Hydrogen for Generator Cooling – The Pressure, Purity and Dewpoint Difference

Presenter:

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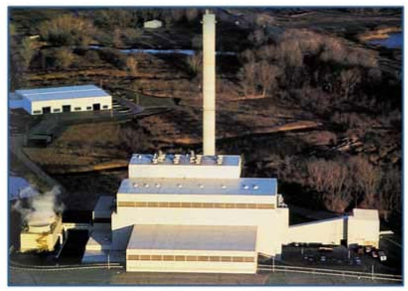
Topic: Safety, Reliability, Heat Rate and Generation Capacity can all be affected by operation of the hydrogen system used to remove heat from the generator windings. My goal is to present information that will be useful in running your plant in the most profitable way for the long term.

Generator Winding Cooling

- Open air cooling
- TEWAC
- Hydrogen cooling
- Hydrogen-water cooling

Most utility-scale generators use hydrogen to cool the generator windings because of its superior characteristics versus alternatives. TEWAC cooling has become newly popular in the US for smaller facilities – up to about 100 MW capacity, and is sometimes used up to 200 MW+ overseas, particularly in 50 cycle markets. Hydrogen cooling is the standard for baseload plants.

Plants of all types share same issues



Whether you are running a brand-new CCGT facility, or a fossil facility that has celebrated 50 years and is still running strong, or a baseload nuclear facility, or a WTE or biofuel plant built to maximize the available energy with the least possible emissions, you deal with hydrogen every day.

Generator Cooling Goals

- Minimize drag - “windage”
- Keep generator internals clean
- Maximize generator output
- Minimize electrical, mechanical and corrosion problems
- Maintain low dewpoint for component durability

The cooling system for the generator needs to meet several goals, and recirculating closed loop hydrogen systems have proven to meet these challenging goals for nearly 60 years. There is every reason to expect that hydrogen cooling will continue to be the standard approach to baseload utility scale generator cooling.

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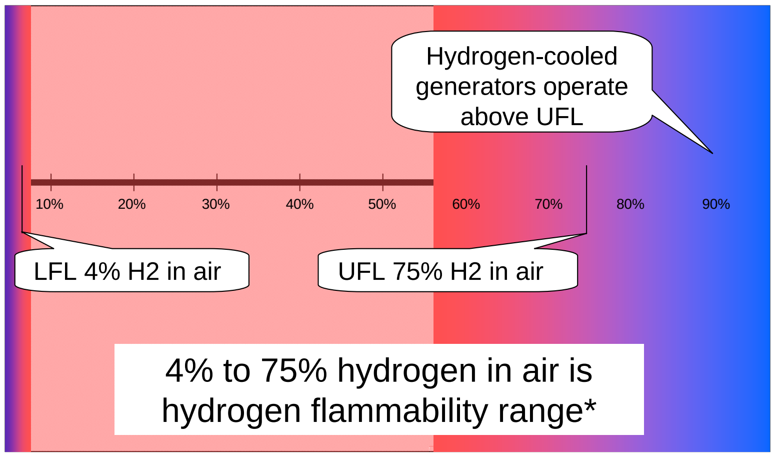
Hydrogen cooled generator – sealed cavity – recirculating pressurized hydrogen atmosphere

Why Hydrogen Cooling ?

- Lowest density gas yields lowest drag
- Highest heat conductivity of any gas
- Controlled atmosphere to maintain Clean & Dry
- Inexpensive
- Easy to detect
- Excellent electrical properties
- Easy to manage – not readily miscible with CO_2 purge gas
- **Flammable**

Hydrogen has attractive characteristics as a fluid to bathe the windings of the generator, and to remove heat from the windings and deliver that heat to the cooling water. Hydrogen is nearly the perfect cooling gas, except for its one massive flaw.

Hydrogen Flammability Range



* At normal temperature range. Flammability envelope is wider at high temperature.

Hydrogen has a wide flammability range. Unlike most applications involved with flammable gases, where the effort is to keep the gas below the LFL, the safety of hydrogen generator cooling is based on staying above the UFL.

