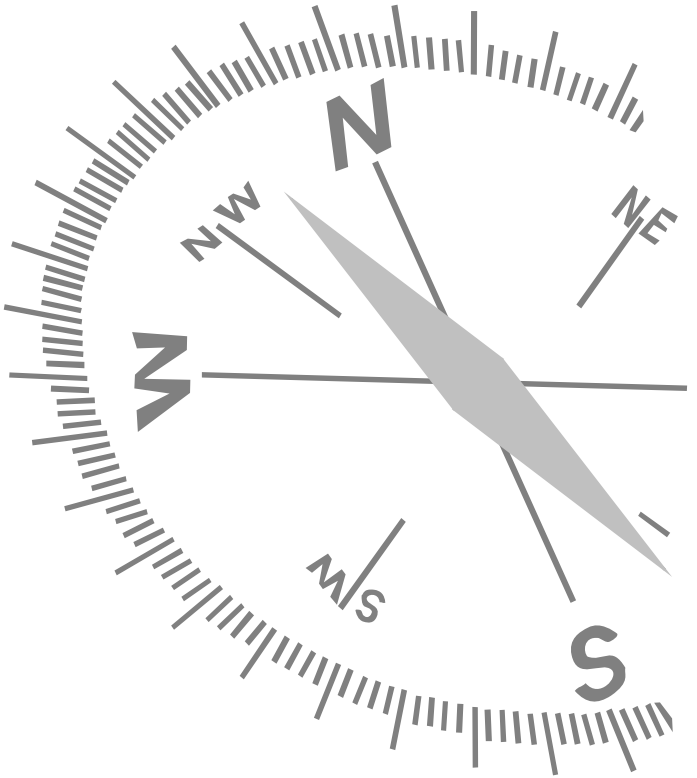
DNV·GL

MARITIME ACADEMY

(Future) Fuels & Fuel Converters

Navigator

- Fuel types
- Natural gas
- Fuel cells
- Quiz

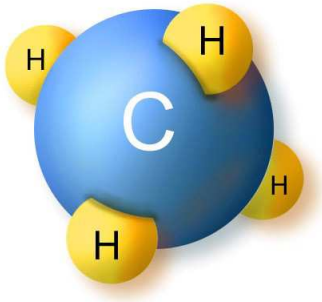


What is a “fuel”?

Fuel: **Substance** which in

- **chemical reaction** with an
- **oxidizer** (typically oxygen) releases
- heat

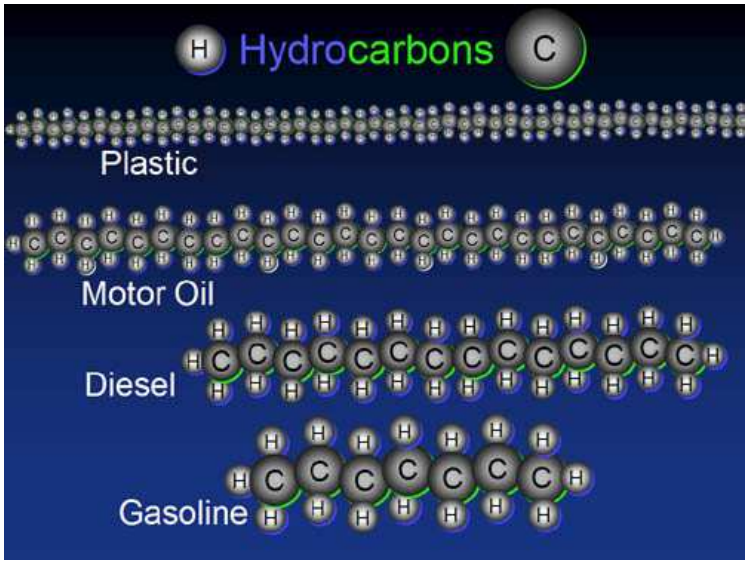
Carbon-based fuels



Most fuels contain carbon-hydrogen compounds

Longer chains:

- **heavier** fuel
- more **viscous** fuel
- **lower calorific** value
- **higher temperature** to evaporate



Fuels – come in different forms

Fuels may be

- solid
- liquid
- gaseous

Fossil vs Renewable

Fuels may be

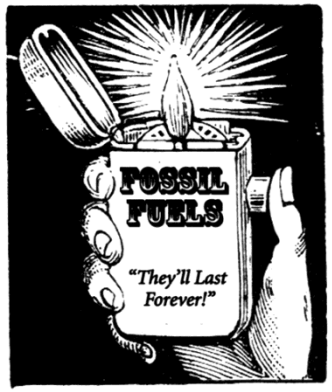
fossil

- coal
- petroleum-crude derived
- natural gas

OR

renewable

- wood
- refuse
- agricultural residues
- bio fuels



Case Study – Fuel & Energy

Rank fuels in energy obtained when 1 g of the fuel is burnt

- alcohol (C_2H_5OH)
- butane gas (C_4H_{10})
- solid carbon (C)
- glucose sugar ($C_6H_{12}O_6$)
- hydrogen gas (H_2)

Place 5

Place 4

Bronze

Silver

Calorific value

Gold

Calorific values

Sugar	**18 kJ/g**	
Alcohol	**30 kJ/g**	
Coal	**30 kJ/g**	
HFO	**41 kJ/g**	Heavy Fuel Oil
MDO	**44 kJ/g**	Marine Diesel Oil
MGO	**45 kJ/g**	Marine Gas Oil
Butane	**50 kJ/g**	main component of LPG
Carbon	**53 kJ/g**	
Hydrogen	**143 kJ/g**	good for storing energy (e.g. from wind)

LPG = Liquid Petroleum Gas

Marine fuels in use

– MGO (Marine Gas Oil)	roughly equivalent to No. 2 fuel oil made from distillate only
– MDO (Marine Diesel Oil)	blend of gasoil and heavy fuel oil
– IFO (Intermediate Fuel Oil)	blend of gasoil and heavy fuel oil (less gasoil than MDO)
– MFO (Medium Fuel Oil)	blend of gasoil and heavy fuel oil (even less gasoil than IFO)
– HFO (Heavy Fuel Oil)	(nearly) pure residual oil roughly equivalent to No. 6 fuel oil

Common fuels

Viscosity of fuels (ordered by increasing price):

- IFO 380 intermediate fuel oil with $\nu \leq 380$ cSt
- IFO 180 intermediate fuel oil with $\nu \leq 180$ cSt
- LS 380 low-sulphur (<1.5%) IFO with $\nu \leq 380$ cSt
- LS 180 low-sulphur (<1.5%) IFO with $\nu \leq 180$ cSt
- MDO Marine diesel oil < 30 cSt at 50°C
- MGO Marine gas oil < 6 cSt at 40°C

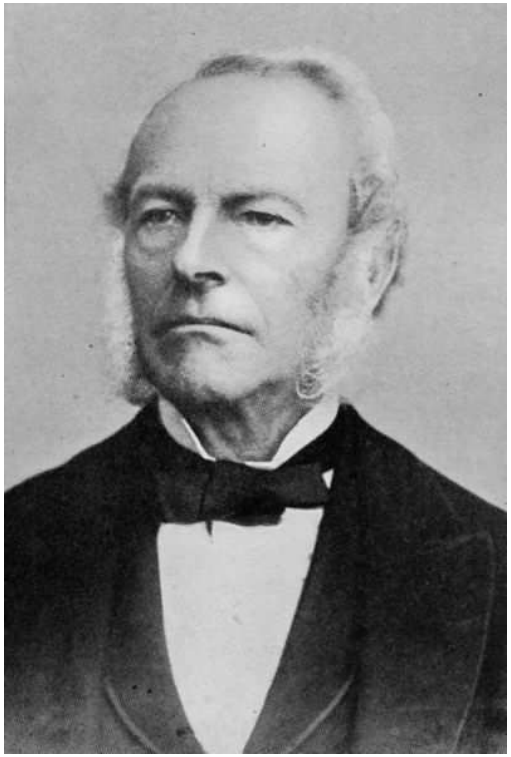
Viscosity

Kinematic viscosity:

$$\nu = \frac{\mu}{\rho}$$

μ = dynamic viscosity [Pa·s]
ρ = density [kg/m^3]
ν = kinematic viscosity [m^2/s]

1 stokes [St] = 1 cm^2/s = 0.0001 m^2/s
1 centistokes [cSt] = 1 mm^2/s = 10^{-6} m^2/s



Sir George Gabriel Stokes, 1st Baronet (1819–1903)

Coming to terms with viscosity 1/3

milk 4.3 cSt

just like...

