Industrial Applications for Generated Nitrogen Gas at Honda

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As a responsible corporate neighbor and partner, decisions made within Honda of America Manufacturing Inc. ("Honda") affect not only the local community but have far-reaching ramifications both nationally and internationally. Nowhere is this more evident than in finding innovative and environmentally responsible solutions to the day-to-day operational needs within its factories. The use of generated nitrogen gas is an example of this philosophy in action.

Fig. 1. V-6 Earth Dreams Technology™ engines *(courtesy of Honda of America)*

What began as a handshake between Soichiro Honda and then Ohio Governor James Rhodes in 1977 has grown into an Ohio operation of global stature and influence, a creative worldwide leader responsible for the launch of Honda models throughout the world.

Even before the first U.S.-made Honda Accord rolled off the assembly line at Honda's Marysville, Ohio, manufacturing plant in November 1982, Honda has had an unwavering commitment to supporting the U.S. manufacturing community. What began as a dream to do great things has become a reality through hard work and the dedication of a motivated group of associates. Over the years, the quality of the products produced and the unstoppable spirit of the highly skilled Ohio associates have allowed Honda to continually set new standards of engineering excellence. Today, the manufacturing operations include 11 state-of-the-art plants in six Ohio communities, employing more than 13,700 people and contributing millions of dollars to the Ohio economy every year.

Honda Corporate Philosophy

Honda operations are large and always changing. At the heart of this change is its core philosophy of continuous process improvements. Processes are constantly being evaluated for enhancements that can improve quality, line efficiency and/or reduce cost in order to produce more value to the customer. The introduction of a nitrogen generator into the manufacturing of engine components is a prime example of these types of process improvements. This technology is now being used at the Anna Engine Plant (AEP), where Honda produces the next generation of fuel-efficient engines to greatly reduce the environmental impact of their vehicles (Fig. 1).

Honda's philosophy is at the heart of each manufacturing facility, where conservation of resources such as electricity to power air compressors is a focal point. To manage this resource, Honda has a system in place to ensure that only the right pressure at the right time is delivered where and when it is needed. Furthermore, ultrasound technologies identify leaks, speed the repair process and eliminate waste/discharge to the environment.

Introduction to the Anna Engine Plant (AEP)

The Anna Engine Plant manufactures many of the components that go into the engines that are assembled in Ohio (Fig. 2). The ferrous manufacturing department (FMD) manufactures the cylinder sleeves, connecting rods, balancers, camshafts and crankshafts to support engine production. In addition, a drivetrain-manufacturing department (DMD) was added, which produces pulleys for continuously variable transmissions (CVT). Processes to produce these items include melting, casting, machining and heat treatment.

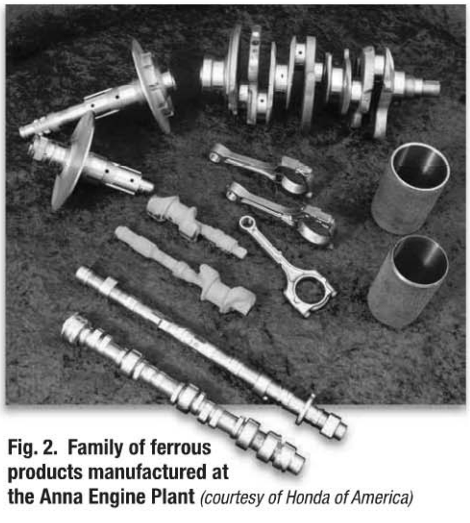

Fig. 2. Family of ferrous products manufactured at the Anna Engine Plant *(courtesy of Honda of America)*

Honda's Nitrogen Project

As part of the company's philosophy of environmental responsibility and process improvement, a review of the applicability and usage of nitrogen at AEP was undertaken. The review was broken down into five steps, namely:

1. An analysis of the need for industrial nitrogen – Why is it necessary and what are industrial uses for it?
2. An analysis of the existing nitrogen system – its relevance for various processes being performed at Honda's AEP plant. This included both an evaluation of the internal users (including any future users) and an assessment of the requirements of each user. This led to the development of a project specification.
3. An investigation of technologies available for nitrogen users.
4. The selection of a nitrogen generator system.
5. The development of a business case for changes to the existing nitrogen system. This included a review of the changes that were implemented to confirm the savings were real.

