flow rate between cascade banks and vehicles, and to allow for compressor operation only during recharging.

- **Version 1.2**

The feature added to version 1.2 was a graphical display of the interaction of the compressor and vehicles with the storage banks.  It presents a clearer picture than was possible with the listing of compressor and vehicle switching times.

- **Version 1.1**

The minimum amount of natural gas left in the vehicle tank is determined based on a minimum operating pressure of 50 psig.  Previously, the program simulated that the vehicle could draw the entire stored amount from the vessel.

The program based some of its calculations on an exhausted vehicle state.  All calculations now assume that every vehicle in the fleet is refueled at the end of each operating day.  Specifically, this changes the total daily demand and average required flow per shift.

The ability to specify dual natural operation was added in this version.  This allows the user to have the simulated vehicle use the available natural gas in the vehicle's storage (down to the 50 psig minimum) and still be able to return to the station.  The distance that can be traveled with natural gas is reported for those conditions where the total route mileage could not be met using only natural gas.

Another new function is the help key, **<F1>**.  By pressing **<F1>** when the notice about help being available is shown, the user can display a window adjacent to the field that the cursor is in containing a detailed description of the item whose value is to be entered.