Hydrogen and Fuel Cells in Ports and Shipping Workshop

The Path to Hydrogen Shipping

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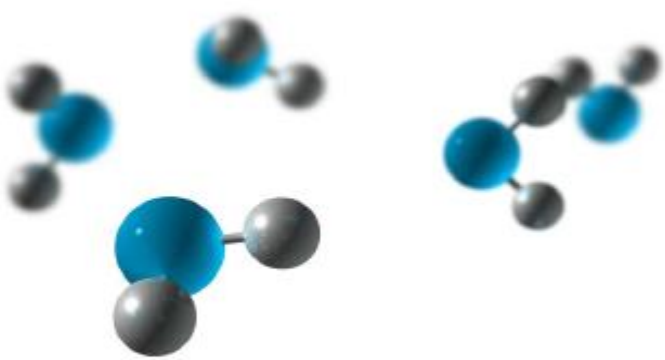
09 October 2018



CALIFORNIA HYDROGEN BUSINESS COUNCIL

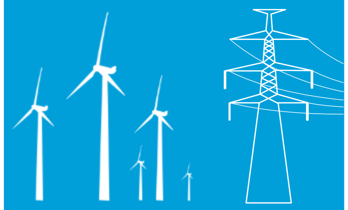
Hydrogen Means Business in California!

Our vision: global impact for a safe and sustainable future

MARITIME

OIL & GAS

ENERGY



BUSINESS ASSURANCE

DIGITAL SOLUTIONS

TECHNOLOGY & RESEARCH

Global reach – local competence

150+ years	**100+** countries	**100,000+** customers	**12,500** employees

Industry consolidation

DNV

GL Group

KEMA

NOBLE DENTON

GARRAD HASSAN

ADVANTICA

DNV GL Americas

1600 employees and 75 offices in North America

Agenda

1. Intro- Motivation Drivers
2. Technology overview
3. Regulation update
4. Maritime Fuel Cell Development /Projects

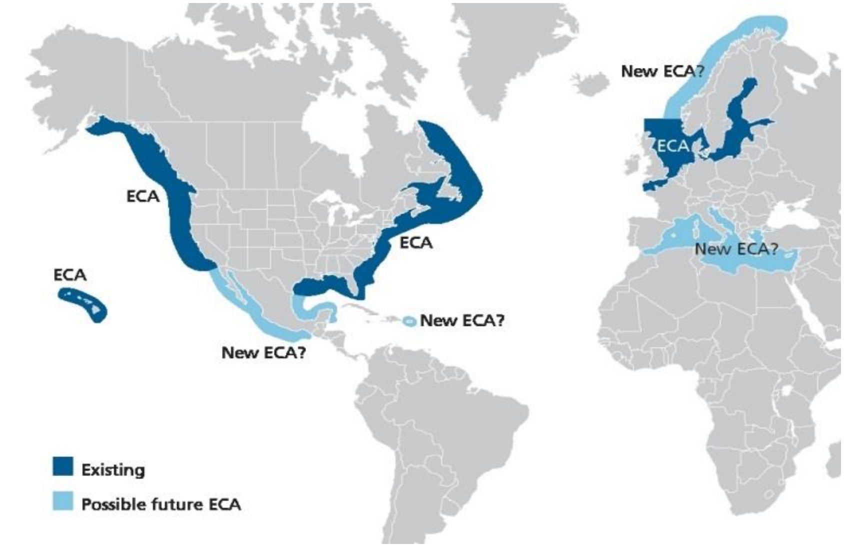
Introduction

Motivation

- Improvement of Ship Energy Efficiency
- Reduction of emissions to air
- Reaching insignificant noise and vibration level

Driver

- Environmental regulations and initiatives to
  - Increase efficiency of ship operation
  - Reduce NO_X, SO_X, CO_2 and particle (PM) emissions