SAE 20 Crankcase Oil

SAE 75 Gear Oil

Coming to terms with viscosity 2/3

tomato juice 220 cSt

just like...

SAE 50 Crankcase Oil

SAE 90 Gear Oil

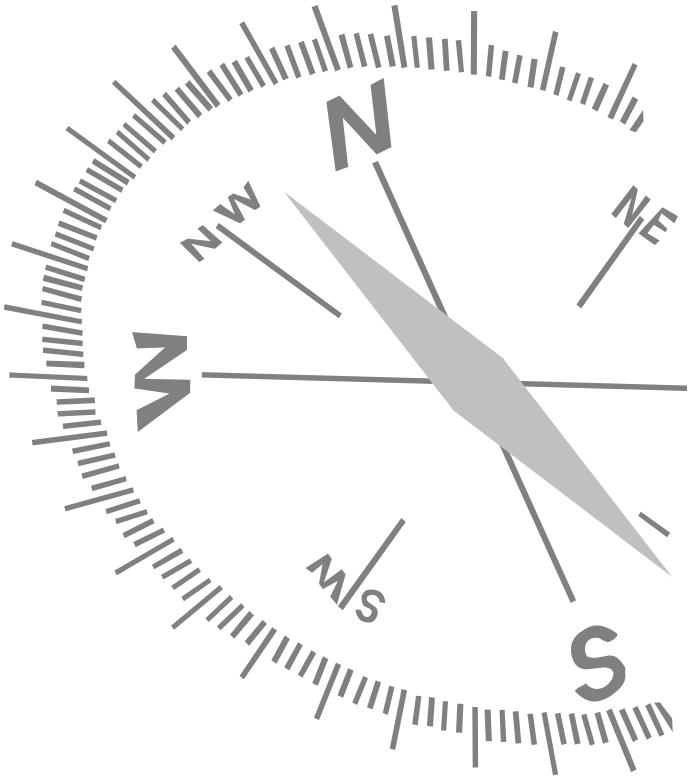
Coming to terms with viscosity 3/3

honey 2200 cSt

Questions so far?

Navigator

- Fuel types
- Natural gas
- Fuel cells
- Quiz

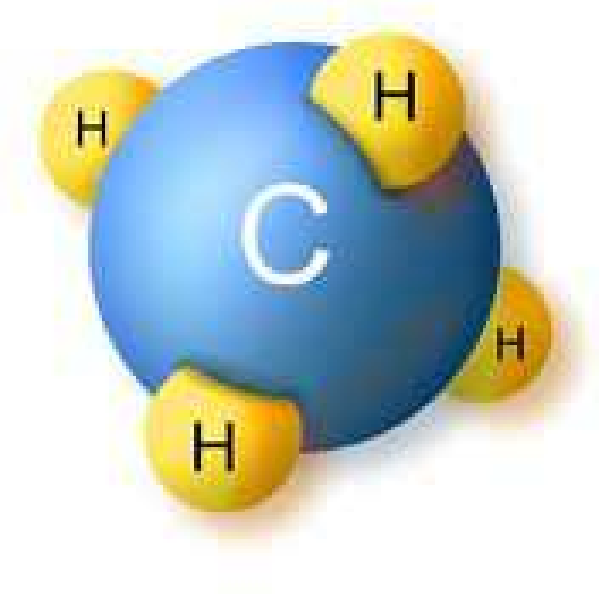


What is “natural gas” ?

- Composition of different gases
- Actual mix depends on gas field (and processing of gas)

What is the main component in natural gas?

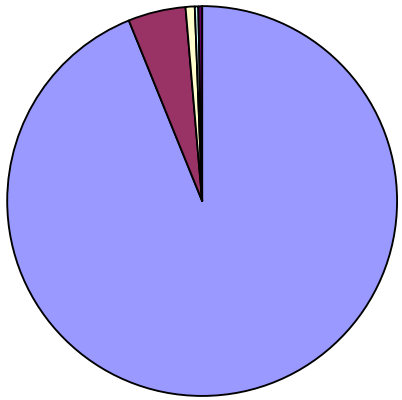
What is the “usual” name of the shown substance ?



(Liquefied) natural gas – Methane dominates

Typical composition in volume %

Methane	94.0 %
Ethane	4.7 %
Propane	0.8 %
Butane	0.2 %
Nitrogen	0.3 %

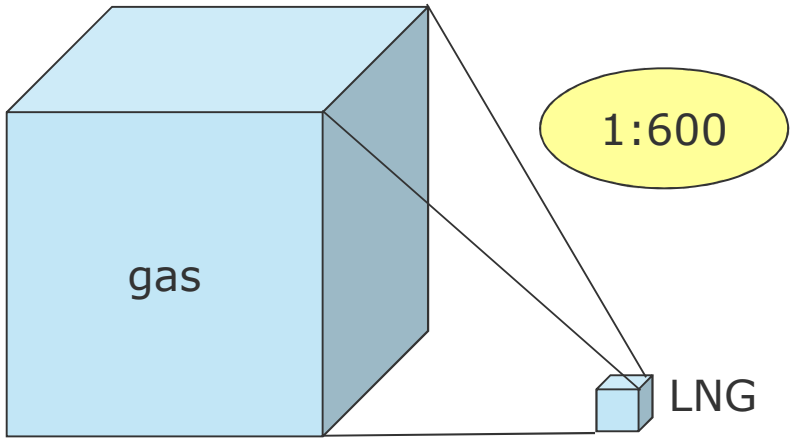


Density: 0.716 kg/m^3 at 273 K (0°C) and ambient pressure

Liquid gas takes up much less space

Volume ratio liquid : gas (LNG) = 1:600

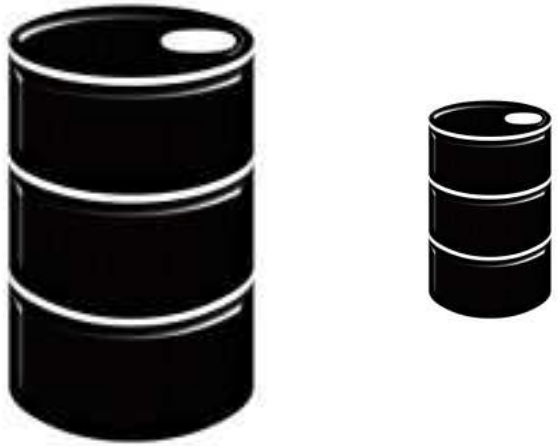
(1 bar, -163°C: ρ = 425.0 kg/m^3)
(1 bar, 0°C: ρ = 0.7 kg/m^3)



Quiz

LNG vs HFO

For the storage of 1 t of LNG, you need...



a. roughly the same...
b. roughly twice the ...
c. roughly five times the ...
d. roughly ten times the ...

...volume as for 1 t of HFO ?

