COMPRESSED HYDROGEN INFRASTRUCTURE PROGRAM (“CH_2IP”)

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1. PROJECT GOALS

Vancouver is a centre of excellence for clean transportation technology. To support the introduction of hydrogen powered vehicles into the market place, industry is continuing to develop lightweight, on-board hydrogen storage systems. Development of cost effective and safe infrastructure for fueling hydrogen vehicles is of equal importance. The goal of the Compressed Hydrogen Infrastructure Program (CH_2IP) is to demonstrate the technical feasibility of hydrogen infrastructures for both transportation and power generation markets. Along with the Provincial government of British Columbia (B.C.) and the Federal Government of Canada, a number of companies from industry have participated in funding this program. These companies include BC Hydro, Dynetek, Stuart Energy, BP, Shell Hydrogen, ChevronTexaco, BOC, and JFE Container. This program managed by Powertech is demonstrating a number of important advances to promote the use of compressed hydrogen as a fuel for vehicles including:

- Fast filling hydrogen vehicles at 35 MPa (350 bar/5,000 psi);
- Demonstrating lightweight mobile trailers for transporting hydrogen;
- Fast filling vehicle storage systems to 70 MPa (700 bar/10,000 psi);
- Demonstrating a hydrogen generator / compressor package;
- Supporting testing of prototype 70 MPa vehicle storage systems;
- Providing data to produce safety standards for hydrogen fueling stations.

2. GENERAL DESCRIPTION OF PROJECT

The Compressed Hydrogen Infrastructure Program (CH_2IP) is a multi-year program initiated in 2001 to demonstrate the technical feasibility of hydrogen infrastructures for both transportation and power generation markets. Through this demonstration program, CH_2IP will provide data for the standardization, construction and operation of high-pressure hydrogen fueling stations, and will provide a basis for the commercialization of hydrogen fueling station infrastructure. Through its successful development, demonstration of technology, and its wide base of participants, the program will help to increase public awareness and acceptance of hydrogen as a safe, sustainable and viable fuel.

The project consists of the design and construction of a hydrogen production and dispensing facility at Powertech Labs in Surrey, B.C. The project will demonstrate the technical and commercial feasibility of high-pressure gaseous hydrogen storage for fuel cell vehicle applications. Hydrogen for the project is produced by electrolysis from renewable sources. Together with BC Hydro, Powertech Labs and external participants the project will identify the risks and logistics associated with the production and distribution of hydrogen. Unique experience will be gained with the operation of a fueling station at high pressures, keeping the project participants at the forefront of hydrogen fuel cell vehicle infrastructure development.

To facilitate the undertaking of this project, it was structured into three separate and distinct phases, comprising the following stages:

2.1 Stage I – 35 MPa (350 bar) Station

This initial phase consisted of the construction of a 350 bar fueling station using an electrolyser manufactured by Stuart Energy Systems. The on-site electrolyser produces approximately 24 kg of hydrogen per day based on 24-hour operation. The electrolyser also contains 2 small compressors that provide hydrogen at 350 bar. The compressed hydrogen is stored in 350 bar lightweight, aluminum-lined, carbon-fiber-reinforced cylinders (174 liters water volume each), which are manufactured by Dynetek Industries Ltd. The hydrogen is dispensed through a 350 bar dual hose hydrogen / compressed natural gas (CNG) dispenser supplied by Fueling Technologies Inc. The 350 bar station was completed in January, 2002.

2.2 Stage II – 70 MPa (700 bar) Station

The second stage of the program consisted of upgrading the existing 350 bar fueling station to dispense hydrogen at 700 bar (10,000 psi). Testing of 875 bar (12,500 psi) storage cylinders from Dynetek Industries Ltd. was completed as part of this stage. A diaphragm compressor was installed to compress the 350 bar hydrogen storage to 875 bar. The 875 bar upgrade was completed by June, 2003.

2.3 Stage III – Satellite Station

The third stage of the program consisted of the construction of a 700 bar hydrogen satellite station is to demonstrate a low-cost method of establishing hydrogen station infrastructures. The satellite station will demonstrate the concept of generating hydrogen at a central facility and transporting it to supply a remote fuel station location. The concept is not much different from existing liquid petroleum fueling stations, where the liquid fuel is transported by truck. The hydrogen will be transported in a high-pressure ISO container unit mounted on a trailer. The container unit consists of lightweight carbon fiber wrapped cylinders rated for 875 bar service. A small booster compressor is used to transfer compressed hydrogen between the cylinders to maintain a high pressure for fast filling operations. The container unit is parked at the satellite site within the Powertech compound and is connected to a fueling dispenser permanently mounted on a fuel island.