Enhancement of Ship‘s emissions, efficiency and comfort

- *Fuel option*
  - HFO + scrubber
  - MGO
  - LNG
  - Other low-flashpoint fuels
- *Energy efficiency*
  - Hull form
  - Machinery improvement
  - Alternative energy converters
  - *Logistics and speed*
    - Speed reduction
    - Vessel utilization
    - Alternative Sea routes

Maritime Fuel Cells are promising to enhance

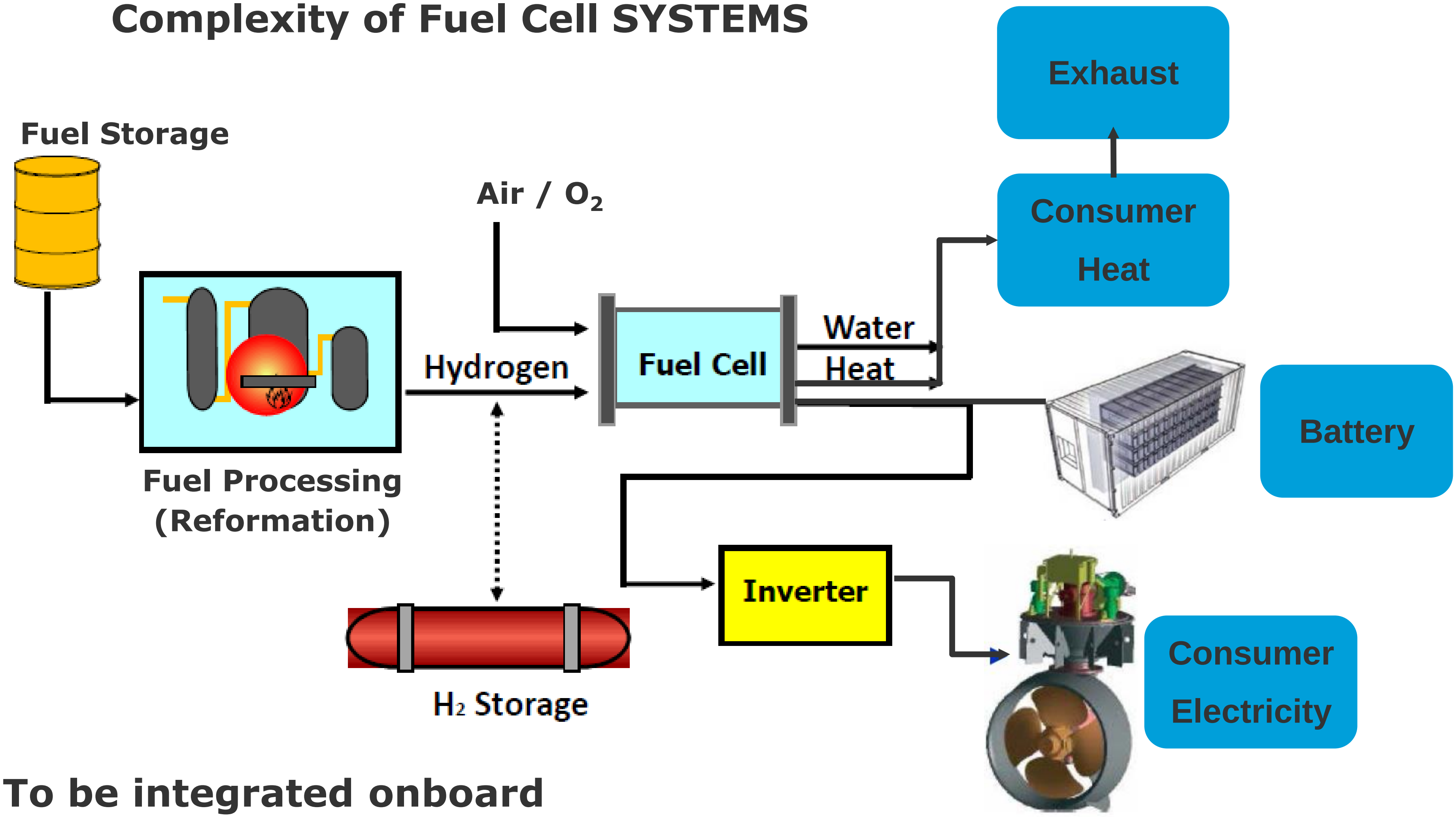
- Ship Energy Efficiency
- Emissions
- Noise & Vibration

