Expected Purity Level of Hydrogen Economy to be fed into a European Hydrogen Infrastructure

Brussels – January 18, 2007

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Expert Workshop on Synergies between HYPOGEN and the Hydrogen Economy

Existing Hydrogen infrastructure

- Pipelines (~2000 km)
  - Specifications : Chemical Industry
- Large Plants (NG based SMR)
  - Specifications : Refineries
- LH2
  - Specifications : >99.9999%
- Cylinders
  - Various grade: Case-by-case basis

Future European Hydrogen Infrastructure

→Driven by largest & most demanding consumer

Transport & PEM Fuel Cell

- Large H2 production plants (20 to >100,000 m3/h) able to produce H2 at low cost with CO2 mitigation, distributed by
  - Pipeline network
  - Cylinders
  - Liquid H2

HYPOGEN

- Small delocalized production units

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Hydrogen Fuel Quality Specification
(ISO TC197 WG12 – nov9, 2006, HNEI, Honolulu)

- The fuel specification must
  - Be compatible with automotive FC system performance & total life cycle costs
  - Be developed via a consensus process using input from key stakeholders
  - Be practical, sustainable & cost effective to implement & operate at H2 stations
  - Be feasible for H2 production & purification
  - Use applicable standardized methods for measurement & monitoring
  - Be based on experimental data, analysis & verification
  - Be compatible with durability & performance requirement of the FC

Actors ….

- ISO specifications issued (ISO TS14687-2)
- SAE :   harmonized with ISO's
- ASTM
- Dynamis

ISO main specifications

H2 purity	> 99,99%	
		ASTM
Impurities	max level	Detection limits
	umole/mole	umole/mole
CO	0.2	0.2
CO2	1	0.1
Sulphur Compounds	0.004	0.004
THC	2	0.1
Oxygen	5	1
Ammonia	0.1	0.1
Inert Gases (N2, Ar, He)	100	60
Water	5	0.5
Halogens	0.05	0.01
Max Particulate Concentrations	20 ug/mole	
Max Particulate Size	10 um	1 um

Issues

- A moving target
  - FC requirements are changing with the development of new materials (lower precious metal loading)
- Lack of experimental data
  - Effect of various impurities
  - Long term effect
  - Numerous configurations

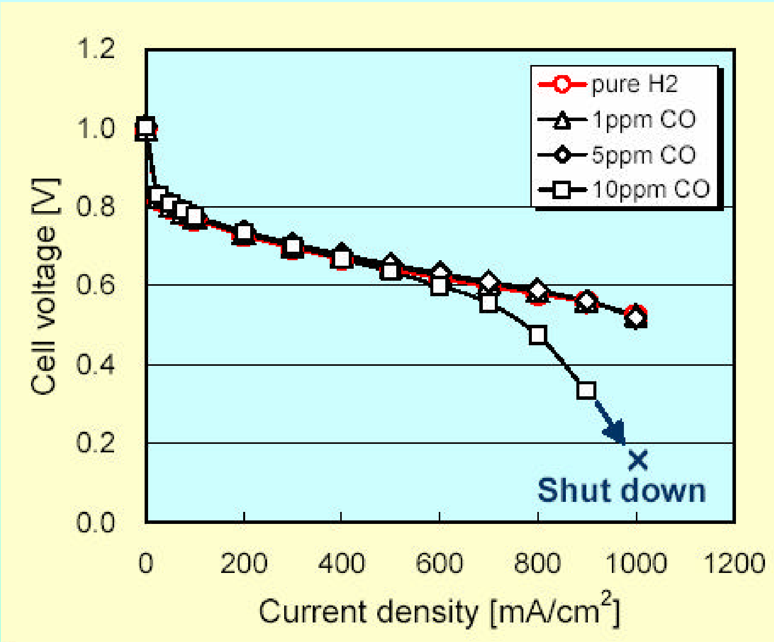
➔ Non mature technology

Publications of test work at various labs for a decade

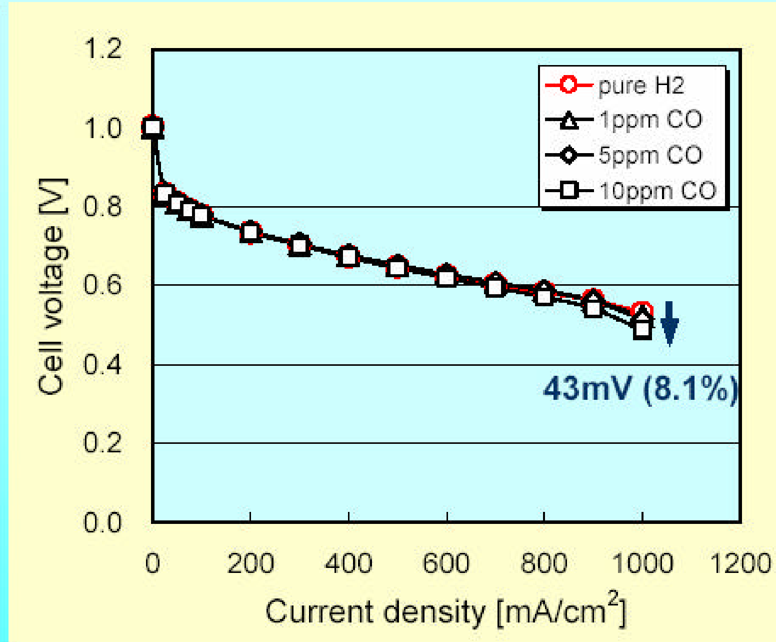
- Public & private Labs
  - JARI
  - Los Alamos NL
  - NERL
  - GTI
  - Technical University of Denmark
  - ….