Operating Above UFL is different

- In nearly every case, we try to maintain flammable gases below LFL
- Operating below LFL, leaks don't ignite
- Above UFL is safe except for leaks
- Above UFL, every leak is a potential fire
- The generator must be kept pressurized, because air ingress can be catastrophic
- Procedures are important, and not obvious

Operating above the UFL is a different world. There may be no other situations where we in industry have experience operating a system above UFL. The differences must be recognized and respected. Every leak is a source of concern – because the leak will pass through the flammability envelope. Leak detection and mitigation is critical.

Stored Hydrogen Hazards

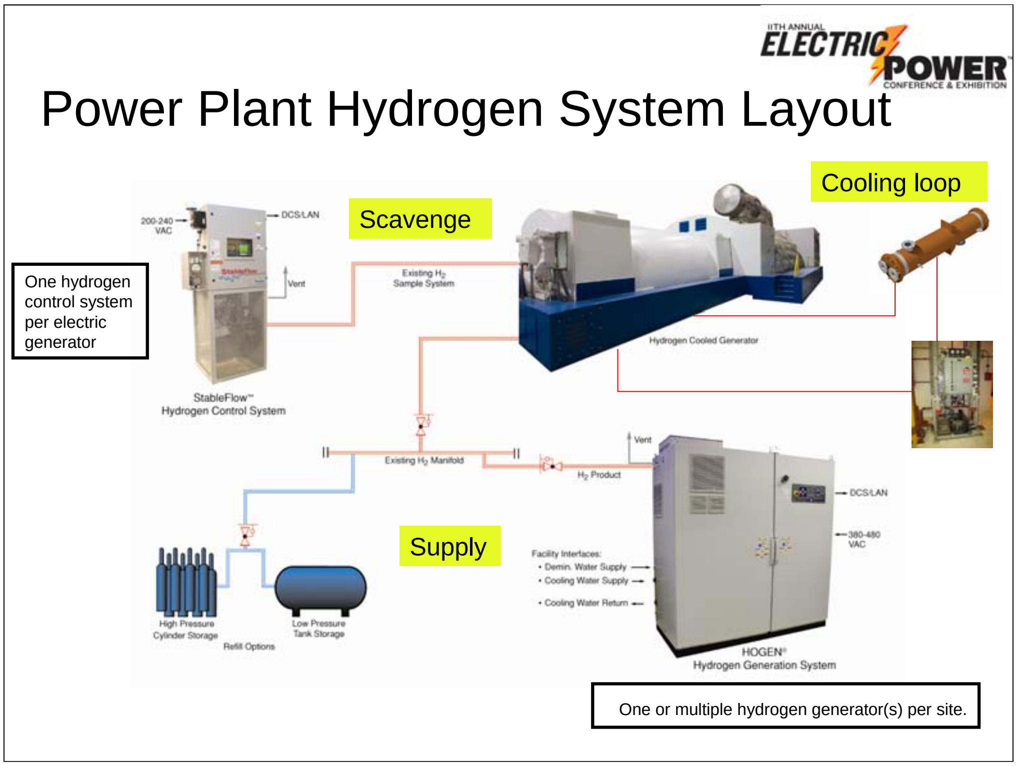
Stored hydrogen has a terrific safety record, but it is easy to become a statistic. Hazards include – pressure, flammability, and physical mishaps – falls, hand & foot injuries…

Hydrogen is a flammable gas – no more dangerous than other flammable gases. It is very buoyant, escapes readily and does not pool. Hydrogen has no natural odor, and is not odorized, so leaks require detection equipment. Hydrogen has no health effects other than potential flammability, and the ability to displace oxygen. The chief challenge with hydrogen is managing inventory and dealing with fast-leaking gas.