Abstract from DNV GL Energy Transition Outlook 2017: Maritime Forecast to 2050

Towards zero emissions in shipping

- **HYBRID**
  - "Vision of the Fjords" – The ship of the year 2016 – Flom-Gudvangen
  - Diesel hybrid 2 * 150 kW el- engines, 600 kWh batteries
  - Fastest ever - 14 months from contract to delivery 18.july 2016
- **BATTERIES**
  - "Future of the Fjords"
  - 100% electric 2 * 450 kW el- engines,
    1.8 MWh batteries
  - Delivery 1.april 2018
- **HYDROGEN – FUEL CELLS**
  - Next generation
  - Increased range
  - Reduced weight possible
  - More flexible charging/bunkeri

Complexity of Fuel Cell SYSTEMS



To be integrated onboard

Technology overview- Fuel Cells types

- Electro-galvanic fuel cell (EgFC)
- Enzymatic Biofuel Cells (EnzFC)
- Magnesium-Air Fuel Cell (Mg-AFC)
- Metal hydride fuel cell (MHFC)
- Protonic ceramic fuel cell (PCFC)
- Microbial fuel cell (MFC)

- Alkaline fuel cell (AFC)
- Direct borohydride fuel cell (DBFC)
- Direct carbon fuel cell (DCFC)
- Direct formic acid fuel cell (DFAFC)
- Direct methanol fuel cell (DMFC)
- Direct-ethanol fuel cell

- Molten carbonate fuel cell (MCFC)
- Phosphoric acid fuel cell (PAFC)
- Solid oxide fuel cell (SOFC)
- PEMFC
- High Temperature PEM
- Reformed methanol FC (R-MFC)

- Regenerative fuel cell (RegFC)
- RFC – Redox
- Solid acid fuel cell (SAFC)
- Upflow microbial fuel cell (UMFC)
- Zinc-air battery

Maturity and Relevance

Solid Oxide Fuel Cell	Molten Carbonate FC	Phosphoric Acid FC	**HT PEM fuel cell**	Alkaline fuel cell	**PEM fuel cell**	Direct Methanol FC

Tolerance for cycling

Lifetime

Efficiency

Emissions

Relative cost

Modular power levels (kW)