LNG = Liquefied Natural Gas
HFO = Heavy Fuel Oil

Quiz

LNG vs HFO

For 1 m^3 of LNG, you get

a. roughly 10% less than the ...
b. roughly the same ...
c. roughly 10% more than the ...
d. roughly 20% more than the ...

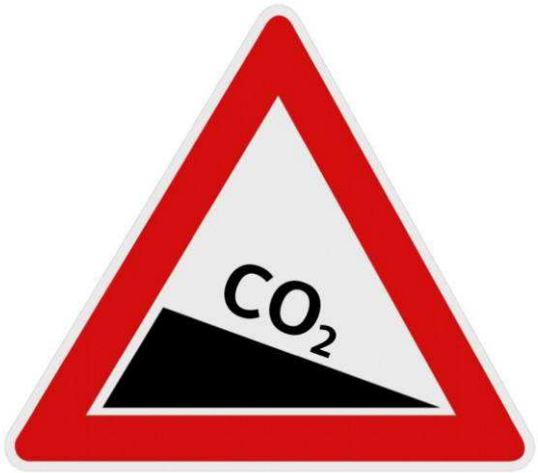
... heat for 1 m^3 of HFO ?

LNG = Liquefied Natural Gas
HFO = Heavy Fuel Oil

Quiz

LNG vs HFO

Compared to HFO, LNG decreases CO2 emissions by roughly...



a. 10% ...
b. 25% ...
c. 40% ...
d. 90% ...

... for the same work [g CO_2/MJ]

LNG = Liquefied Natural Gas
HFO = Heavy Fuel Oil

Cause the fuels, they are a-changing

Over time, the “standard” (or predominant) fuel has changed

Bring the fuels (below in alphabetical order) in correct order of time from medieval times to “future”

- coal
- hydrogen
- natural gas
- oil
- wood

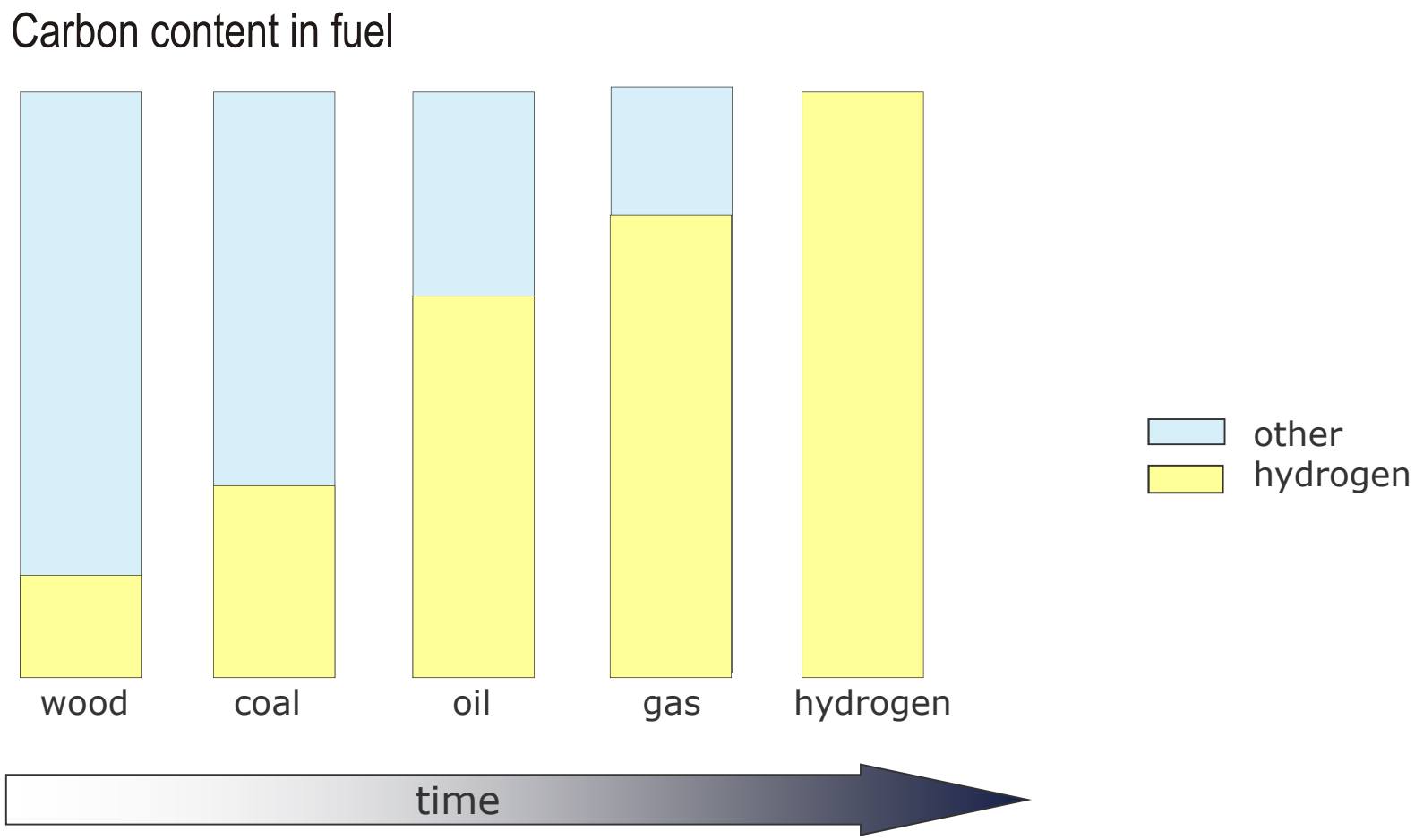
Sort again – by hydrogen content

All fossil fuels contain hydrogen and carbon

Bring the fuels (below in alphabetical order) in correct order of increasing hydrogen content

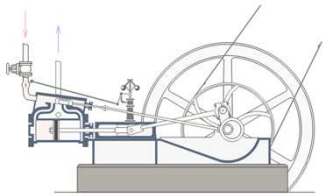
- coal
- hydrogen
- natural gas
- oil
- wood

Fuels have changed over time



Different strokes for different fuels

Engines (Energy converters) change with time (and fuel)

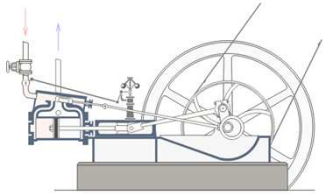


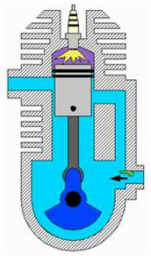
time

19th Century

Different strokes for different fuels

Engines (Energy converters) change with time (and fuel)





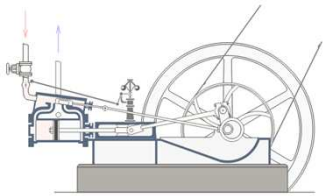
time

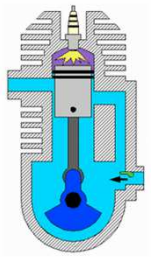
19th Century

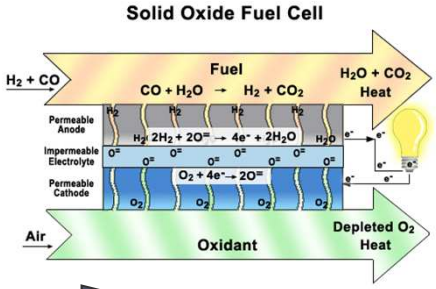
20th Century

Different strokes for different fuels

Engines (Energy converters) change with time (and fuel)







time

19th Century

20th Century

21th Century

Questions so far?