The satellite station was built, tested and commissioned as of December, 2004. Discussions with several automotive OEMs regarding the deployment of their prototype 700 bar vehicles are currently underway.

3. DESCRIPTION OF COMPONENTS

3.1 Stage 1 – 35 MPa (350 bar) Station

In order to supply a pressure of 350 bar to the vehicles from the dispenser, the filling station was design to compress and store hydrogen at 438 bar (1.25 time the service pressure).

3.1.1 Station layout

Station facilities installed include:

- Civil design and installation work
- Electrical installations
- Installation of an electrolyser and compression system
- Installation of a 438 bar hydrogen storage bank
- Installation of a 250 bar natural gas compressor
- Mechanical connections for high pressure piping for all the components.

The schematic layout diagram of the station is shown in Figure 1.

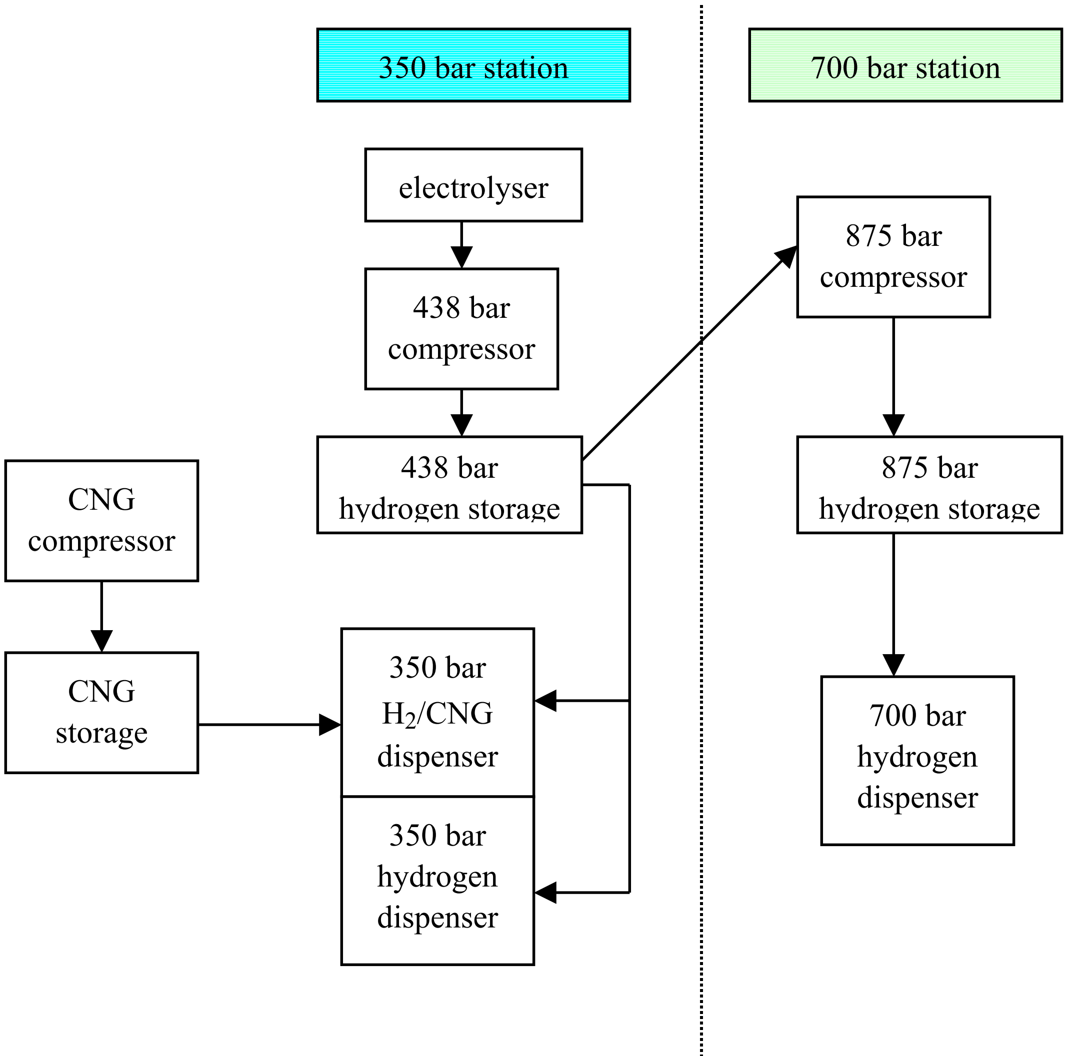

Figure 1: Station layout diagram

3.1.2 Electrolyser

An essential aspect of the CH_2IP fueling station has been to demonstrate the on-site production of hydrogen gas. As part of their contribution to the project, Stuart Energy supplied a prototype "CF-400 Community Fueler" for the program. This system involves the packaging of an electrolyser and compression equipment to generate hydrogen at a pressure of 438 bar. The hydrogen and oxygen generated by the electrolyser are kept separated after the electrolytic reaction by highly efficient inorganic membranes, and are then channeled to separate hydrogen and oxygen outlets.

