This article, which summarizes the essentials of the report, is primarily intended to:

• present the physical chemical, toxicological and environmental properties of gas R-410A;
• describe the use of gas R-410A in geothermal systems;
• analyze the behaviour of gas R-410A in case of an underground leak; and finally,
• evaluate the potential relative impacts of gas R-410A on the environment and on global warming, in particular by evaluating a CO\textsubscript{2} equivalence should it become dispersed in the air.

Description and Applications
Refrigerant gas R-410A was developed and patented by Honeywell. It is an azeotropic mixture of difluoromethane (CH\textsubscript{2}F\textsubscript{2}, HFC-32) and pentafluoroethane (CHF\textsubscript{2}CF\textsubscript{3}, HFC-125). The proportions of the two components are 50% each (half and half). This refrigerant mixture was developed as a substitute for R-22 (HCFC-22), which was targeted by the Montreal Protocol, and the use of which will be restricted in Canada starting in 2010 and prohibited starting in 2015.

Furthermore R-410A provides better energy efficiency in new air conditioning installations, condensers or for commercial refrigeration equipment, and a refrigerating power markedly higher than that of R-22. In new installations designed for R-410A, we noted an energy yield 5% to 6% higher than for R-22.

Since the pressure that can be reached is higher, the gas also enables the design of more compact air conditioners. Refrigerant gas R-410A can also be used as a substitute for other refrigerant gases, whether in condensers or for commercial refrigeration equipment, such as refrigerated vehicles or low temperature industrial refrigeration systems.

Physical-Chemical Properties
The principal physical chemical properties of refrigerant gas R-410A are presented in Table 1. Note firstly that refrigerant fluid R-410A is not inflammable under normal temperature and pressure conditions, and that its self ignition temperature (at which it catches fire spontaneously) is about 750°C. Next we note in particular that the boiling point is about 50°C at an atmospheric pressure of 101.3 kPa. So under normal temperature and pressure conditions, R-410A is in a gaseous state. Also, comparing the relative density of the gas to that of air, we note that the gas is about 3 times as dense as air. The gas thus has a tendency to remain confined at ground level.

Furthermore, R-410A is relatively insoluble in water, which means that in case of a leak neither the gas nor the liquid will mix with the surrounding groundwater. R-410A’s volatility is very high, which means that volatilization will occur rapidly and that all of the fluid will pass into a gaseous state.

Introduction
Several officials from municipal and provincial governments have approached the CGC in recent years to obtain clarifications concerning the use of refrigerant gas R410 A in the geothermal industry.

Requiring more complete technical information, the CGC retained the professional services of Hudon Desbiens St Germain Environnement inc. (HDS Environnement) in order to prepare a report\textsuperscript{1} presenting a summary of the environmental impacts associated with the use of gas R-410A in geothermal systems.

\textsuperscript{1} The conclusions and recommendations presented in this article are based on professional opinions expressed specifically in the context of the mandate awarded to HDS Environnement by the CGC. HDS Environnement assumes no responsibility for any use of this article in another context or by other parties unless it has been expressly informed in advance and unless it accepts such use. For more information on HDS Environnement, visit the Web site www.hdsenv.com. You can also contact HDS Environnement at (514) 398 0553 or by e-mail at info@hdsenv.com.

\textsuperscript{2} Said of a liquid mixture that boils at a fixed temperature while maintaining a fixed composition.
Note that R-410A’s half life in the atmosphere is relatively long (6 – 40 years), which means the gas will be persistent in the environment and take a long time to decompose.

Since the coefficient of octanol water partition is low (log $K_{ow} = 1.48$), there will be very little bio accumulation of the gas in the environment. The gas tends to move toward the air, soil or water, rather than being absorbed by organic material. However, the coefficient of soil water partition (log $K_{oc} = 1.05$ to 1.7) is also relatively low. So R-410A will not have a tendency to adsorb itself onto soil particles, but rather to move toward water or air.

### Significant Environmental and Health & Safety Data

With regard to depletion of the ozone layer, refrigerant gas R-410A has no effect, being free from chlorinated compounds. Its ozone depletion potential (ODP) is effectively considered nil. However, it presents a relatively high global warming potential (GWP) of 1,890 kg CO$_2$ eq. Given that under normal temperature and pressure conditions gas R-410A is stable (Honeywell, 2007), it will have a strong tendency to volatilize once in the environment. However, it is composed of products that could contribute to global warming, and the consequences of a leak on the environment are discussed in Section 5.