  - OMG dmc2
  - Air Liquide & Axane
  - …

Examples of 1st step evaluation test (CO)



Electrolyte: GORE-SELECT
Electrode catalyst (Anode/Cathode): Pt/Pt



Electrolyte: GORE-SELECT
Electrode catalyst (Anode/Cathode): Pt-Ru/Pt

- If 10ppm CO is contained, the voltage drop ratio is more than 2%.
- Pt-Ru catalyst has the tendency of preventing CO poisoning.

JARI Source

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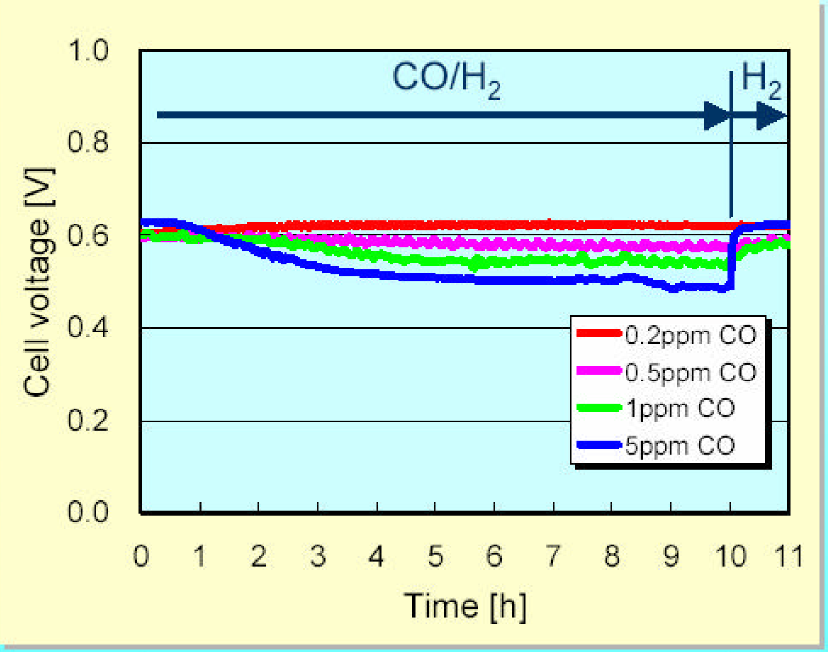
Examples of 2nd step evaluation test (CO)



Electrolyte: GORE-SELECT
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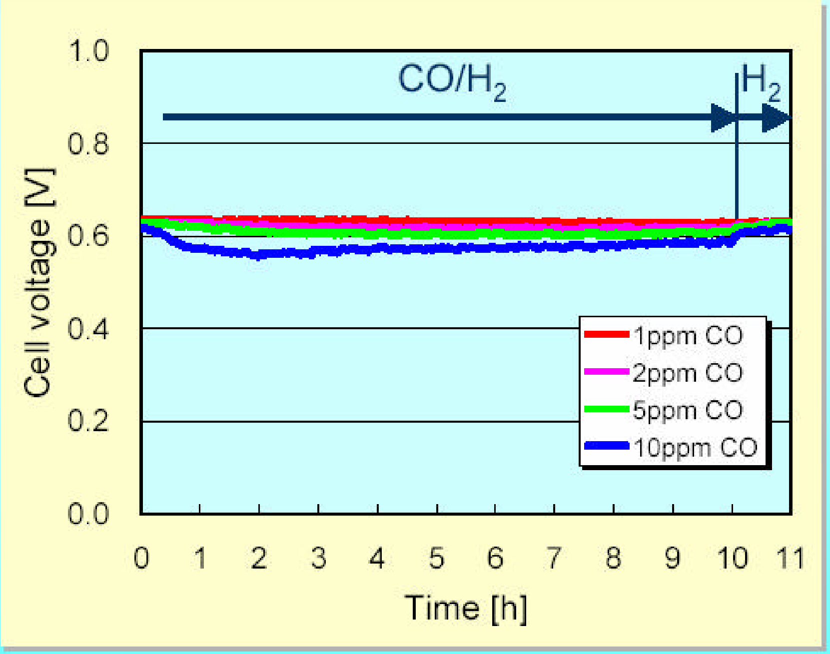