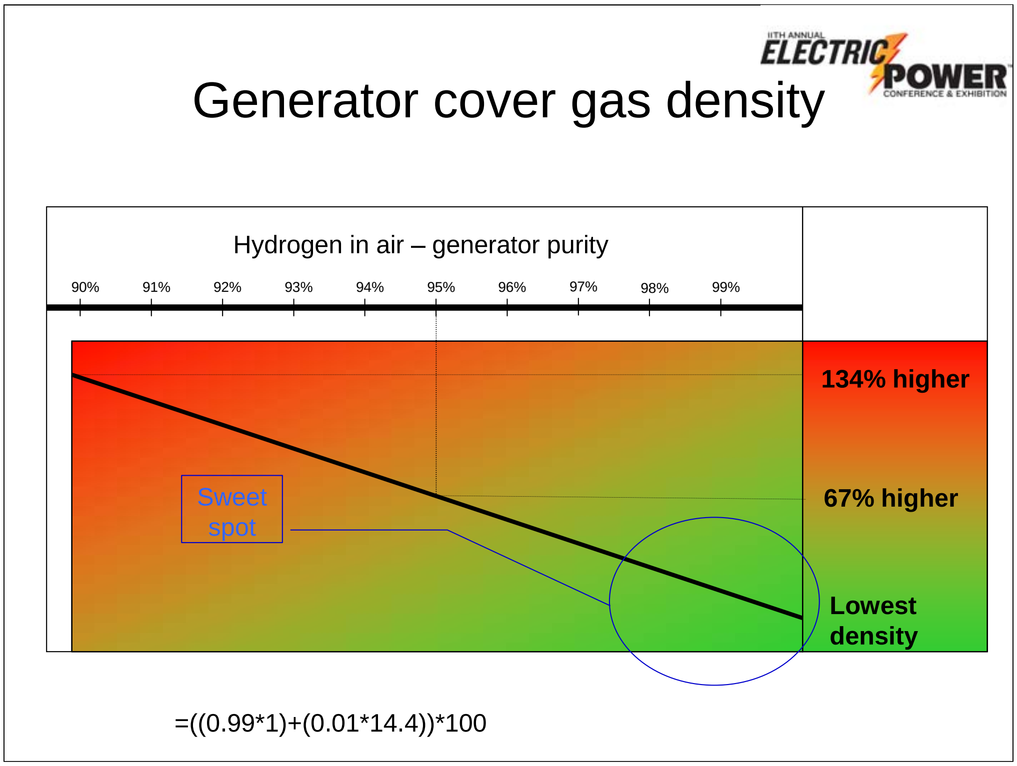
Windage Loss

- Windage loss = friction (drag) on the rotor
- Cause is aerodynamic resistance.
- Drag = Energy (fuel, steam) lost to friction
- D = Cd * ref Area * .5 * **fluid density** * **Velocity^2**
- Drag is proportional to fluid density, and related to the square of the velocity.
- 50 cycle generators and nuclear plants with 4 pole generators are less affected, because they spin slower
- **Windage loss affects heat rate**