Also, the relative densities of the gases being greater than that of air, they will have a tendency to remain along the ground until dissipated by air currents.

Sub-products of the decomposition of R-410A in the environment could be fluoride compounds that would be likely to slightly contaminate the groundwater or the surrounding soil. The criteria established by the Ministère du Développement durable, de l’Environnement et des Parcs du Québec (MDDEP) for total fluorides are 1,500 µg/l in drinking water and 4,000 µg/l in groundwater. In soils, the MDDEP has defined criteria A, B and C (representing respectively the background concentration, the concentration admissible for residential use and that admissible for industrial use) of 200, 400 and 2,000 mg/kg.

Finally, toxicological tests were conducted on rats and dogs to evaluate the toxicity of the two components of R-410A. In case of acute inhalation, the respective lethal concentrations for R-125 and R-32 on rats are 800,000 ppm and 520,000 ppm. In case of chronic exposure, inhalation of R-410A can cause cardiac problems. In case of contact, irritation of the eyes and skin can also occur, as well as rapid freezing of skin surfaces.

### Use of Gas R-410A in Geothermal Systems

In geothermal systems, refrigerant gas R-410A is used in heating and air conditioning systems as a coolant. R-410A is progressively replacing the coolant R-22, which is more harmful to the environment with respect to destruction of the ozone layer and global warming.
In direct expansion geothermal systems, R-410A is contained within copper tubes that form loops between the building to be heated or air conditioned and the ground which serves as a heat source (for heating) or heat sink (for air conditioning). Heat exchanges between the coolant and the ground, which in certain conditions remains at the same temperature of about 9°C all year, allow the building to be heated or cooled.

In each installation, a compressor is connected to one or more conduits in the form of a loop containing R-410A. The loops are installed either at the surface or underground. Generally speaking, underground loops can be shorter, but drilling costs are higher. The number of loops depends on the power of the compressor. In this report, we consider only underground loops to ensure treatment of potential leaks both on the surface and underground.

In the case of underground installations, for every 3.5 kWh of the compressor, a loop 30.5 m in depth is installed. The two branches of the loop do not have the same diameter, and each serves as a conduit for R-410A in either its gaseous or its liquid state. A reducer is installed at the end of the loop to ensure transformation of the gas into a liquid or the liquid into a gas.

For a typical system, a 7 kWh compressor (normal heating and air conditioning for a residence of 100 m² of floor space) requires two loops installed to a depth of about 30.5 m. If we consider that the diameter of the conduits for the gas half of the loop is 19.05 mm and that the diameter of the conduits for the liquid half is 9.52 mm, we obtain a total conduit volume of about 19.2 liters of gas and about 4.8 liters of liquid. In total, the volume of the refrigerant fluid is thus about 24 liters.

Here we consider a compressor with two loops, since if the number of loops is increased, the power of the compressor will increase equally. So for purposes of a comparison, which we develop in the following section, we must compare the compressor to a more powerful traditional system. In any case, the results would be proportional and the conclusions similar.

**Behaviour in Case of Leakage**

Two leakage scenarios were evaluated, one underground and one on the surface. In both cases, the pressure and temperature conditions would cause the R-410A that escapes from the system to be in its gaseous form.

For purposes of this article, the following hypotheses are proposed for the two scenarios:

- a 7 kWh generator requires two underground loops;
- the loops are inserted to a depth of 30.5 m;
- each “half loop” is used either for the gas or for the liquid;
- the diameters of the conduits for the gas and the liquid are respectively 19.05 mm and 9.52 mm;
- the total lengths of the conduits for the liquid and the gas are equal, measuring about 67.4 m.

The volumes of gas and liquid thus measure respectively about 19.2 liters and 4.8 liters, for a total volume of R-410A of about 24 liters. Two scenarios will be studied, one in which a leak occurs underground and one in which a leak occurs on the surface (see Figure 1).

**Scenario 1: Underground Leak**

When a leak occurs underground, we may presume that all of the R-410A fluid ends up in the environment. If the temperature and pressure conditions are close to the standard values, refrigerant fluid R-410A will be found primarily in its gaseous form. So it is necessary to convert the 4.8 liters of liquid into a volume of gas.