Electrolyte: GORE-SELECT
Electrode catalyst (Anode/Cathode): Pt-Ru/Pt

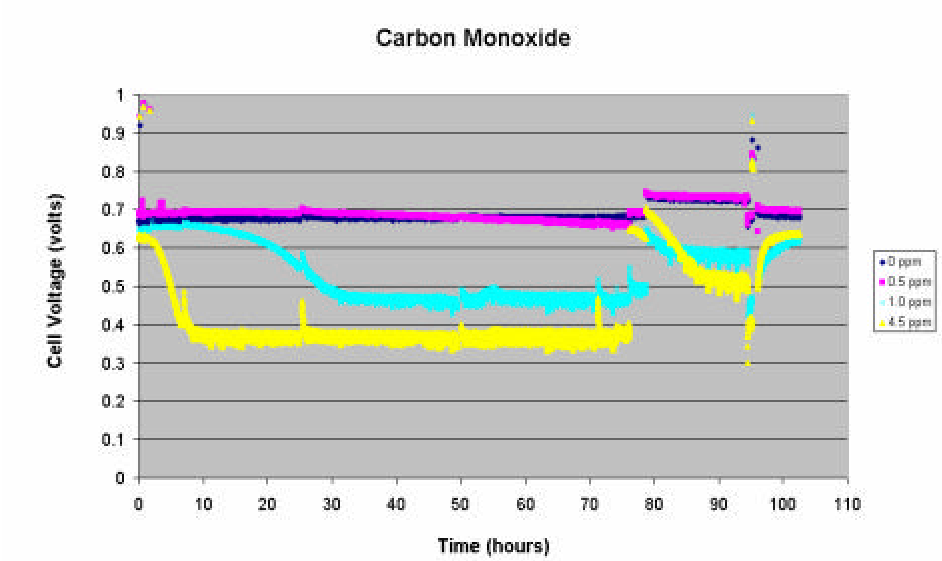
- Compared with 1st evaluation test, lower impurity concentration have influence on the fuel cell performance.
-After 10 hours test, the cell voltage is recovered by supplying pure hydrogen.

CO poisoning is reversible

JARI Source

H_2 Impurities *(from Air Liquide's # Impurities *(from Air Liquide's Labs)*

- Carbon Monoxide (CO)
  - Mechanism – Adsorption of CO onto Pt sites, oxidation of CO to CO_2, desorption of CO_2
    - Equilibrium is established
    - Fully recoverable



  - Results
    - 0.5 ppm – Small observable loss beginning at 70 hours
    - 1.0 ppm –Time to reach equilibrium 32 hours, **20 % voltage loss**
    - 4.5 ppm – Time to reach equilibrium 10.7 hours, **42 % voltage loss**

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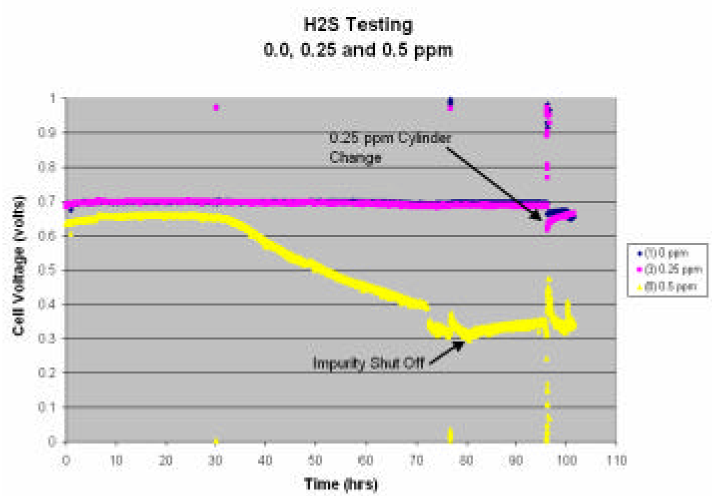
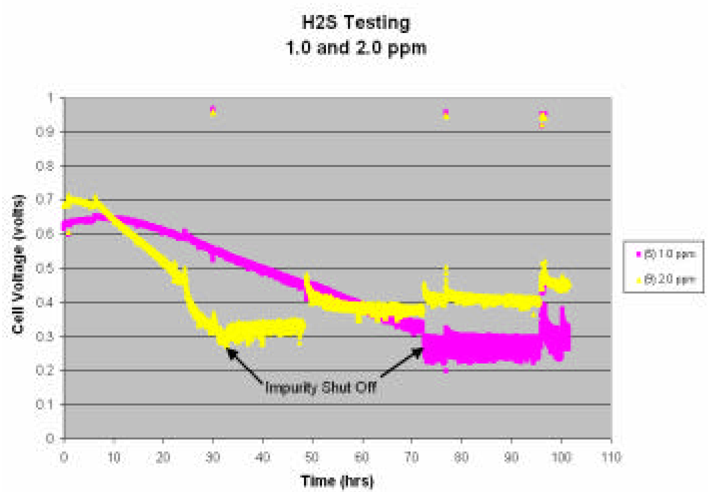
H_2 Impurities *(from Air Liquide's Labs)*

Dynamis

- Hydrogen sulfide (H_2S)
  - Mechanism – Adsorption of H_2S onto Pt sites followed by oxidation to sulfur
    - Cumulative in nature
    - Not easily recoverable
  - Concentrations tested → 0.25, 0.5, 1.0, 2.0