Step #1: Analysis of the Need for Industrial Nitrogen

Why nitrogen?

Nitrogen is the most common purging, blanketing and process gas used in the heat-treatment industry today, with the possible exception of air, and is considered to be "inert" to most materials. (Note: Nitrogen can be reactive under certain conditions to certain alloys containing chromium, molybdenum, titanium and niobium.)

The principal reason for nitrogen's popularity is cost. What is important to remember is that nitrogen is nonreactive with air or oxygen present in or entering the furnace. As such, nitrogen must "push" oxygen molecules out of the furnace rather than react with them. Furnace pressure and atmosphere flow as well as the tightness of the furnace or oven become important considerations when attempting to run clean or "bright" work.

Nitrogen makes up 78.03% of air (by volume), has a gaseous specific gravity of 0.967 and a boiling point of -195°C (-320.5°F) at atmospheric pressure. It is colorless, odorless and tasteless. Commercially, nitrogen is produced by a variety of air-separation processes, including cryogenic liquefaction and distillation, adsorption separation and membrane separation. Nitrogen supplied from nitrogen generators uses either membrane or adsorption technology.

Step #2: Analysis of Existing Nitrogen Systems at AEP

Current N_2 System

Nitrogen for AEP with a purity of 99.9999% was being delivered from an 18,000-gallon liquid tank. The annual usage was 72,000,000 cubic feet. The monthly demand exceeded the capacity of the vaporizer, which was 4,500,000 scf/month. This resulted in the need to "de-ice" the vaporizer in winter months. The tank was filled three times a week with delivery charges for each fill. The total cost of the liquid-nitrogen system including tank rentals, HAZMAT charges, delivery fees and cost of liquid nitrogen exceeded $250,000/annually.

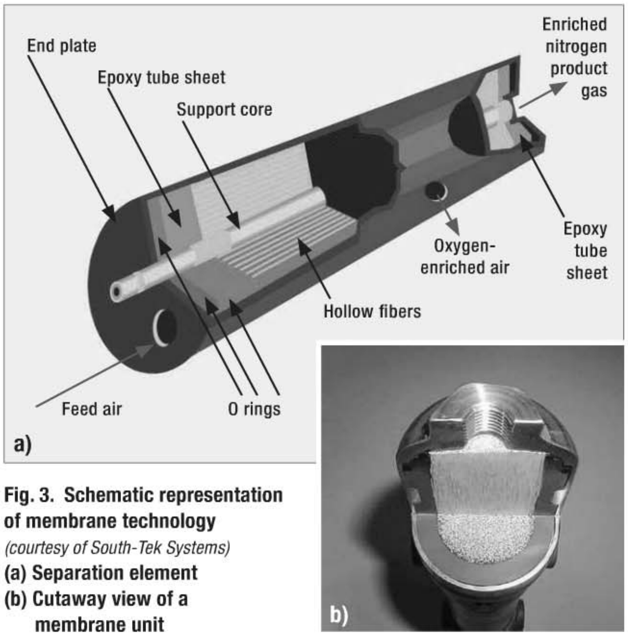

Fig. 3. Schematic representation of membrane technology
(courtesy of South-Tek Systems)
(a) Separation element
(b) Cutaway view of a membrane unit

Processes Using Nitrogen

Current AEP processes that require nitrogen include:

- **Isothermal annealing**. Annealing involves heating a ferrous or nonferrous alloy above its critical temperature and holding at processing temperature followed by cooling at a controlled (slow) rate for such purposes as reducing hardness, improving machinability, facilitating cold working, producing a desired microstructure (for subsequent operations), reducing internal stresses, or obtaining desired mechanical, physical or other properties.