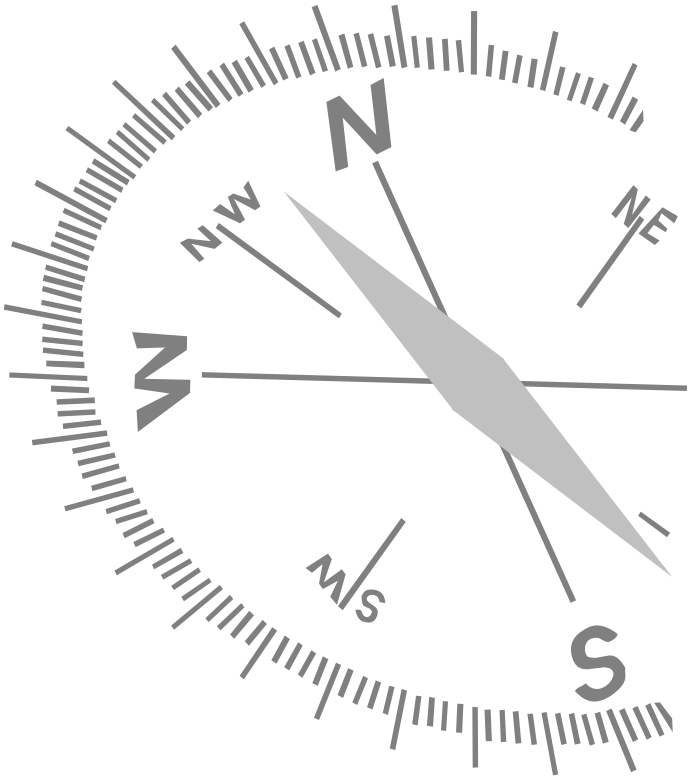
Navigator

Fuel types

Natural gas

Fuel cells

Quiz



What is a fuel cell ? 1/2

Let's start with something similar, but much more familiar

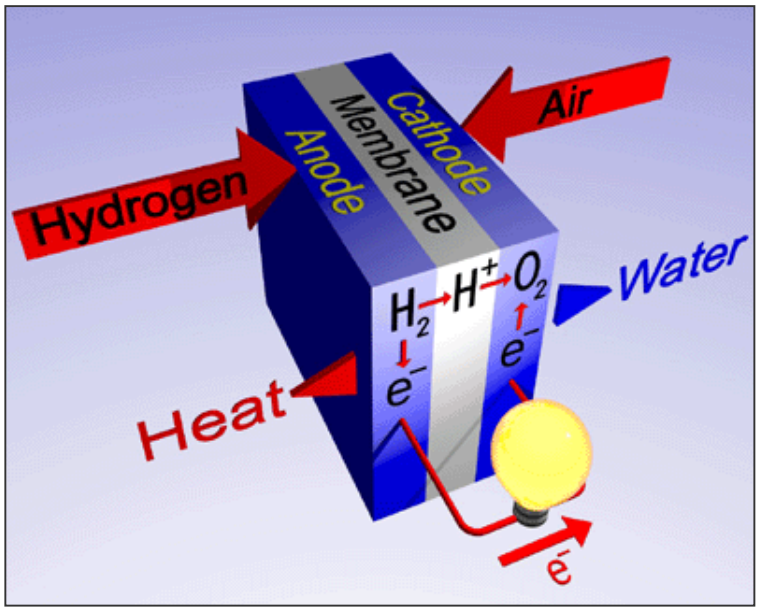
An electro-chemical energy conversion device ...
... or simply: "**battery**"

- all chemicals stored inside
- converts the chemicals to electricity
- will eventually "go dead"

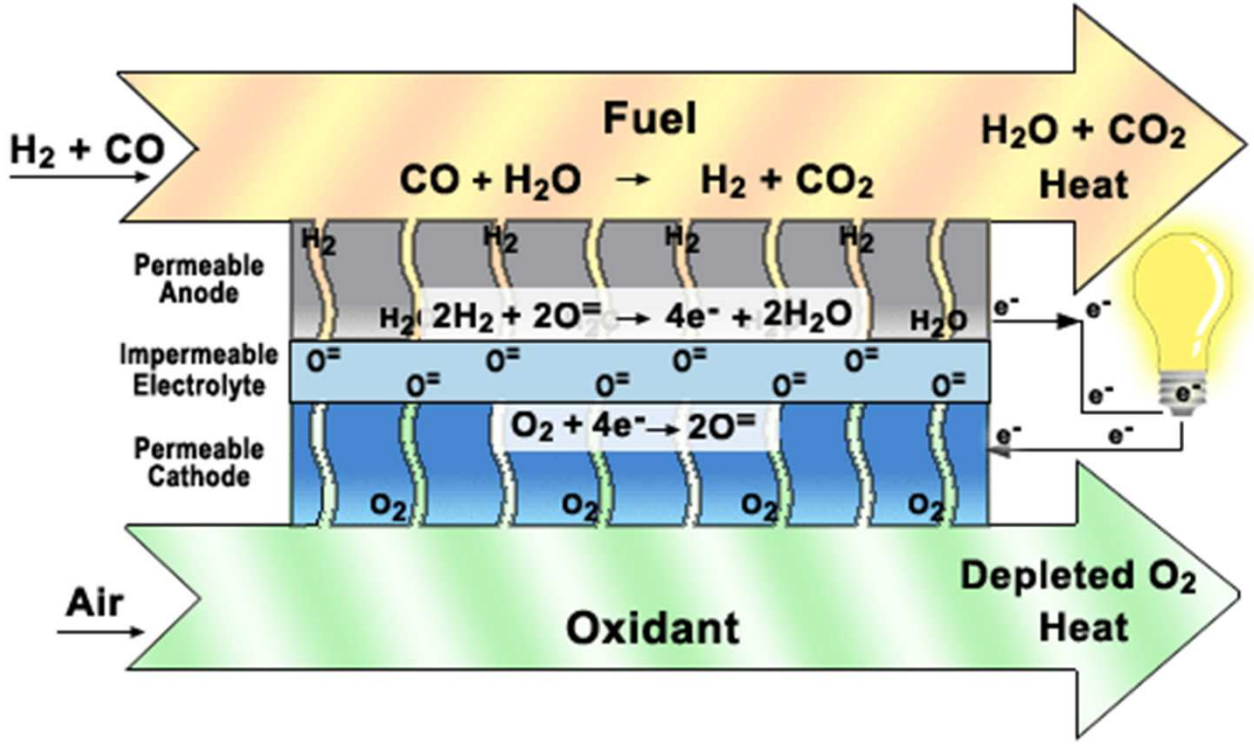
What is a fuel cell ? 2/2

Also an electro-chemical energy conversion device

- Chemicals constantly flow into the cell (it never "goes dead").
- Most fuel cells use hydrogen & oxygen, producing water & electricity.



Fuel cell in action



Source: NASA

Many variations on the theme

Fuel cell types differ by:

- electrolyte (main classifier)
  - PEM (Proton Exchange Polymer)
  - PAFC (Phosphoric Acid Fuel Cell)
  - MCFC (Molten Carbonate Fuel Cell)
  - SOFC (Solid Oxide Fuel Cell)
- fuel (hydrogen, methanol, ethanol, natural gas, carbon-monoxide, ...)
- oxidant (usually oxygen)
- temperature
  - low temperature (< 100°C)
  - high temperature (600-1100°C)

Cool and fast...