- Results
  - 0.25 ppm H_2S – No observable voltage loss (for 100 hours)
  - Higher concentrations – "Linear" voltage drop over time
  - Recoverability – Limited recoverability after impurity removal

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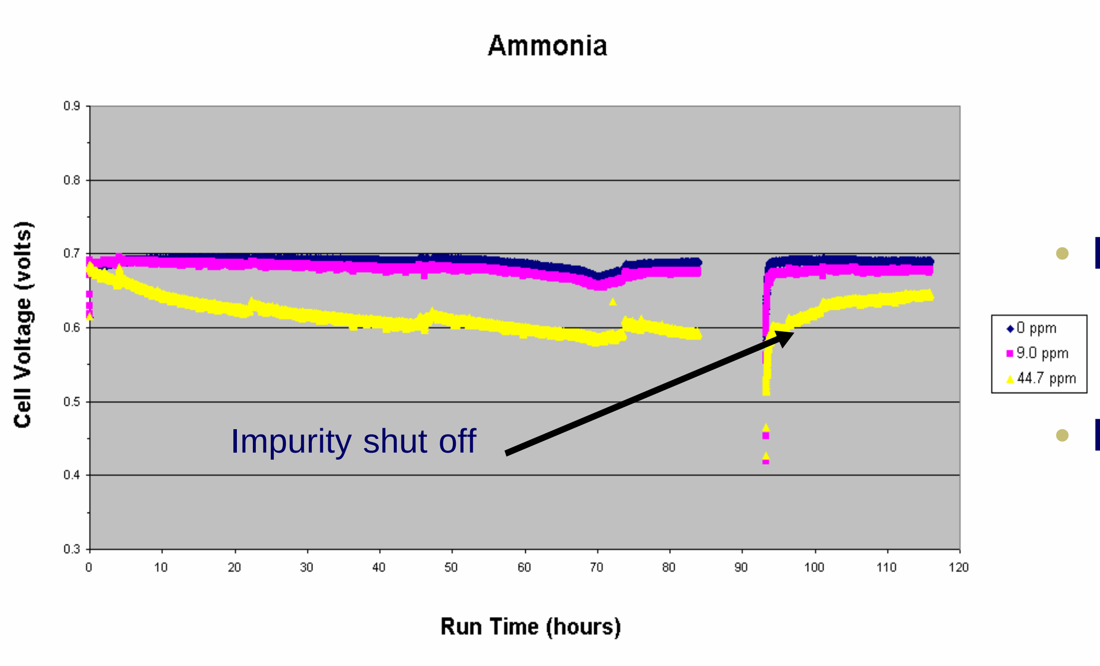
H_2 Impurities *(from Air Liquide's Labs)*

- Ammonia (NH_3)
  - **Mechanism – Long term exposure results in loss of proton conductivity**
  - **Concentrations tested → 0, 0.5, 1.0, 9.0, 44 ppm NH_3**



- **Results**
  - ***13 % drop of 44 ppm***
- **Recovery**
  - ***93 % recovery after 20 hours for 44 ppm***

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	ISO	Dynamis
H2 purity	> 99,99%	> 99,99%
Impurities	max level	max level
	umole/mole	umole/mole
CO	0.2	1
CO2	1	2
Sulphur Compounds	0.004	0.01
THC	2	1.5
Oxygen	5	6
Ammonia	0.1	10
Inert Gases (N2, Ar, He)	100	500
Water	5	10
Halogens	0.05	0.1
Max Particulate Concentrations	20 ug/mole	20 ug/mole
Max Particulate Size	10 um	10 um