Safety aspects

Physical size

Flexibility towards type of fuel

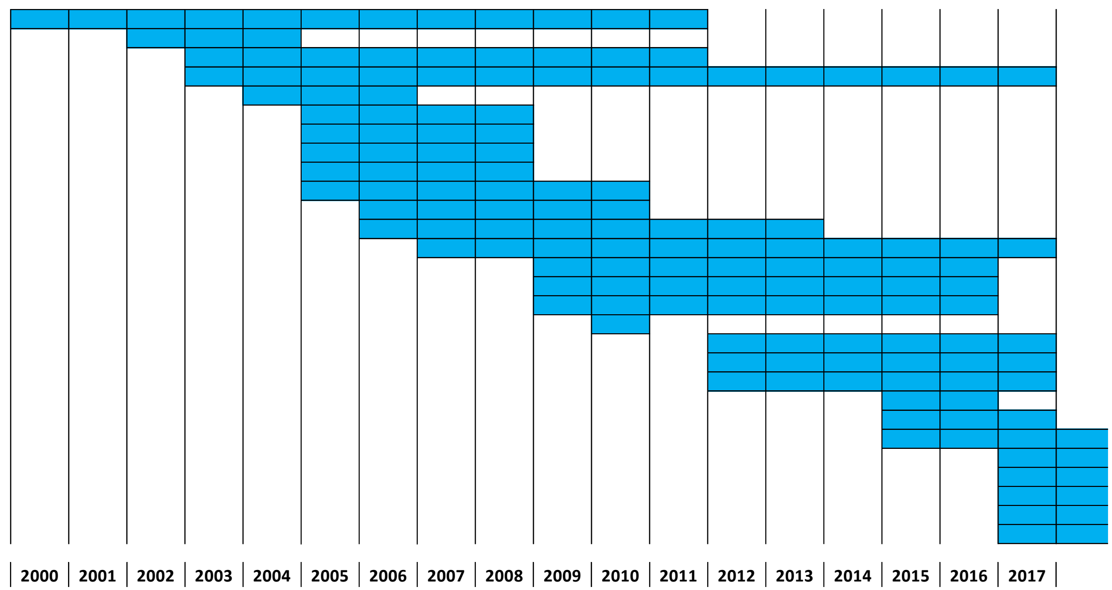
Sensitivity for fuel impurities

Technological maturity

Maritime FC- Developments

- Start with first maritime FC applications in the early 2000
- Mostly based on European and US development programmes
- Technology readiness was proven: **SOFC and PEMFC Technology are most promising for maritime**
- Recent development projects focusing on a **common rule frame work for maritime Fuel Cells**

Maritime Fuel Cell Project Time table



Regulation overview - status

Requirements for on-board energy generation systems

Fuel specific requirements

Maritime Fuel Cell Systems

INTERNATIONAL MARITIME ORGANIZATION

IGF code entered into force Jan. 1st 2017

Contains detail requirements for natural gas as fuel only, and internal combustion engines, boilers and gas turbines

Work started on technical provisions for methyl-/ethyl- alcohols as fuel and fuel cells

Alternative Design Approach

Most classification societies have established Rules covering fuel cells and to some extent low flashpoint liquids

Regulation overview - Alternative Design

Currently, for Fuel Cells and Hydrogen

- IGF codes provides the possibility for alternative design process
- The *equivalence* of the alternative design shall be demonstrated by a ***risk-based approach*** as specified in SOLAS regulation II-1/55 and approved by the Administration
- The "Guidelines on Alternative Design and Arrangements for SOLAS Chapters II-1 and III (MSC.1 / Circ. 1212)" providing guidance to perform the ***Alternative Design Process***

Preliminary Analysis

- Identification of rule deviations
- Hazard Identification
- Scenarios, methods and assumptions for quantification

Quantitative Analysis

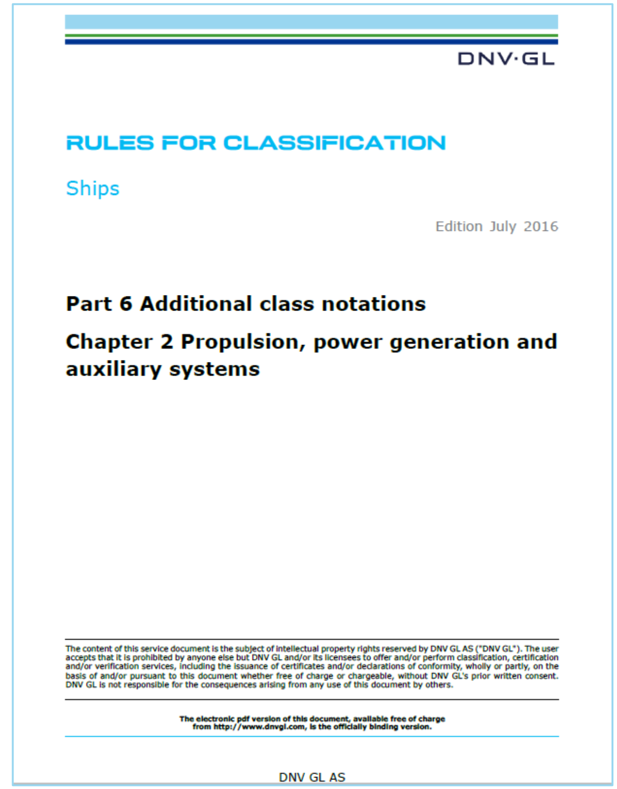
- Quantification of selected scenarios
- Comparison to conventional design