  At Honda, annealing furnaces are utilized to reduce internal stresses and produce a suitable microstructure for machining final components. Three-row pusher furnaces are used to perform the annealing process. The furnace atmosphere is 100% nitrogen for the purpose of minimizing scale. The goal is to eliminate heavy, flaky scale, which is detrimental to subsequent operations.

  In other industrial applications, annealing is performed in both batch and continuous furnaces. Common types of batch-annealing furnaces include bell furnaces, which typically process wire coils and flat strip stock, as well as box, car-bottom and tip-up furnaces. The most common types of continuous annealing furnaces are the horizontal and inclined mesh-belt conveyors, which are typically used for annealing of tubular steel and stainless steel products, as well as roller-hearth and pusher furnaces.

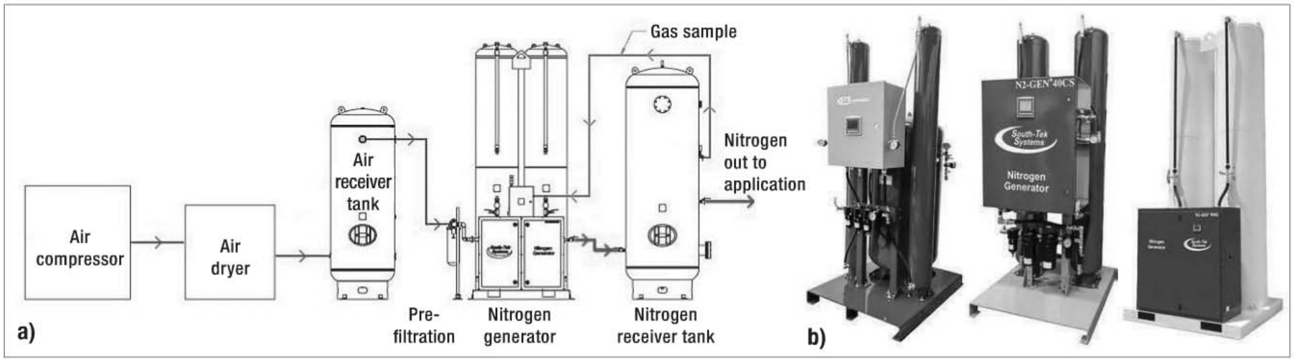

Fig. 4. Schematic representation of PSA technology *(courtesy of South-Tek Systems)* **(a) Typical system layout (b) Typical generator-system options (left to right): tank-mounted, compact skid, skid-mounted**

- **Ferritic nitrocarburizing (FNC)**. FNC is a case-hardening process similar to nitriding, but it involves the introduction of both nitrogen and carbon into the ferrous alloy while holding below the lower-critical temperature (Ac_1). The resultant compound (aka white) layer with an underlying diffusion zone contains iron and alloy nitrides. Quenching is not required to produce a hard case.

  Honda utilizes single-row pusher furnaces to perform FNC under controlled conditions. Nitrogen is used as a purge and cooling gas as well as a blanketing gas when the furnace is idling at temperature without product running through it.

  In other industrial applications, FNC is commonly performed in batch integral-quench, pusher and tip-up furnaces.
- **Pouring of molten metal**. Nitrogen is used both as a pressurizing gas during the pour and as a blanketing gas to reduce oxidation. A blanketing (aka covering) gas is a term used to describe an inert gas, such as nitrogen, introduced into a furnace to prevent oxidation of the