2006 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review

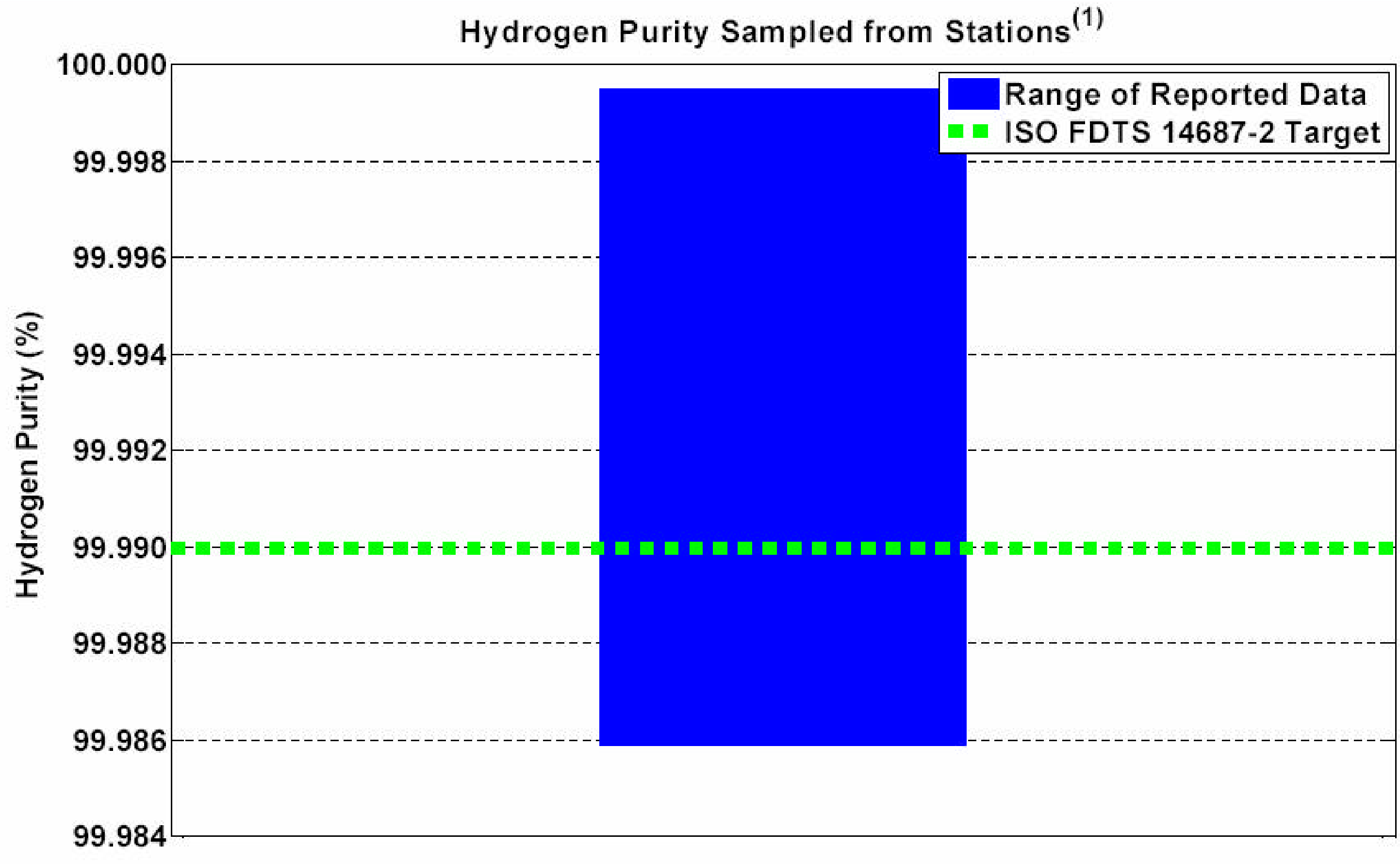
Controlled Hydrogen Fleet and Infrastructure Analysis

Keith Wipke, Senior Engineer II
NREL
May 19, 2006

Project ID# TV-12

This presentation does not contain any proprietary or confidential information

Hydrogen Purity Sampled from Stations Meets Target Majority of the Time



(1) Includes sampling from both electrolysis and reforming

Created: 21-Feb-2006

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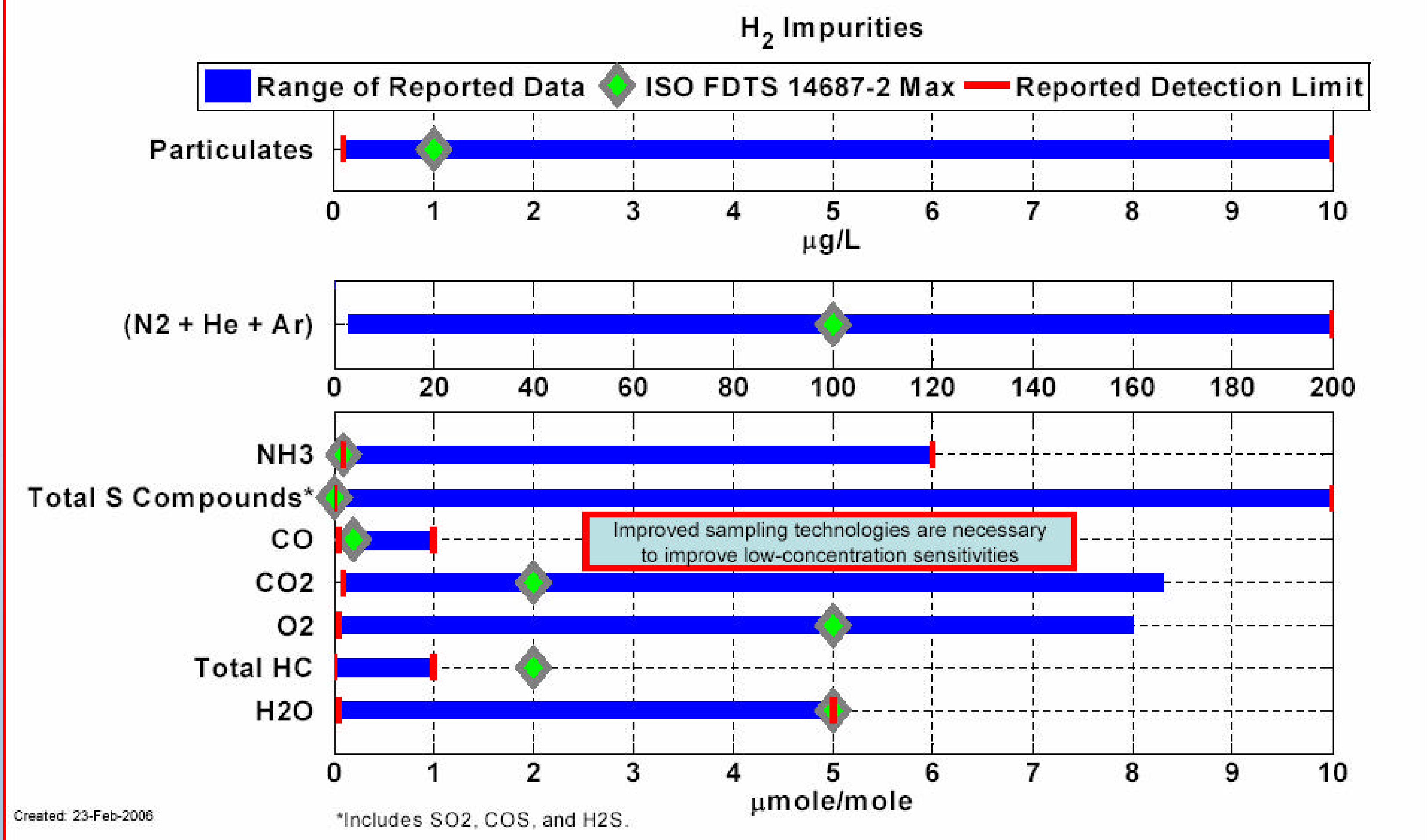
Hydrogen Impurities Sampled from All Stations – Includes On-Site Reformation, Electrolysis, and Delivered H_2