The prototype unit supplied by Stuart is shown in Figure 2. It has operated for over 10,000 hours in service to support hydrogen vehicles, and the testing needs for the CH_2IP program. Being a prototype unit, there were a number of design and maintenance issues that had to be resolved during the course of the program. Powertech worked closely with Stuart to resolve these issues. As a result, a number of design changes were instituted into newer models of the electrolyser.

Figure 2: Prototype electrolyser used for the CH_2IP program. The package also included 2 small compressors and the equipment needed for hydrogen purification

3.1.3 438 bar Compressors

The 438 bar hydrogen compression system is integrated into the electrolyser package. There are two compressors that are four stage air-cooled, oil-lubricated piston type reciprocating compressors. The compressor motors are 7.5 kW (10 hp), 480 V, 3 phases, 60 Hz, 1800 rpm motors.

3.1.4 438 bar Station storage

The 438 bar hydrogen storage unit consisted of aluminum lined carbon fiber wrapped cylinders (Type 3) supplied by Dynetek. Figure 3 shows the 438 bar hydrogen storage manifolded into stackable steel racks. The storage capacity can be easily increased by stacking more cylinder racks.

Figure 3: 438 bar hydrogen station storage bank consisting of carbon fibre composite cylinders. The storage bank allows the vehicles to be fast filled with hydrogen

3.1.5 Mechanical piping

Mechanical piping for the hydrogen station was designed to CSA B51-03, Part 1 (Boiler, Pressure & Piping Code). Calculations were also made to ensure proper flow capacities to the dispenser. Since there are no existing codes available for hydrogen stations, Powertech has been working with the Gas Safety Branch of British Columbia to review the station design. The requirements of the codes for natural gas vehicle stations were used as a basis for the design and construction of the station.

Figure 4: ICE vehicles converted to operate on a combined CNG and hydrogen fuel (Truck: Ford F150 / Passenger vehicle: Ford Crown Victoria)

3.1.6 Hydrogen and hydrogen/CNG blend dispenser

Fueling Technologies Inc. (FTI) manufactured the hydrogen/CNG dispenser shown in Figure 4. This dispenser has two filling nozzles, one supplying 100% hydrogen at 350 bar, and the second supplying a blend of 50% hydrogen and 50% CNG at 350 bar.

3.1.7 Vehicles

Three internal combustion engine (ICE) vehicles were purchased for the project to provide a load for the 350 bar hydrogen station until fuel cell vehicles become available. These dedicated CNG vehicles were converted to run on a 50/50 blend of natural gas and hydrogen. The engines and control systems were modified to operate efficiently with the hydrogen blend. The 200 bar on-board fuel storage systems were replaced with 350 bar hydrogen/CNG storage systems.

3.2 70 MPa (700 bar) Hydrogen Station Upgrade

In order to supply a pressure of 700 bar to the vehicles from the dispenser, the filling station was design to compress and store hydrogen at 875 bar (1.25 time the service pressure).

3.2.1 Station layout

The civil design and mechanical installation has been completed for the 700 bar station upgrade.

3.2.2 875 bar Components

Powertech worked with a number of suppliers worldwide to provide components for the hydrogen station capable of withstanding pressures of 875 bar. In many cases, prototype parts were supplied for the project. These parts were all tested in Powertech’s high pressure testing facilities prior to their installation in the station. These parts include tubing, fittings, valves, regulators, relief valves, PRDs, hoses, nozzles.

Figure 5: The PPI Diaphragm compressor, cooling system, and purification system were housed in a container package by IMW Industries. Attached in the container is a compartment where the controls and data acquisition systems were installed.

3.2.3 875 bar Compressor

A diaphragm compressor with a capacity of 0.71 m^3/min (25 scfm) and capable of pressurizing the storage banks to 875 bar was purchased from Pressure Products Industries. Powertech performed design of the pressure piping, the cooling system, the control logic, and the purification system. IMW Industries was contracted to package the compressor, shown in Figure 5.

Figure 6: Stationary storage – 875 bar carbon composite cylinders. Steel cylinders of equivalent capacity would be approximately 3 times the weight of the composite cylinders.