Considering a liquid density of 1,080 kg/m³, a molar mass of 72.6 g/mol and a molar volume of 22.4 l/mol (similar to a perfect gas), this enables us to convert the total liquid volume in order to determine the gaseous equivalent. So the 4.8 liters would volatilize into approximately 1.6 m³ of gas. Added to the 0.02 m³ of original gas, this represents about 1.62 m³ of gaseous R-410A in the environment, which is less than the volume of a garbage bin, for example.

Note that the relative density of R-410A, like the relative densities of its two components, is greater than that of air. So R-410A should remain confined within the ground. Since R-410A is not very soluble in water, only a very low quantity will be dissolved into the groundwater. If it should rise to the surface, gas R-410A will remain primarily confined at ground level. Air movements will then likely dissipate it.

The main leaks that could occur are at the distributor connecting the loops to the network. The distributor is usually placed at a depth of 3 feet (0.9 meters). A leak at this depth would probably lead to an underground degassing that would rapidly be found in the ambient air at the surface. Leaks are also likely to occur at the reducer, at the bottom of the underground loops.

If the gas remains confined in the ground it will decompose very slowly, since the half lives of R-410A and its components are of several years. It should remain in its gaseous form given that at the temperatures and pressures found in the ground, it cannot liquefy. Decomposition of R-410A can lead to the formation of fluoride compounds that are likely to dissolve into the groundwater and to adsorb onto particles of soil and organic material, without, however, significantly contaminating them.

**Scenario 2: Surface Leak**

Leaks at the surface can also occur, in particular during installation of the conduits, which are filled prior to installation for underground loops. As in Scenario 1, a leak in the conduits would lead to a maximum loss of 1.62 m³ of gas R-410A.

However, in this case the gas would be already at the surface, and would be found at ground level since its density is greater than that of air. Outdoors this should not be a problem since the gas will likely be dissipated quite rapidly. However if the leak occurs in a confined room, the gas, which is heavier than air, can expel the ambient air, reducing the oxygen concentration in the room. The location would therefore no longer be accessible to users, and would have to be ventilated before any other use.
Note that the gas has no colour, but has a weak odour. This risk of asphyxiation should be the principal concern following a leak of R-410A, given that the gas is not inflammable. However, considering the toxicity of the components of R-410A, the American Industrial Hygiene Association has prescribed an exposure limit for R-410A and its components of 1,000 ppm over eight (8) hours. Under a hypothesis in which all of the fluid is expelled from the system, this concentration could be achieved relatively quickly in a room of small volume depending on the flow rate of the leak. While this is a workplace concentration limit, it would be possible to evacuate the lightly scented gas present in a dwelling within far less than eight (8) hours simply by airing out the room.

Greenhouse Gas Emissions
Direct expansion geothermal systems, like glycol systems, represent good alternatives to conventional heating and air conditioning installations since they use the geothermal energy contained in the earth and in groundwater to heat or cool a dwelling. In this section, a direct expansion system is compared, from an environmental point of view, to a traditional heating and air conditioning system. The approximations are made only comparatively for purposes of this report, and are not absolute.

Consider that, in order to work, a traditional system requires input power about ten (10) times higher than that of a direct expansion system. So if the power of a 2 ton direct expansion system is about 1,700 W, that of an equivalent traditional system is about 17,000 W.

Over a period of one year (365 days), used at the rate of about 12 hours per day, this corresponds to energy consumed of approximately 7,500 kWh for the direct expansion system and 75,000 kWh for the traditional system.

Considering that the energy used in Quebec is primarily from hydroelectricity, the carbon dioxide equivalence is about 5 g of CO₂ per kWh. So a direct expansion system would be equivalent to about 37 kg CO₂ eq. per year and the traditional system to 375 kg CO₂ eq. per year.

If a leak occurs in a direct expansion system, gas R-410A could escape. This leakage can also be quantified in terms of CO₂ equivalent. Basically, a kilogram of R-410A is equivalent to about 1,890 kg CO₂ eq. If we consider that of all the R-410A contained in the system only one quarter is likely to be discharged into the environment, this represents, from the original 1.62 m³, about 0.4 m³. Converting this volume to mass, we obtain a leak of about 1.3 kg. So a leak of one quarter of a direct expansion system into the environment represents about 2,450 kg CO₂ eq.