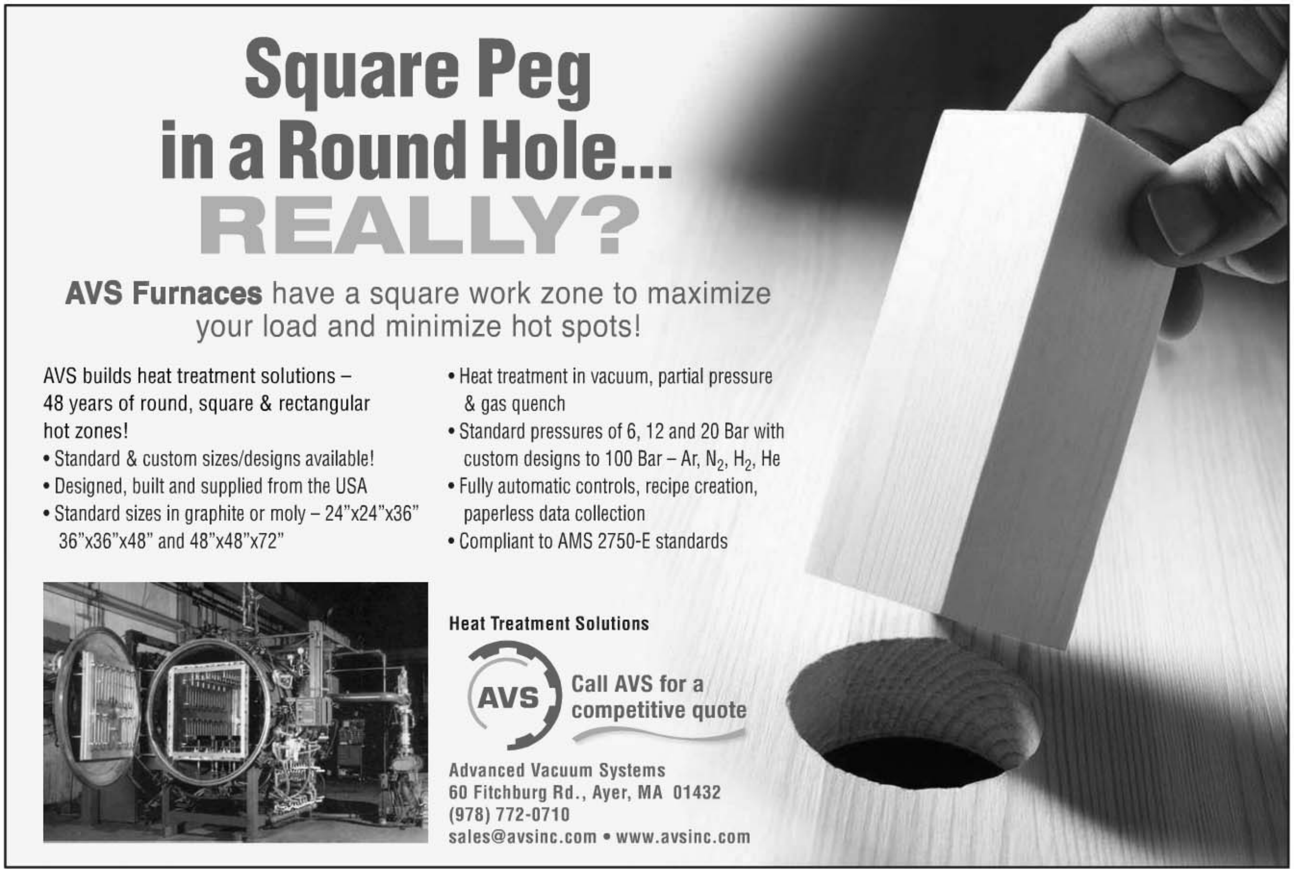

Table 1. Nitrogen purity and pressure requirements as a function of process need

Equipment/Process	Reason for use	Purity level (%)	Pressure (psi)	Flow type	Process-dependent
Nitrocarburizing	Cooling and safety purge	99	10	Variable	Yes
Isothermal annealing	Scale reduction	97	10	Constant	No
Pouring vessel	Oxygen blanketing	97	10	Variable	No
Spin casting	Oxygen blanketing, vessel pressurization	97	40	Variable	Yes

component parts being heat treated. The flow rate and pressure of the atmosphere and the equipment type (e.g., gas-tight construction) must be sufficient to limit the influx of air.