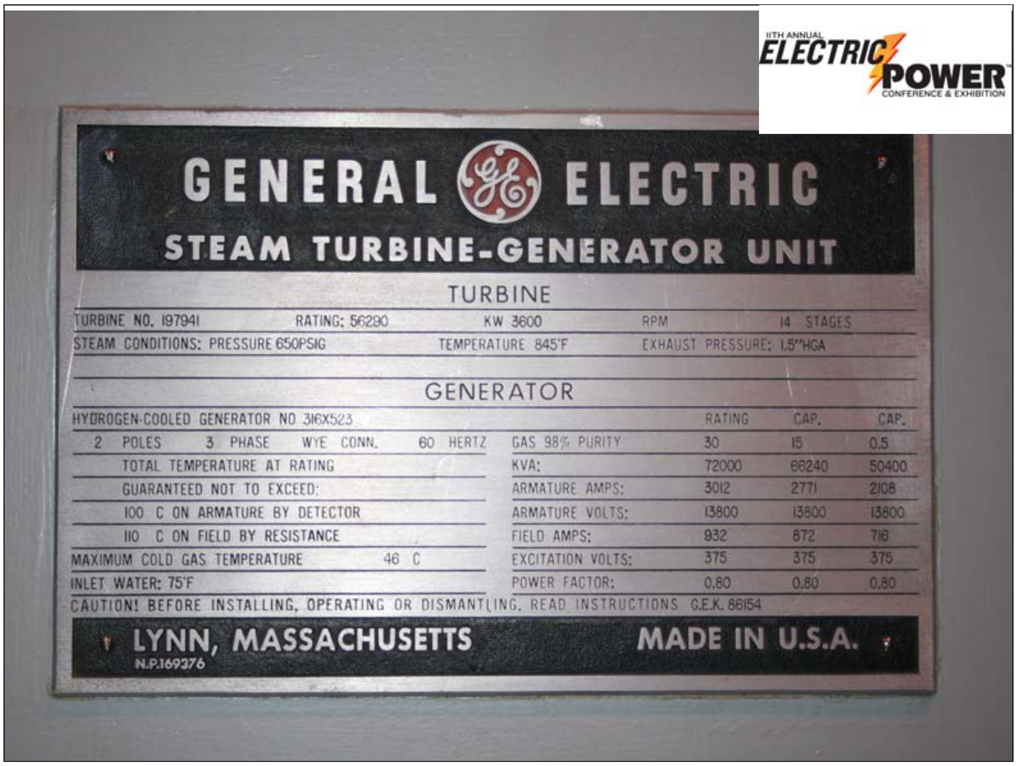
If your compensation or bonus are related to plant financial results, you want to pay attention to heat rate – the amount of BTU's necessary to deliver a KWh of electricity. Many factors affect heat rate, and windage loss (drag) in the generator casing is a controllable contributor to heat rate – improve windage losses, and your plant will make more money. If you burn less fuel, and make the same amount of electricity, the dollars saved are 100% profit.



This is a standard hydrogen-cooled generator equipment layout. There are basically three hydrogen "systems" – the hydrogen supply side of the generator, the hydrogen recirculating cooling loop, and the hydrogen scavenge portion of the system. Hydrogen safety and quality can be affected by the choice, capabilities, and operation of the technologies in each of the systems.



Because air is 14 times as dense as hydrogen, the density of the fluid in the generator casing rises quickly with air impurity level. As can be seen from the equation, every 1 percent of air contamination is worth about 14% increase in fluid density. Increased fluid density means increased windage loss.



Note the manufacturer plate on your generator, and the guidelines in the user manuals. The gas in the generator casing must be kept at the manufacturer recommended purity in order to achieve the manufacturer commitment on heat rate. Note that the generator capability varies according to the gas pressure in the casing – if pressure is allowed to degrade – think Bleed & Feed – then the generator cannot deliver full capacity.

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Purity Degradation vs Plant Economics

Purity action level	95	%
Maximum purity level	99	%
CF%	60	%
Generator size	175	MW

7FA typical example

Avg purity	97	%		
"Optimum" purity	99.5	%		
Average purity deficit	2.5	%		
KW wasted to windage	182.3	KW	@ 60% CF	
MWH lost to windage	4.4	MWH/day	958.1	MWH/year

Energy value loss	$50/MWH	47,906	$/yr
	$60/MWH	57,488	$/yr
	$70/MWH	67,069	$/yr
	$80/MWH	76,650	$/yr

Profit dollars !

The payback from purity enhancement is immediate and impressive. An improvement from 95% to 99% purity, on a generator of 175 MW capacity, with a 60% CF%, is worth between $48,000 and $77,000 annually in additional sales dollars. Because there is no additional fuel burned to achieve these sales, the profitability is virtually 100%.