So if we consider the extreme scenario of one leak per year, the direct expansion system represents a greater potential for global warming (about 2,487 kg CO₂ eq. compared to 375 kg CO₂ eq. for the traditional system). However, this situation is greatly exaggerated, and we note that for a scenario of one leak every 7 or 8 years, the two systems are relatively equivalent. Beyond that limit, that is, considering less than one leak every eight years, the direct expansion system becomes more advantageous with respect to greenhouse gas emissions than the traditional system. Furthermore, the risk of a coolant leak present in traditional systems has been ignored in this calculation.

Other Potential Environmental Impacts
The principal environmental impact of R-410A is thus potentially an increase in global warming as a greenhouse gas. The other impacts should be minimal, in particular because the quantities involved are relatively low and the gas is not very soluble in water and not very bio accessible (low log KOW).
In case of an underground leak, fluoride compounds might be found in the groundwater, and much less significantly in the soil. However, the quantities involved should mean that concentrations of fluorine in the water remain relatively low. In gaseous form R-410A is very stable and should not degrade unless subjected to extreme pressure or temperature conditions. Its half life varies between 6 and 40 years.

So if we estimate that 80% of the gas (1.62 m³) degrades into fluoride compounds, and that this degradation takes place at a rate of about 0.02% per day (7.3% per year), it means that every day about 0.026 m³ of gas could dissolve into the groundwater. Assuming that these compounds are only of fluorine, with a molar volume of about 22.4 l/mol and a molar mass of 19 g/mol, this represents about 22 g of fluorine. To reach the threshold concentration specified by the MDDEP in drinking water (1,500 µg/l), the groundwater would have to have a maximum water volume of about 15,000 l, which is 15 m³. Considering a porosity of 25%, this represents a total volume for the groundwater (water and soil) of about 60 m³, or 5 m x 4 m x 3 m. For purposes of comparison, groundwater is considered as having a “high aquifer potential” if it can permanently tapped from the same well at the rate of 25 m³ per hour. So groundwater containing 15 m³ of water is of relatively small dimensions.

These hypotheses are, however, very conservative and show that an underground leak of R-410A would likely cause little problem, especially since R-410A is noted for being very stable. Decomposition should therefore take a very long time to occur, and the concentrations in groundwater should never reach the established limits.

**Conclusions**

Use of the refrigerant gas R-410A in heating and air conditioning installations seems to be an excellent alternative compared to other coolant gases currently used in the industry. The gas is not very harmful to the environment, in particular because its potential to deplete the ozone layer is nil. It is also stable under normal temperature and pressure conditions. So in case of a leak, R-410A would be strictly gaseous. In case of an underground leak, it would remain confined in a pocket in the ground and degrade slowly. In the case of a surface leak, it would remain confined at ground level and would be rapidly dissipated by air currents. A leak in a room of a house represents the only problem case, where the R-410A, colourless and with little odour, could take the place of air and make the location unbreathable to users. However, the gas is not inflammable and could be evacuated from the room rapidly.

In order to prevent the risk of personal accidents, these systems should be installed in locations that can be easily ventilated. Also, precautions should be taken during placement of the conduits in order to avoid gas leaks during installations. Finally, the geochemical characteristics of soils and of groundwater could be verified in order to ensure that the risk of corrosion at the distributor is minimal. Note that the conduits are protected either by insulation (in the case of conduits between the dwelling and the distributor) or by sand and bentonite (in the case of underground loops) and should not be unduly subjected to corrosion.

However, given its relatively high potential as a greenhouse gas, it is important to compare a system using R-410A to a traditional system. A macroscopic comparison has shown that the two systems are similar with regard to CO₂ equivalence if we consider a scenario in which a leak occurs on average every eight years and in which about one quarter of the fluid contents ends up in the environment. This scenario is conservative, and in the more realistic scenario of less than one leak occurring every eight years, the direct expansion system becomes more advantageous with regard to greenhouse gas emissions than the traditional system.

Finally, in order to be able to pronounce definitively on the environment efficiency of gas R-410A, it would be necessary to compare it in more detail to the other gases currently used in the industry. By comparing their advantages and disadvantages, including their global warming potential, we could pronounce which is the best coolant gas to use. Comparison of the life cycle analyses for various traditional heating & air conditioning systems and those using geothermal energy would justify the implementation of new mechanisms. Modeling of the transportation of refrigerant gases would enable us to know precisely what becomes of them in the environment. And finally, in order to limit the risk of leaks and to be aware of consequences, the people using refrigerant gases could take training sessions adapted to their needs.

The French article can be found in the Spring/Summer 2009 edition of GeoConneXion Magazine.