At Honda, the tundish (pour vessel) uses pressurized nitrogen to aid in the pouring process, helping to move the molten metal from the ladle to the mold. The blanketing gas covers the top of the molten iron bath.

In general applications, vessels used to pour molten metal are equipped with blanketing and pressurizing capabilities with nitrogen or argon.

Additionally, future process needs at AEP include:

- **Carburizing**. Carburizing is another type of case-hardening process that involves the introduction of carbon into a component-part surface by holding above the critical temperature (Ac_3) while in contact with a suitable carbonaceous atmosphere. Carburizing is followed by rapid cooling (quenching) and tempering.

  Single-row roller-hearth furnaces are used for carburizing. Nitrogen is used for safety purges and to blanket the furnaces when not in operation.

  In other industrial applications, carburizing is commonly performed in batch integral-quench and pusher-style furnaces.
- **Vacuum vapor degreasing**. Following oil quenching after carburizing, the parts are cleaned in a vacuum degreaser.

  Parts are “rinsed” in a light mineral oil, which dissolves the quench oil. A vacuum is then employed to vaporize the mineral oil from the surface, leaving the parts clean. A nitrogen backfill is employed to return the unit to atmospheric pressure prior to unloading.

Internal Users and User Requirements

All of these processes were critically evaluated to determine current and future process requirements. A review of the processes (Table 1) revealed that the pressure and purity of the current liquid-nitrogen system exceeded process needs. It was also determined that any change to the liquid-nitrogen system would require a backup system to ensure flow and safety purge capability.

Reviewing the data, it was determined that nitrogen flow rates were constant for some processes and variable for others. The flow was studied under various operating conditions to determine the overall flow requirements (Table 2).

Table 2. Flow demands

Furnace condition	Total demand (cfh)		Total usage (cfh)
	Constant	Variable	
Production	5,150	3,697	8,847
Idling	2,950	0	2,950
Emergency	14,500	0	14,500

Development of Goals and Technical Specifications

The goal was to achieve at least a 10% cost reduction over existing technology with a favorable return on investment. Analyzing the data collected, a target specification was developed for upgrading the nitrogen system. Technical requirements included the following:

1. Nitrogen flow (constant): 10,500 scf/hour (Note: Flow interruption is not acceptable.)
2. Nitrogen purity: 1,000 ppm oxygen maximum (including a safety factor)
   a. Nitrogen pressure (minimum): 50 psig (Note: This includes a 10 psig safety factor.)
3. System maintenance: no additional maintenance personnel or specialized training

Step #3: Investigation of Available Nitrogen Technologies

After reviewing the process needs for nitrogen, two main options were considered: expanding the liquid nitrogen system including vaporizing capacity or replacing liquid nitrogen with generated nitrogen. During the investigative phase, it was determined that both options need to maintain full nitrogen flow at all times, so this criterion was incorporated into the project. Each option was then thoroughly evaluated in light of current and future needs, paying particularly close attention to the target specification requirements (Table 3). Based on this analysis, it was decided to explore generated nitrogen.

Table 3. Evaluation of options for the nitrogen systems

	Requirement	Expand liquid system	Generated nitrogen
Flow	10,500 scf/hour with 100% uptime	●	●
Purity	1,000 ppm O_2 max	●	●
Pressure	50 psi min	●	●
Maintenance	Maintain low maintenance	●	●
Cost	10% reduction	⊘	●
Uptime	Must maintain N_2 flow at all times	△ [a]	△ [a]

Notes: [a] Preventing a supply interruption was identified as a criterion that needed to be addressed for both systems – the liquid nitrogen tank could run dry or the nitrogen generator could go offline.

A review of the nitrogen generation industry determined that there were two main types of commercially available nitrogen generators. A quick review of each type is given.