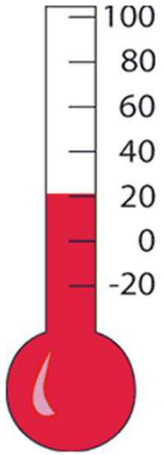
Low-temperature fuel cells

☺ rapid start-up

☹ requires hydrogen or methanol as fuel
☹ catalysts easily poisoned
☹ low efficiency

Applications:

- portable devices
- frequent on/off cycles
- compact devices



Hot and slow…

High-temperature fuel cells

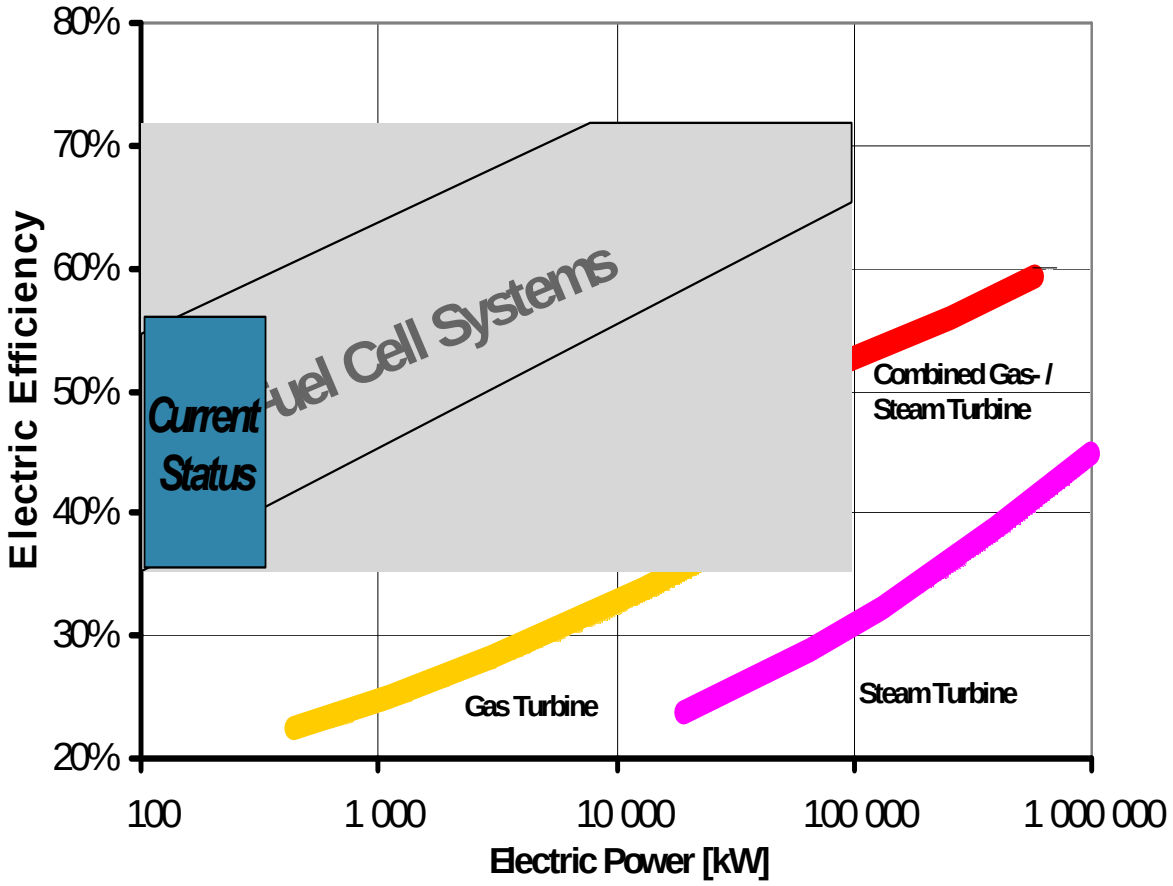
☺ fuel flexible
☺ high efficiency

☹ long start-up

Applications:

- stationary power
- ships

Higher efficiency than diesel engines



History of fuel cells

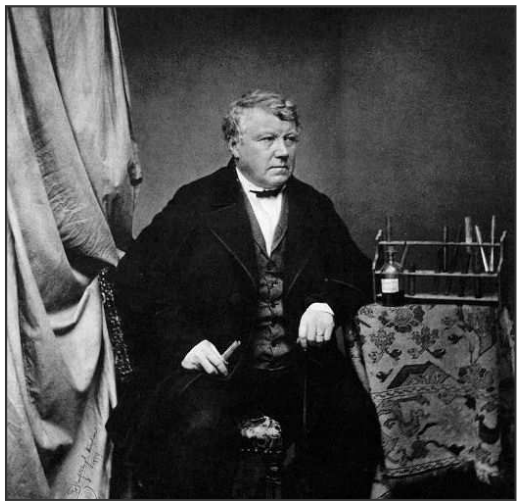
1838 Christian Friedrich Schönbein (Germany)

chemist

discovers principle of fuel cells

(using two platinum wires and sulphuric acid)