Report of Assessment

- Documentation
- Presentation to flag

Regulation overview -DNVGL Fuel Cell Rules

- DNVGL Rules for Classification – Ships
  - Part 6 Chapter 2 Section 3 – **Fuel Cell Installations – FC**
    - The Rules offer two class notations:
    - **FC(Power)**
      - Given to ships that fulfils design requirements in the Rules, where the FCs are used for essential-, important- or emergency services.
    - **FC(Safety)**
      - Given to ships that fulfils the environmental- and safety requirements in the Rules, where the FCs are not used for essential-, important- or emergency services.



DNV·GL

RULES FOR CLASSIFICATION

Ships

Edition July 2016

Part 6 Additional class notations

Chapter 2 Propulsion, power generation and auxiliary systems

The electronic pdf version of this document, available free of charge from http://www.dnvgl.com, is the officially binding version.

DNV GL AS

Maritime Fuel Cell Product Certification/Type Approval – under development

- DNVGL has initiated the development of a class program CP for Fuel Cell Power Installations, describing the procedures and technical requirements for the approval and certification of such systems (similar to the DNV GL CP-0418 for Lithium Batteries https://rules.dnvgl.com/docs/pdf/DNVGL/CP/2015-12/DNVGL-CP-0418.pdf).

- Technical basis will be e.g. the draft of the IGF-Code for fuel cells, the DNVGL CG-0339 'Environmental test specification for electrical, electronic and programmable equipment and systems‘ https://rules.dnvgl.com/docs/pdf/DNVGL/CG/2015-11/DNVGL-CG-0339.pdf and the IEC 62282 'Fuel Cell Technologies'.

- Since the technical requirements for fuel cell power installations are equivalent for case-by-case or type approval (only the procedure is different) and due to the very different kinds of fuel cells (PEM, HTPEM, HTFC etc.) the procedures and the technical requirements for approval and certification (CbC or TA) of such systems will be developed together with manufacturer and class until the above mentioned Class Program is available.

Maritime FC- Noteable Projects






FellowSHIP	320 kW MCFC system for auxiliary power of Offshore Supply Vessel	Eidesvik Offshore, Wärtsilä, DNV	2003-2011	MCFC	320 kW	LNG
ZemShip - Alsterwasser	100 kW PEMFC system developed and tested onboard of a small passenger ship in the area of Alster in Hamburg, Germany	Proton Motors, GL, Alster Touristik GmbH, Linde Group etc.	2006-2013	PEM	96 kW	Hydrogen
E4Ships - SchIBZ MS Forester	100 kW containerized SOFC system developed and tested for the auxiliary power supply of comercial ships. Scalable up to 500 kW units.	Thyssen Krupp Marine Systems, DNVGL, Leibniz University Hannover, OWI, Reederei Rörd Braren, Sunfire	Phase 1: 2009-2017 Phase 2: 2017-2022	SOFC	100 kW	Diesel
E4Ships – Pa-X-ell MS MARIELLA	60 kW modularized HT-PEM fuel cell system developed and tested for the decentralized auxiliary power supply onboard passenger vessel MS MARIELLA.	Meyer Werft, DNVGL, Lürssen Werft, etc	Phase 1: 2009-2017 Phase 2: 2017-2022	HTPEM	60 kW (each stack is 30 kW)	Methanol
Nemo H2	Small passenger ship in the canals of Amsterdam	Rederij Lovers etc	2012-present	PEM	60 kW	Hydrogen
RiverCell	250 kW modularized HT-PEM fuel cell system developed and to be tested as a part of a hybrid power supply for river cruice vessles	Meyer Werft, DNVGL, Neptun Werft, Viking Cruises	Phase 1: 2015-2017 Phase 2: 2017-2022	HTPEM	250 kW	Methanol
SF-BREEZE	Feasibility study of a high-speed hydrogen fuel cell passenger ferry and hydrogen refueling station in San Francisco bay area	Sandia National Lab., Red and White Fleet	2015 - present	PEM	120 kW per module. Total power 2.5MW	Hydrogen

Zero/V - Hydrogen Fuel-Cell Coastal Research Vessel

Sandia partnered with the Scripps Institution of Oceanography, the naval architect firm Glosten and the class society DNV GL to assess the technical, regulatory and economic feasibility of a hydrogen fuel-cell coastal research vessel.