- **Membrane separation**
  A membrane "mechanically" separates nitrogen from oxygen and other molecules but does not involve a chemical process (Fig. 3). The basic components of the system are an air supply source (e.g., air compressor), dryer, filters, pre-storage tank, nitrogen membrane and a nitrogen storage tank.
  Membrane-style nitrogen generators can produce nitrogen purities ranging from 95-99.5% with flow rates from 0-2,126 scfh out of a single unit. In order to achieve higher flow rates, multiple membrane nitrogen generators must be linked together. The ratio of airflow to nitrogen generated determines the purity requirement (Table 4). The average life expectancy of a membrane nitrogen generator is 8-12 years if filters are changed using the recommended schedule.

Table 4. Nitrogen purity as a function of operating ratio for membrane technology

Typical purity (%)	Typical purity (ppm)	Ratio (airflow to nitrogen)
95.000	50,000	2.2:1
96.000	40,000	2.4:1
97.000	30,000	2.7:1
98.000	20,000	3:1
99.000	10,000	3.9:1

- **Pressure Swing Adsorption (PSA)**
  PSA, or pressure swing adsorption, systems (Fig. 4) are vessels filled with a carbon molecular sieve (CMS) that is pressurized with air. Oxygen, carbon dioxide, carbon monoxide and certain other molecules (e.g., ammonia) are captured while the nitrogen is drawn off into a receiving tank. Depressurizing the sieve bed then flushes the trapped gases and regenerates the CMS, which is then ready for more air. The basic components of the system

Table 5. Nitrogen purity as a function of operating ratio for PSA technology

Typical purity (%)	Typical purity (ppm)	Ratio (airflow to nitrogen)
98.000	20,000	2.25:1
99.000	10,000	2.7:1
99.900	1,000	4:1
99.990	100	10:1
99.999	10	13:1

Table 6. Comparison of membrane and PSA technology at Honda

	Requirement	Liquid tank (no change)	Membrane	PSA
Flow	10,500 scf/hr with 100% uptime	●	⊘	●
Purity	1,000 ppm O_2 max	●	⊘	●
Pressure	50 psi min	●	⊘	●
Maintenance	Maintain low maintenance	●	⊘	●
Cost	10% reduction	⊘	●	●
Uptime	Must maintain N_2 flow at all times	● *would require redundant systems	● *would require redundant systems	● *would require redundant systems

are an air-supply source (e.g., air compressor), dryer, filters, pre-storage tank, dual CMS tanks (one active, one discharging byproducts), nitrogen storage tank and gas analysis equipment (e.g., oxygen, dew point).

PSA nitrogen generators can produce nitrogen purities ranging from 95-99.999% with flow rates as high as 80,570 scfh. The average life expectancy of a PSA nitrogen generator is 20-25 years, provided filters are changed on the recommended maintenance schedule. A typical return on investment of such systems is in the order of 18-24 months.

The ratio of airflow to nitrogen generated determines the purity obtained (Table 5). For Honda's requirement (1,000 ppm), a 4:1 air to nitrogen ratio would be required.

The cost of generated nitrogen for either a membrane or PSA system is based on compressed-air usage and can be calculated from the electrical usage of the compressor (Eq. 1). The calculation is as follows:

$$\frac{\text{Compressor HP requirement x 0.746 x electrical cost/kwh}}{\text{CCF of nitrogen produced}} \qquad (1)$$

These technologies were then evaluated versus the project goals (Table 6). Based on the results, it was determined that a PSA system would best meet Honda's requirements.

STEP #4: Selection Process

Following the analysis of nitrogen technologies, a business plan was developed to incorporate a PSA unit into Honda's nitrogen systems.

A partner vendor was selected for the project due in part to a two-year system warranty, performance certificate (that certified the system purity, flow and pressure requirements were met), 24-hour technical support and the quality of the sieve material utilized in their systems.

Initially, an air-cooled rotary screw compressor PSA system running on 460/3/60 power was proposed. This proposal was considered but ultimately rejected because, while the system was within the investment budget, the site preparation costs (electrical feed, space, etc.) were deemed too costly. A review of the plant compressed-air system determined that the internal system had enough open capacity to meet the nitrogen generator's needs. This reduced the investment costs and maintenance concerns.