discovered also guncotton and ozone



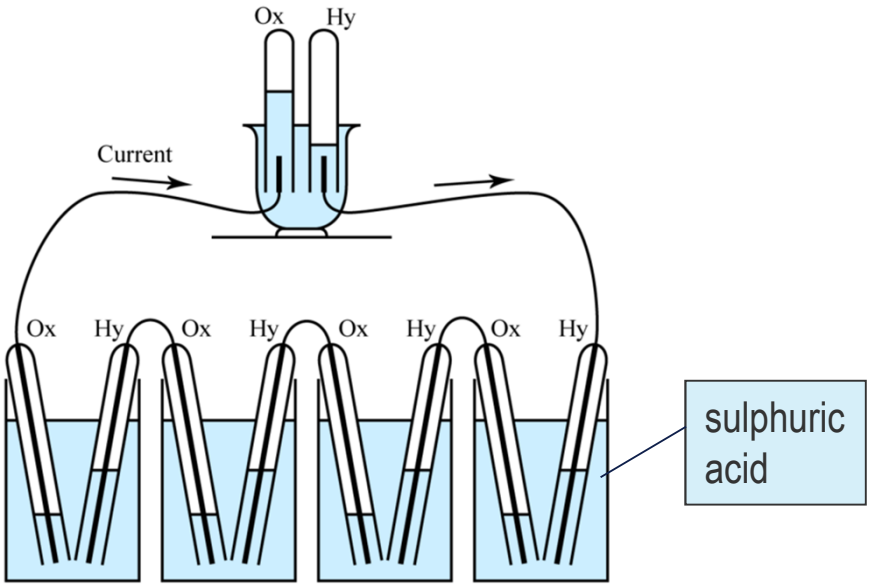
History of fuel cells

1839 Sir William Grove (UK)

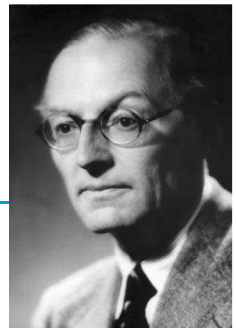
lawyer & physical scientist

first working prototype

voltage ~1 V



History of fuel cells



1932 Francis Thomas Bacon (UK)

chemical engineer

development of practical fuel cells

in 1959: 5 kW alkaline fuel cell, efficiency 60%

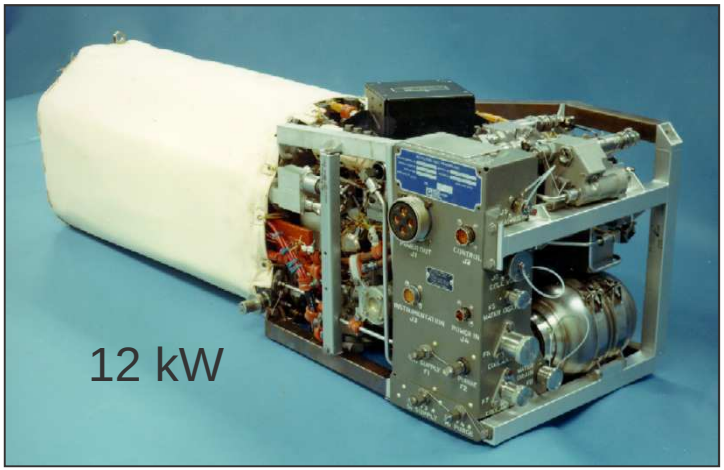
History of fuel cells

1960s NASA modifies Bacon fuel cell

used to supply on-board drinking water & electricity

in Apollo missions

later also in Space Shuttle missions



12 kW

100 kg

0.15 m^3

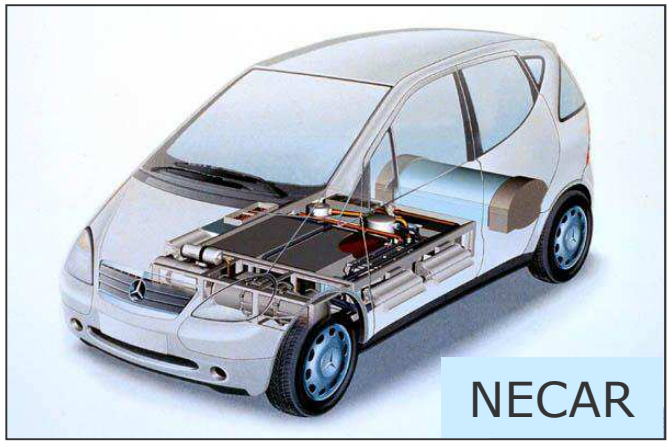
Source: NASA

History of fuel cells

1980s Fuel cells for cars

significant increase in power density over time

all major car manufacturers presented fuel cell prototypes by 2010



History of fuel cells

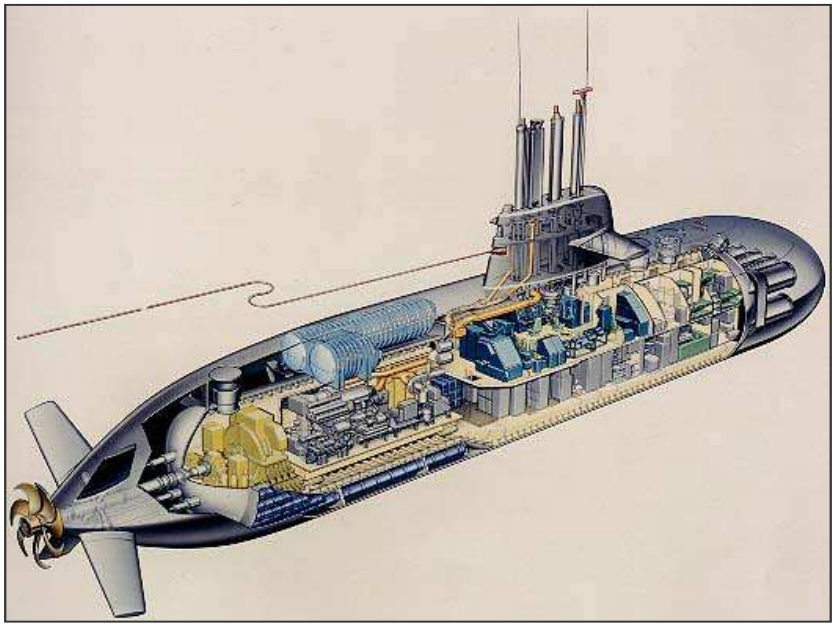
2006 Hamburg tests fuel cell bus

Mercedes Benz Citaro Hybrid-Bus

9 buses used in public transport

History of fuel cells

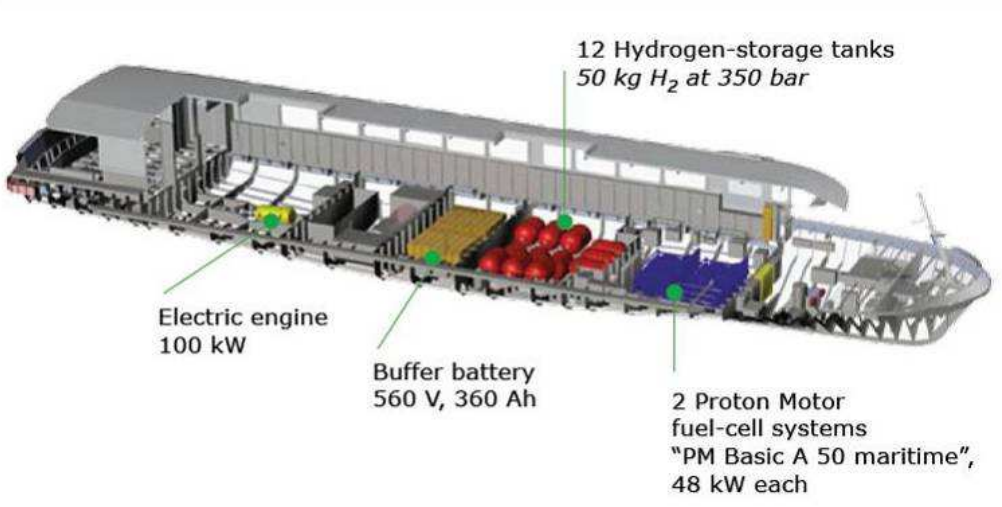
2000 U 212 and U 214 submarines (Germany)
uses PEM fuel cells for air independent propulsion



PEM = Proton Exchange Membrane

Fuel cells for tourist boats

2008 Fuel Cell Ship (FCS) "Alsterwasser"
operated as zero emission ship on lake Alster in Hamburg
driven by fuel cells
co-developed by Germanischer Lloyd



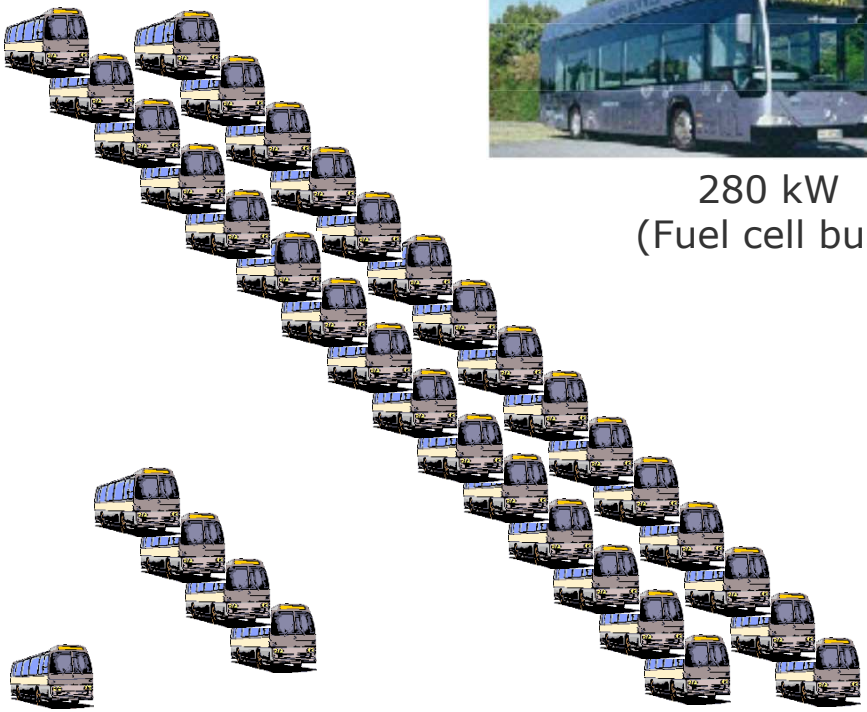
The propulsion system (Source: Schiffstechnik Buchloh)

Fuel cells for ships – A different scale!