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Key Impurities

- CO
- S compounds
- NH3

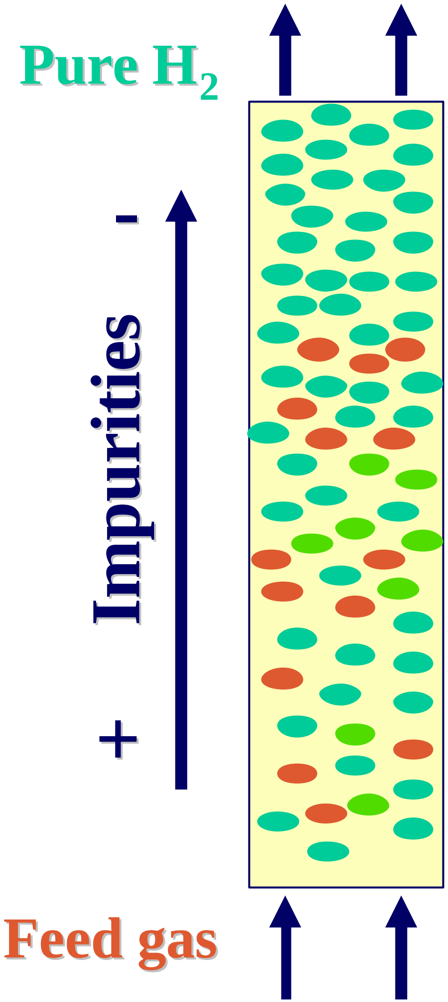
- Inerts (N2, Ar, He)

H2 Purification

- NG SMR
- NG ATR/O2 or Air
- Coal Gasification
- Lignite Gasification

➔ Pressure Swing Adsorption (PSA)

Example: 4 adsorbent layers



Molecular Sieve
Ar, N_2, CO

Activated Carbon
CO_2, CH_4

Silica Gel
C_nH_m, H_2S, BTX

Alumina H_2O, NH_3

Gas / adsorbents affinity (2)

CHOICE OF ADSORBENTS			
Molecular Sieve	Activated Carbon	Silica Gel	Alumina
N_2 CO	Ar CO_2 O_2 CH_4	C_nH_m H_2S BTX*	H_2O NH_3

* benzen, toluen, xylen

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Gas / adsorbents affinity (1)

Relative strength of adsorption			
+	++	+++	++++
He H_2	Ar O_2 N_2	CO CH_4 C_2H_6 CO_2 C_3H_8 C_2H_4	C_3H_6 C_4H_8 C_5+ H_2S NH_3 BTX H_2O

The relative strength depends on the affinity between the adsorbent and the molecule you want to trap.