Figure 7: Manual 700 bar dispenser. All the components including valves, nozzles, and hoses were rated to operate at 875 bar and were tested at Powertech prior to installation

3.2.4 875 bar Station storage

Dynetek Industries supplied prototype cylinders (Figure 6) rated to 875 bar to this project. Testing of the cylinders was performed at Powertech to ensure the safety requirements were met.

3.2.5 700 bar Hydrogen dispenser

A manually operated dispenser was fabricated at Powertech to dispense hydrogen at 700 bar. It is shown in Figure 7. A number of prototype 700 bar parts were tested at Powertech including fittings, valves, nozzles, breakaway devices, and hoses.

FTI has developed an automated 700 bar dispenser to be tested at Powertech in September, 2004.

3.3 70 MPa (700 bar) Satellite Station

The satellite station will demonstrate the concept of generating hydrogen at a central facility and transporting it to supply a remote fuel station location. The hydrogen will be transported in a high-pressure ISO container unit mounted on a trailer. The container unit will consist of lightweight carbon fiber wrapped cylinders rated for 875 bar service. A small booster compressor will be used to transfer compressed hydrogen between the cylinders to maintain a high pressure for fast filling operations. The container unit will be parked at the satellite site within the Powertech compound and will be connected to a fueling dispenser permanently mounted on a fuel island.

3.3.1 Construction of trailer compound

The civil design work for the satellite station has been completed.

3.3.2 250 bar Mobile trailer

A 250 bar mobile trailer was constructed to demonstrate the effectiveness of lightweight composite cylinders to transport compressed hydrogen. The storage tanks used in the compressed hydrogen transportable container units are lightweight designs manufactured by Dynetek Industries. The tanks consist of a thin (3 mm) seamless aluminum liner reinforced with a carbon fiber composite wrap. The thickness of the carbon fiber reinforcement depends on the working pressure of the design. The transportable container trailers manufactured by Powertech are designed to be hauled by a light-duty pick-up truck. The weight of the trailer unit was therefore limited to less than 4,500 kg. To achieve the weight limit, while maximizing the volume of stored hydrogen, Dynetek model W290 tanks (290 liters water volume) were used, measuring 416 mm in diameter and 2,880 mm in length. For a 250 bar design, the weight of each tank is 121 kg. The trailer unit has 16 tanks mounted in a reinforced steel framework. For a service pressure of 250 bar the lightweight trailer unit has a volume of 1,220 m^3 and contains 80 kg of hydrogen. The trailer is less than 6 m long and 2.5 m wide. In comparison, a typical steel tube trailer design with a volume of 2, 678 m^3 and a service pressure of 165 bar will contain 237 kg of hydrogen. The steel tube trailer vehicle has a gross weight of approximately 36,000 kg.

Testing of the Dynetek cylinder design was performed at Powertech in order to obtain approval from Transport Canada to use the trailer for transporting hydrogen. Figure 8 shows the trailer being used as a mobile fueling station at a fuel cell car rally from Los Angeles to Las Vegas.

3.3.3 875 bar Mobile trailer

The design of the 875 mobile trailer has been completed. The hydrogen storage will be mobile, as it will be placed in a 6 m long ISO container. A stationary dispenser and booster compressor will be located at the satellite station site. This system shown in Figure 8 will demonstrate hydrogen delivery to a satellite station from a central hydrogen generating facility.

Figure 8: Demonstration of the hydrogen mobile fueling station. This unit supported fueling of fuel cell vehicles during a road rally from Riverside, California to Las Vegas, Nevada in 2001.

The storage rack will consist of lightweight, carbon-fiber-wrapped, aluminum-lined cylinders at a pressure of 875 bar. The cylinders will be divided into three banks consisting of low, medium, and high bank. An ISO container full of these hydrogen storage racks could store close to 300 kg of hydrogen.

The compressor selected as a booster is a piston-type reciprocating compressor; however it contains full-length isolation spacers to prevent gas contamination by the oil. This compressor allows suction pressures of up to 875 bar to optimize the storage utilization. The compressor will priority-fill from the high bank, followed by the medium bank and finally from the low bank. Once hydrogen in the low bank is depleted, the compressor will fill the high bank using hydrogen from medium bank. This method will always keep the high bank at its maximum pressure to allow for more complete vehicle fills.

A prototype 700 bar dispenser will provide 3-bank sequencing and electronic mass fill control using a smart algorithm. The flow meter used for mass flow measurement will be a Coriolis type meter.