Main Engine 8400 kW

Auxiliary Engine 1000 kW

Emerg. Generator
232 kW



280 kW
(Fuel cell bus)

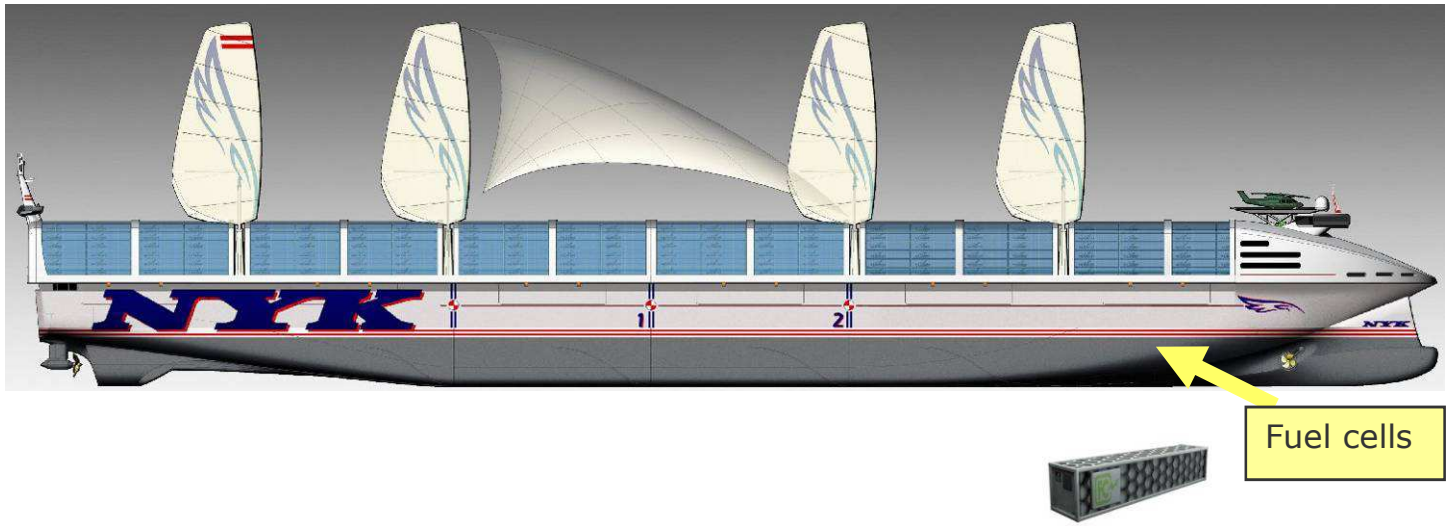
Future technology

2030 Super ECO 2030

Concept study for large container vessel (NYK)

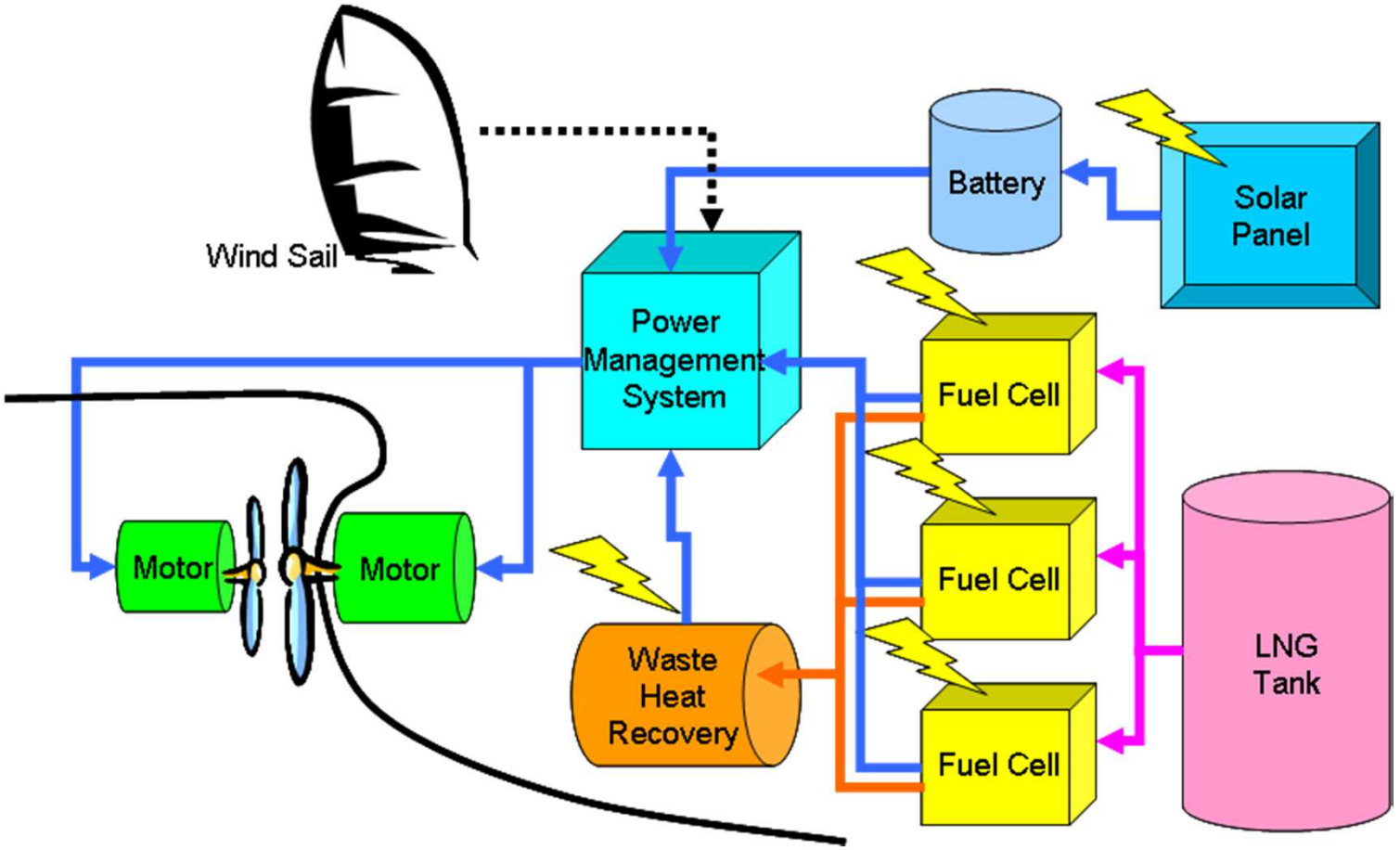
various technologies incl. fuel cells

(claiming 32% less CO_2 due to fuel cells alone)



Source: NYK

Mix of technologies for power supply



Source: NYK

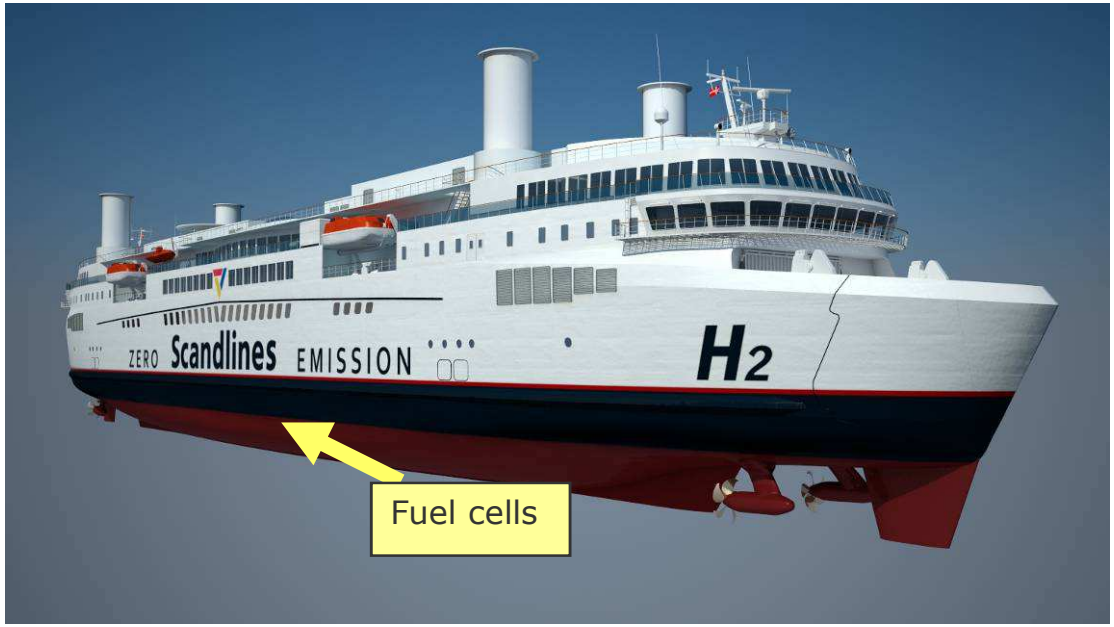
Future technology

2018 (?)