Hydrogen Supply Options

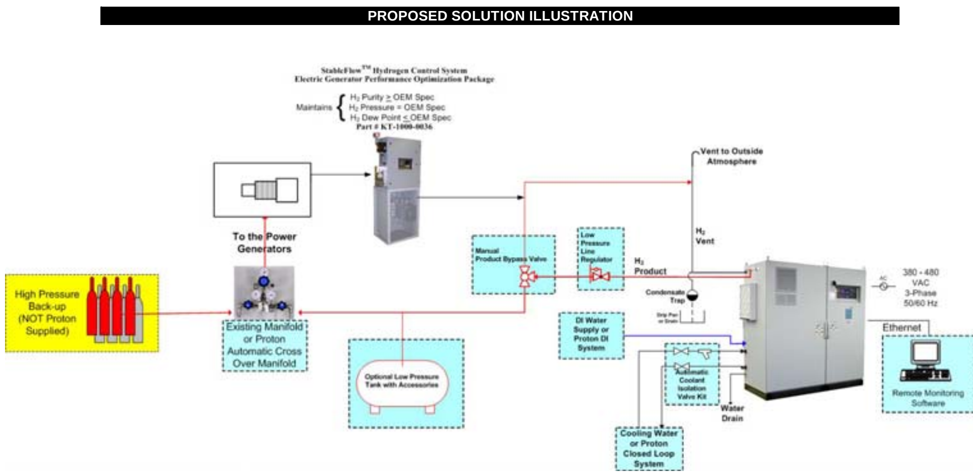
Technology choices on the hydrogen supply side of the generator: stored hydrogen or generated hydrogen. A certain amount of stored hydrogen is required for regas.

Benefits of Onsite Hydrogen Generation

- Reduced inventory (some inventory still req'd for regas)
- Lower pressure
- Limited delivery rate
- Less operator interaction
- Facilitates continuous scavenge

On the hydrogen sourcing side of the generator, the choice of generated hydrogen provides several important advantages. Limited inventory allows for less spacing under NFPA guidelines. Limited delivery rate reduces likelihood of achieving the LFL in case of a leak. The ability to safely float on the supply regulator maximizes the safety of continuous scavenge.

Generated Hydrogen Supply System



Generated hydrogen doesn't eliminate the need to store hydrogen for regas – but it does dramatically reduce the size of storage required, and offers the opportunity to make your own regas hydrogen, eliminating deliveries entirely.

Self-generated Backup/Regas hydrogen

By making your own gas stored for regas, it is possible to entirely eliminate hydrogen deliveries. Self-generated backup/regas hydrogen at Luna Energy in NM and at Basin Electric in ND. Self-generating backup hydrogen is well-suited to plants that are geographically remote, or that have unique security requirements.

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Replacement Instrumentation is not enough

New instrumentation should enable the plant to improve plant operation:

•Improved purity control

•Reduced dewpoint

•Tighter pressure control

Replacing old purity, pressure and dewpoint instruments with new versions without additional functionality doesn't make the plant run better.

New instrumentation should enable the plant to modify procedures to improve plant operation:

•Improved purity control

•Reduced dewpoint

•Tighter pressure control

Lowest possible dewpoint is critical

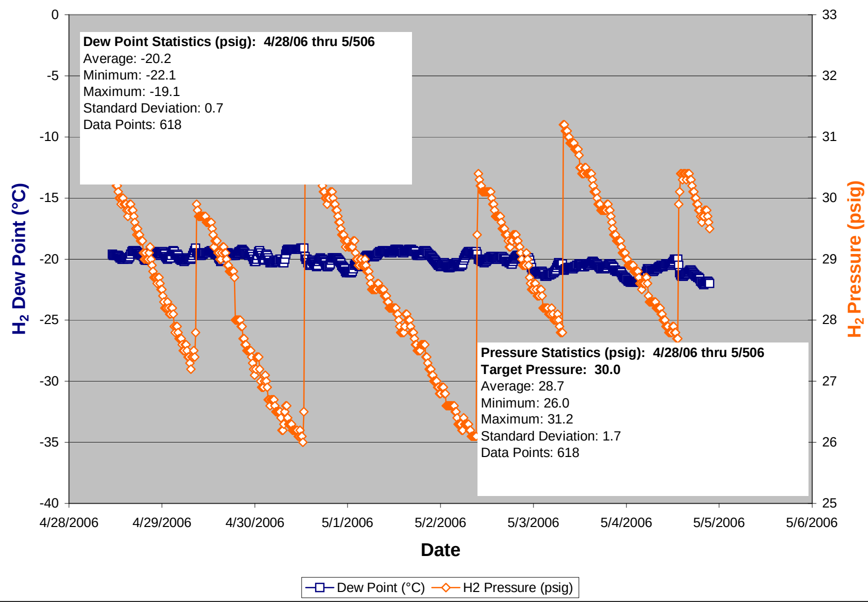
The dewpoint of the hydrogen in the generator casing can affect the lifetime of the generator windings. Wet hydrogen will reduce winding life due to corrosion. Wet hydrogen can be catastrophic in the case of 18/5 rings, susceptible to stress crack corrosion. You must keep dewpoint within manufacturer specs.

StableFlow automated control

Automated control of dewpoint, pressure and purity enable stable, efficient plant operation.

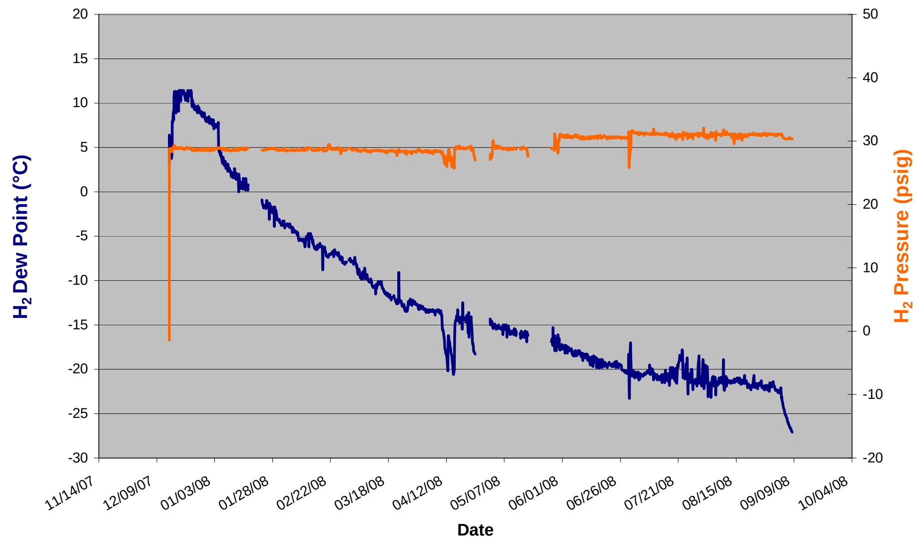
StaableFlow integrates dewpoint, pressure and purity data into a feedback control system to automate control.

Bleed & Feed hydrogen control



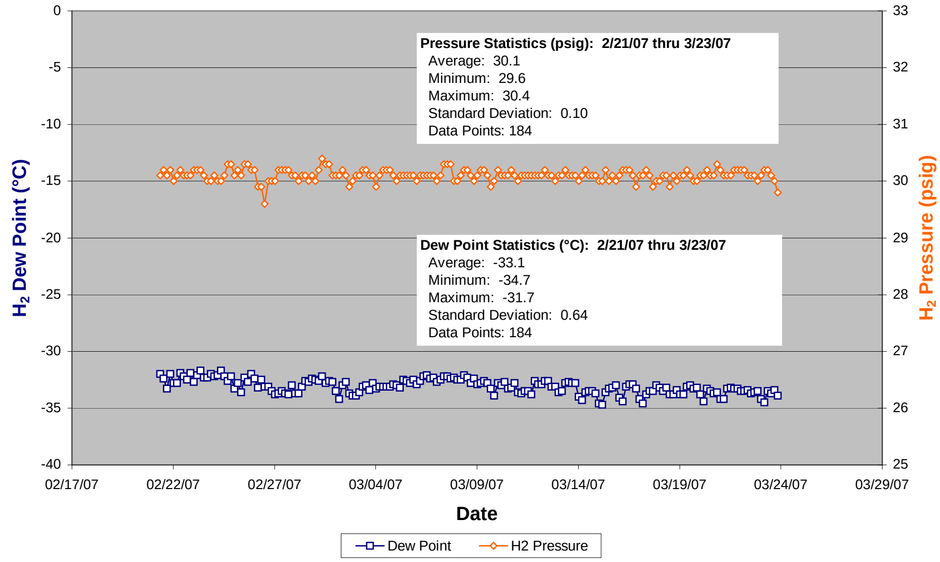
Typical Bleed & Feed hydrogen management approach – Pressure, Dewpoint and Purity may vary.