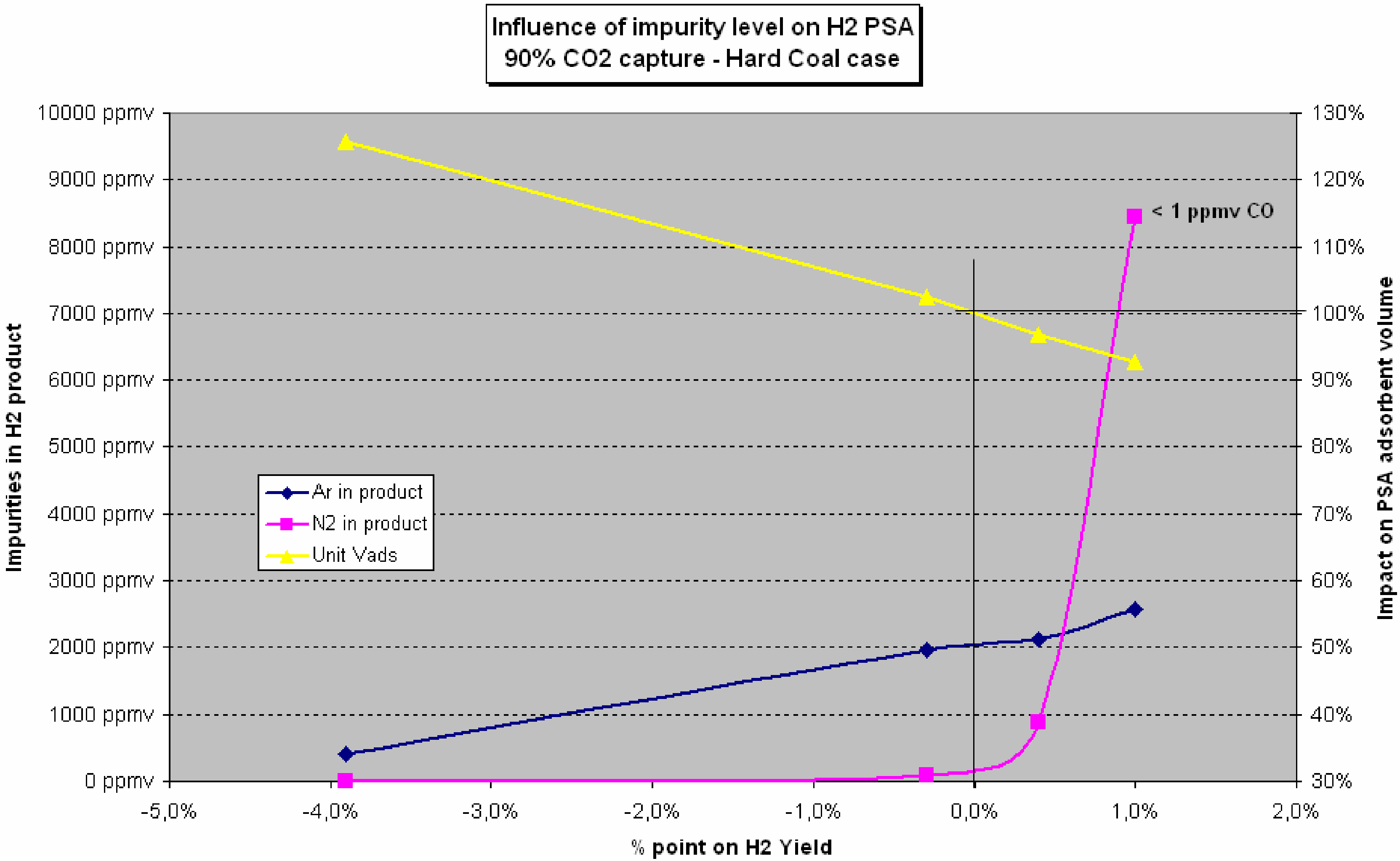
H_2-PSA – a large range of plants

Belgium,
100 000 Nm³/h

Spain,
49 000 Nm³/h

Holland,
13 000 Nm³/h

PSA Efficiency



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Effect of impurities on H2 Storage & Distribution

- Pipelines

- Cylinders   Metal to Polymers (Type IV)

- Cryogenic Tank

  LH2 20°K <99.9999% (TSA Purification)

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Technical Accomplishments/Progress: Fuel Quality – 5-year R&D/Testing Plan Defined

Topic of Investigation	2006	2007	2008	2009	2010
I. Consensus Testing Strategy					
A. Fuel cell-OEMs/fuel providers select n critical species from Table 1 based on key technical/economic drivers					
B. Develop R&D/test plan with WG12					
C. Coordinate activities, revise plan annually					
D. Derive optimal balance bet. fuel cell performance and fuel cost					
II. Fuel Cell Tests ('standard' MEA)					
A. Conduct failure mechanism tests w/re concn. at const. load, RH, T & P with critical constituents (CO, H2S, etc.)	Determine mechanism	Identify regeneration alternatives	Alternate materials		
B. Conduct long-term tests (const. physical conditions) and const. & variable loads with critical constituents (CO, H2S, etc.)	Aging/const load	Aging/variable load	Aging w/regen		
C. Conduct tests with selected combinations of critical constituents (CO, H2S, etc.) and concentrations	Determine mechanisms	Identify regeneration alternatives	Alternative materials use (low cat. loading, etc.)	Commercial Materials	
D. Conduct "Simulated Drive Cycle" tests with H_2 + critical constituents as fuel		Operations with limited contaminants and limits on conditions (load,SD/SU)	Operations with H2 Fuel & typical conditions		
E. Investigate performance/cost trade offs re: critical constituents					
III. H2 Fuel Provider Integration					
A. Define H_2 fuel quality variations based on current cleanup procedures (relative to critical constituent limits)					
B. Define contaminant species/ concentration variations as a function of planned H_2 sources					
C. Investigate H_2 cleanup alternatives commensurate with fuel cell tests					
D. Conduct cost trade-offs re: critical constituents					
IV. Analytical Protocol/Instrumentation					
A. Evaluate adequacy of Table 1 info., set priorities based on IA					
B. Modify ASTM standards to measure critical constituents as needed	Determine variations to current practice	Investigate and incorporate required alternatives to SOP			
C. Validate test methodology and requirements for critical constituents	Identify key species required to be monitored		Finalize species and concns to be monitored		
D. Assess cost trade-offs, esp. in-line measurement					
V. OEM Engine/Vehicle Tests					
A. H2 Fuel with Priority Constituents		Correlate small scale fuel cell tests with large scale	Assemble and evaluate demo and fleet vehicle operations with H_2 fuel quality	Test and demonstrate vehicle/engine dyno tests with	
VI. Advance Storage Materials					
A. Track Development of Adv. Materials					