4. DATA ACQUISITION AND INSTRUMENTATION

Data on the operation of the different equipment have been valuable to assess their performance and maintenance requirements. In particular, a number of durability issues with new components were discovered during the course of everyday operation. In many cases, these issues were related back to the manufacturer for re-design consideration.

Filling data have been collected on a number of hydrogen fuel storage systems from different cylinder manufacturers. The test systems were instrumented with pressure sensors and thermocouples to study the effects of fast filling at varying ambient temperatures.

Data collection has occurred on many aspects of the system, such as hydrogen generation, compression, and storage. Instrumentation of key components in the station has been set up to provide on-going collection of data from refueling equipment and vehicles. The data are collected on two computers located in the control room of the 875 bar compressor.

Continuous data collection included:

- data from 875 bar compressor PLC
- 438 bar storage bank pressure and temperature
- 875 bar storage bank pressure and temperature
- key data from the electrolyser
- power meter data from 875 bar compressor

The following data will be collected during filling of the vehicles:

- 350 bar dispenser
    - flow measurements from 2 flow meters
    - pressure measurements from 2 pressure transducers
    - temperature measurements from 2 thermocouples
- 700 bar dispenser
    - pressure measurements from 1 pressure transducer
    - temperature measurements from 1 thermocouple
    - flow meter measurements
    - mass of cylinder being tested

The system can also connect external temperature and pressure inputs from the test vehicles.

5. SAFETY

Powertech's engineering staff performed extensive safety reviews of the hydrogen filling facilities with input from external expertise in the area of compressed gas stations. Since there are currently no standards covering hydrogen filling stations, the design closely conformed to standards developed for compressed natural gas filling stations. Powertech also contacted the Gas Safety Branch of British Columbia to review the station design. They have registered the design using the natural gas installation code with the necessary changes for hydrogen. Information from this demonstration project will be used to support new standards for hydrogen installations.

5.1 HAZOP Analysis

A Hazard and Operability Study (HAZOP) involves systematically questioning every part of the process to establish how deviations from the design intent can arise. The deviation and its consequence are rated based on the severity of the deviation and the frequency of it. If necessary, action is taken to remedy the situation. Powertech Labs examined three different processes in a HAZOP, a 350 bar hydrogen fuelling station, a 700 bar hydrogen fuelling station and an 875 bar hydrogen compressor.

5.2 Emergency Response Plan

The primary purpose of the Emergency Response Plan for the hydrogen and CNG storage and dispensing facility at Powertech is to provide a course of action to follow should an emergency event occur on site or in the surrounding retail business or community area. The plan outlines the procedures and personnel responsible for executing the plan.

Figure 9: Visit of the Ford Fuel Cell Vehicle to the CH_2IP station for demonstration purposes.

A production vehicle (Ford Focus FCV) will be based at Powertech starting in April, 2005. This vehicle will be a part of a fleet of 5 vehicles operating in the Vancouver area.

6. COMMUNICATIONS

The key objectives of the communications and education plan are to:

- communicate the vision, goals, objectives, project participants and activities of the CH_2IP Program to stakeholders and the general public;
- build support for the construction of a hydrogen infrastructure; and
- familiarize stakeholders and the general public with hydrogen as a safe, clean transportation fuel.

Effective communications and education will serve to remove some of the uncertainty surrounding the technical and commercial feasibility of building a hydrogen infrastructure, thereby helping to accelerate the introduction of gaseous hydrogen-fuelled vehicles and their associated infrastructure.

7. CONCLUSIONS

The CH_2IP program is demonstrating a number of important advances to promote the use of compressed hydrogen as a fuel for vehicles. The CH_2IP station offers the unique option to dispense hydrogen at 35 MPa (350 bar) and 70 MPa (700 bar). In addition the satellite station project will demonstrate the use of a hydrogen trailer as a mobile fueling station for vehicles. The data collected from the design, installation, certification, and operation of the CH_2IP station are used to support the development of the Hydrogen Installation Codes. The CH_2IP industrial participants are being trained in every aspect of design, installation, and operation of the station. During the operation of the CH_2IP station, valuable data are collected on the cost of hydrogen generation, compressing hydrogen to 35 MPa and 70 MPa, and associated maintenance costs. Since there are no specific hydrogen fueling station standards available in Canada, Powertech is working with the provincial authorities to certify the CH_2IP station in British Columbia (Gas Safety Branch). In addition, Powertech is also working to inform the fire department and the municipal government to alleviate any specific concerns.

The CH_2IP program was completed in December, 2004. It is the intention of the project participants to publish data from the project and to share relevant results with various standard development organizations.

8. CONTACT INFORMATION

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