Report published on 7th May- http://energy.sandia.gov/transportation-energy/hydrogen/market-transformation/maritime-fuel-cells/

APPROVAL IN PRINCIPLE
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Maritime Hydrogen Projects

Customer	Scope	Time
Norwegian Public Roads Administration	H2 Ferry 2020 -Study of technical, regulatory and financial feasibility of hydrogen fuel cell ferry by 2020. Frame agreement supporting NPRA in their process for the hydrogen electric ferry that shall be built from dec 2018 – sept 2020, then tested and start normal operation with passengers in 2021.	2016-2021
Green Coastal Shipping Programme – Hydrogen Pilot	Hybrid hydrogen fuel cell powered high speed passenger ferry in Flora. DNV GL contributions are feasibility of concept, cost estimates, emissions savings, regulatory and safety aspects. Launch planned for 2021.	2017
Fiskerstrand. HYBRIDskip	Hybrid hydrogen (700 – 100 kg H2/day)fuel cell ferry with batteries. Ferry to start operation by 2020. DNV GL contribute with safety and classification competence and experience. 2017-2018 activities supported by PILOT-E.	2017-2018
European Maritime Safety Agency (EMSA)	Study on the use of fuel cells in shipping covering fuel cell technologies, review of applicable standards, regulations and guidelines, regulative gaps, safety assessment (Available on: http://emsa.europa.eu/main/air-pollution/alternative-fuels.html)	2016-2017
Sogn og Fjordane County Authority	Potential for hydrogen production, utilisation and value creation in Western Norway. Hydrogen value chains including maritime use. Technologies, market, potential production sites, scenarios for future hydrogen demand, regional competence. (Source https://www.dnvgl.no/publications/index.html)	2016
Eidesvik JIP	FellowSHIP/Viking Lady 330 kW molten carbonate FC for auxilliary power. Hybrid supply vessel with DNV GL class notation – Fuel Cell Safety	2009

DNV GL's services on Fuel Cell / Hydrogen

R&D	•Applied research and development including *experimental* setups •Explosion and fire experiments and research
Innovation & demonstration	•Realization of *demonstration* projects •Techno-economic *road mapping* for technology or solutions •System integration with renewables/electricity/..
Implementation support	•Technology qualification •Explosion and fire save design analysis •*Recommended practice* and standards development •Guideline for HRS user interface improvement process
Realisation support	•Consortium initiation/execution •*Safety assessments* (HAZOP, HAZID, QRA, RRR, CFD modeling)
Operational excellence	•Custody transfer? •Performance validation •Process optimization •H2 Incident and accident database (HIAD)

Safer, Smarter, Greener...

EMSA Report available at http://www.emsa.europa.eu or search www: EMSA + DNVGL + fuel cell

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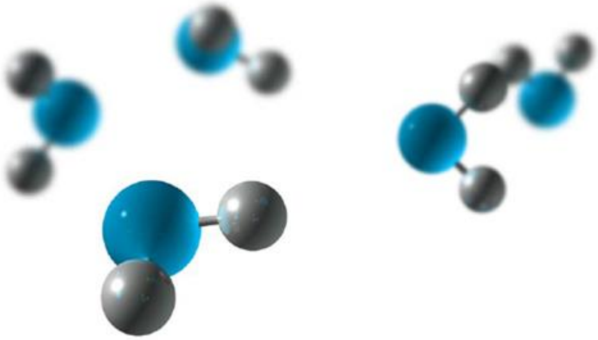

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