The vendor then quoted the project utilizing the shop air system. A decision was made to add a filter and refrigerated drying system to the incoming air system to ensure air quality. The nitrogen quality verification was integrated into the system utilizing an oxygen analyzer.

The last remaining consideration was how to achieve 100% uptime. The PSA system would shut down in the instance of a power outage. The unit could be put on a backup generator, but the compressed air feed would require too large of a draw for it. With this in mind, it was decided to incorporate the liquid-nitrogen tank as a backup system. To accomplish this, the PSA system was placed inline between the liquid-nitrogen tank and the end nitrogen users. If the nitrogen generator goes off-line or fails to meet the nitrogen supply needs, the pressure would drop and an inline pressure regulator would open. Nitrogen from the liquid-nitrogen tank supplements the flow until the nitrogen generator's air supply could be restored. This system provided 100% uptime reliability.

Step #5: Development of a Business Case

With the system design complete, the last step prior to installation was evaluating the business case for a change to the nitrogen system. The case would be evaluated against a SEQCDM model (Safety, Environmental, Quality, Cost, Deliverables, Morale).

- **Safety** – Project would meet safety goals by ensuring 100% uptime, monitoring gas quality and eliminating the risk of exposure to liquid nitrogen.
- **Environmental** – Project would reduce the liquid-nitrogen deliveries, thus reducing truck traffic, the chance of a liquid nitrogen spill and venting of large amounts of liquid nitrogen to the atmosphere.
- **Quality** – Project would meet quality goals with continual gas monitoring.
- **Cost** – Project would meet 10% gas cost reduction. In point of fact, a calculated reduction of 68% was expected, based on compressed-air usage and an allowance for liquid backup usage.

- **Deliverables** – Project would meet or exceed all of the nitrogen users' requirements for flow, pressure and purity.
- **Morale** – Project would eliminate the need to constantly monitor the liquid-nitrogen tank and add no major equipment to maintain.

Based on the results of the evaluation, the plan was approved, equipment was purchased and installation of a PSA system was undertaken. The results were verified over time using the business-case criteria and can be reported as follows:

- **Safety** – The system was tested multiple times with power failures being simulated. The backup system functioned correctly 100% of the time with no nitrogen outages experienced.
- **Environmental** – The average daily tank draw from before and after the installation of the nitrogen generator was dramatically reduced with the addition of the nitrogen generator (Table 7). Based on these results, the deliveries of liquid nitrogen went from three times a week to only once or twice a year.

Table 7. Daily nitrogen usage

Condition	Average nitrogen tank usage (%)
Prior to installation	18.77
After installation	0.49

- **Quality** – The gas quality goal was met and maintained. Monitored results found the average oxygen level to be 598 ppm.
- **Cost** – Compressed air usage was monitored and found to meet the 4:1 ratio that was expected. The allowance for liquid-nitrogen usage was found to have been overestimated.
- **Deliverables** – All purity, flow and pressure requirements were met and maintained in service.
- **Morale** – No maintenance tasks were added. Monitoring of the system is performed once a day and recorded on a check sheet by Honda associates.

Summary

The installation of a PSA nitrogen generator system achieved Honda's goals and objectives. The PSA system met Honda's present and future needs. In particular:

- **Flow (10,500 scf/hour with 100% uptime)** – A nitrogen flow of 10,500 scfh or more could be consistently supplied. The backup system worked as planned.
- **Purity (1,000 ppm oxygen maximum)** – This was met by design. A system for monitoring and adjusting flow was also included with the PSA system to ensure consistent quality over time.
- **Pressure (50 psi minimum)** – The PSA system met the required operating pressure. An air supply source above 90 psi was necessary.
- **Maintenance** – To reduce strain on the maintenance department, the unit was manufactured with standard components. This included a PLC and its programming, which resulted in very low maintenance without additional training being required.
- **Cost (10% reduction)** – The actual cost reduction was determined to be 76% since the actual backup liquid usage was far less than anticipated.

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