Drive dewpoint down without a dryer

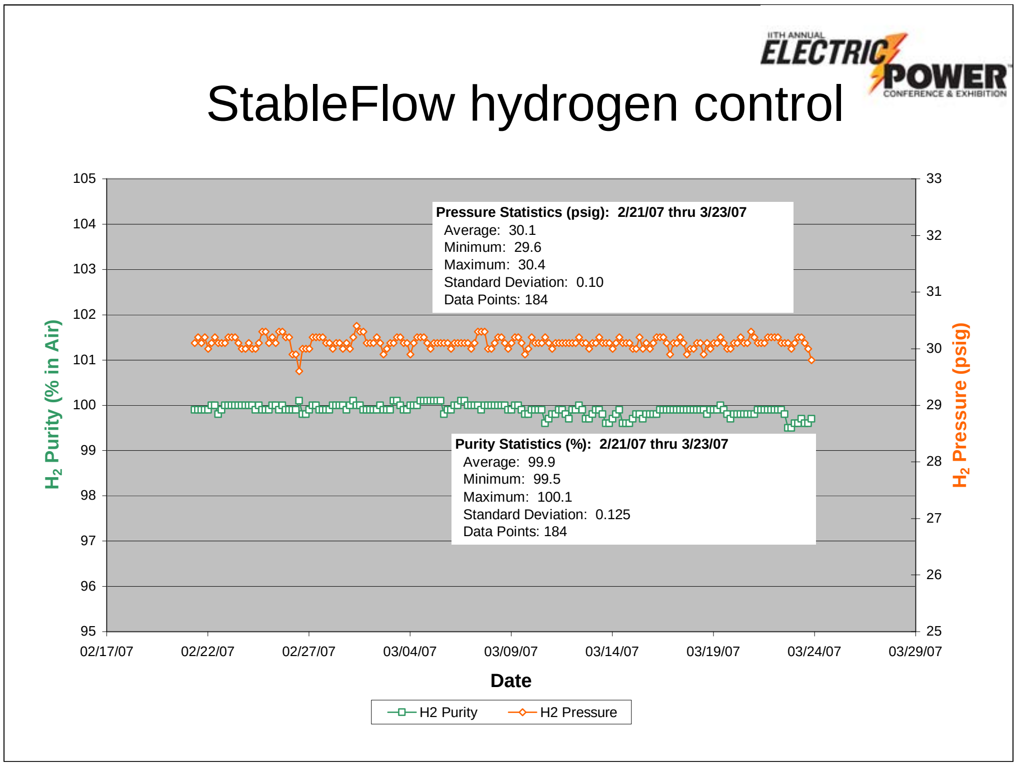


Either a dryer in the recycle loop, or an optimized scavenge system can control hydrogen dewpoint. This chart illustrates the performance of a StableFlow hydrogen control system driving dewpoint to manufacturer compliant levels without a dryer. Note the pressure stability – the benefit of optimized constant scavenge.

StableFlow hydrogen control



StableFlow hydrogen control system – stable, compliant hydrogen specifications translates into maximum generator performance and lifetime



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Thank You,

Questions ?