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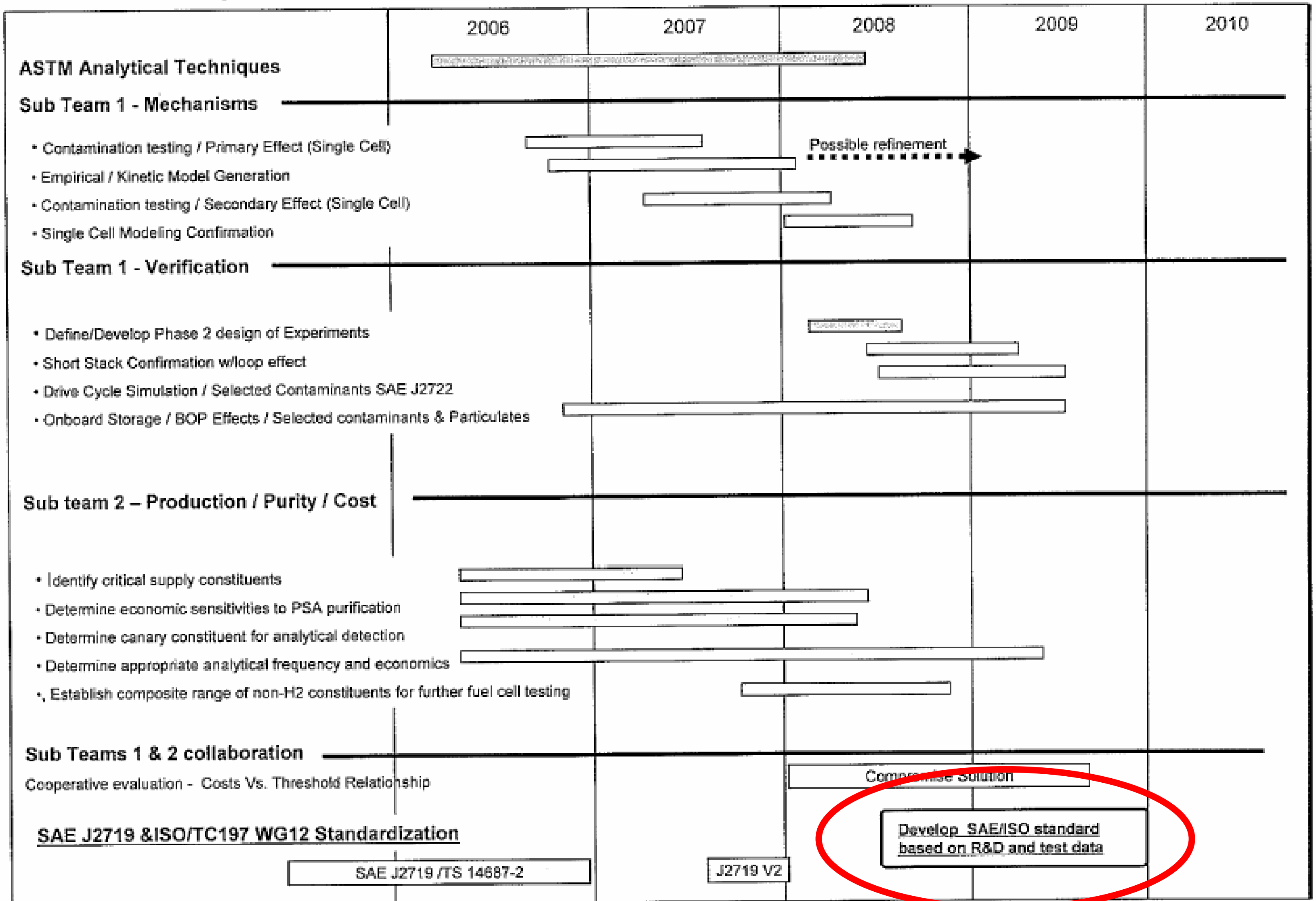
Dynamis

Timeline for Hydrogen Quality Standardization



Conclusions

- Needs
  - For additional research work on influence of impurities (including inerts), with more materials & longer test periods
  - To better share information of consequences of unrealistic specifications (ex: 4 vpm S-compounds) on H2 production costs
  - For stronger involvement of European actors into international organizations (ISO)