Zero-Emission Scandlines project (FutureShip design)

hydrogen-powered fuel cells

use excess wind power to generate hydrogen



Future technology

2030 GL ZERO (zero-emission Feeder)
Concept study of Germanischer Lloyd
fuel cells + batteries (technology of 2010)

Movie time – Zero-emission feeder

Fuels & Fuel Converters

Questions so far?

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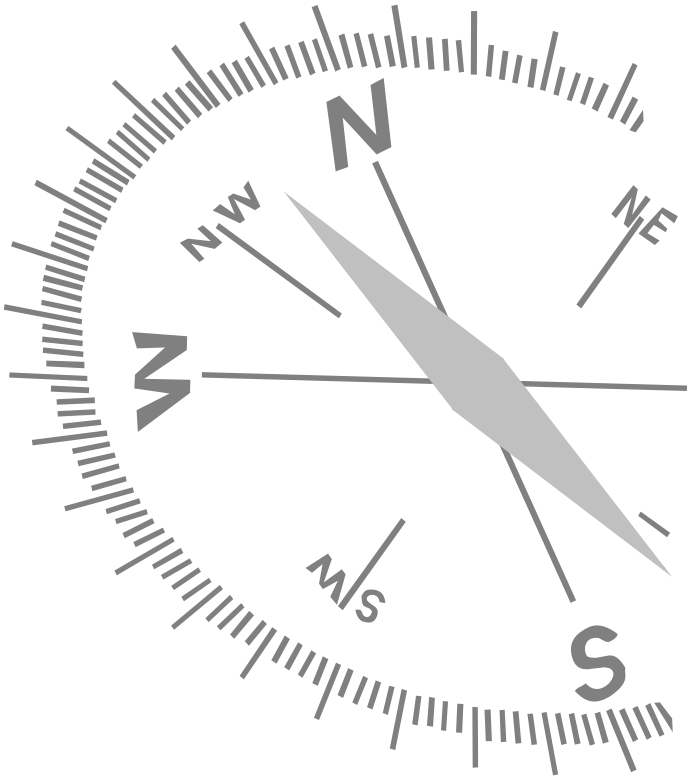
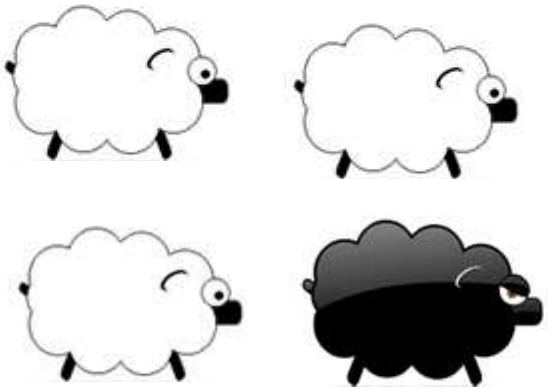


Quiz: Do you know your fuel types ?

What is not true ?

Longer chains in hydro-carbons lead to...



a. heavier fuel
b. lower temperature to evaporate
c. higher viscosity
d. lower calorific value

What is not a fossil fuel ?

a. hydrogen
b. coal
c. heavy fuel oil
d. LNG

Which fuel has the highest calorific value ?

a. alcohol
b. butane gas
c. coal
d. glucose sugar

Which fuel has the highest calorific value ?

a. Heavy Fuel Oil (HFO)
b. Marine Gas Oil (MGO)
c. Marine Diesel Oil (MDO)
d. Liquefied Natural Gas (LNG)

Which fuel contains the most gasoil percentage?

a. HFO

b. IFO

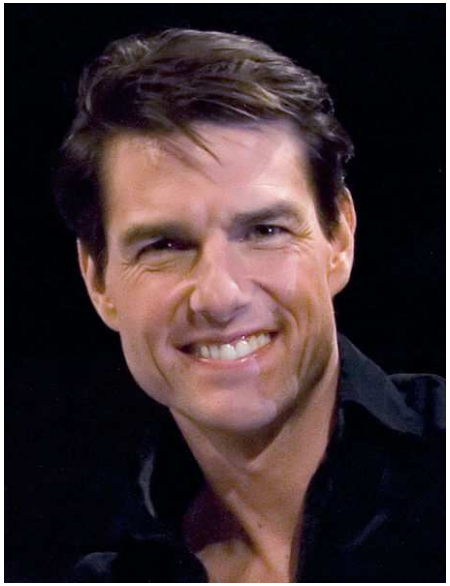
c. MDO

d. MFO

IFO 180 is closest in viscosity to...

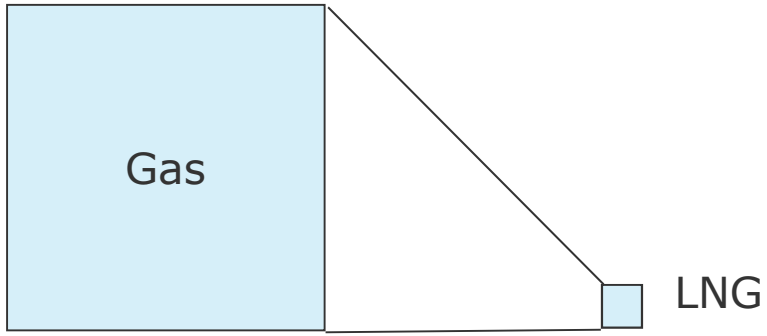
a. Milk
b. Tomato juice
c. Honey
d. Tooth paste

What is the main component in natural gas ?



a. Ethane
b. Methane
c. Nitrogen
d. Propane

The volume ratio between LNG and natural gas is…



a. 1:600

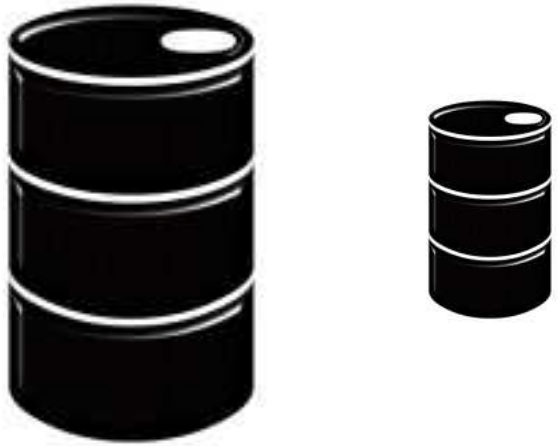
b. 1:200

c. 1:64

d. 1:8

LNG vs HFO

For the storage of 1 t of LNG, you need...



a. roughly the same...
b. roughly twice the ...
c. roughly five times the ...
d. roughly ten times the ...

...volume as for 1 t of HFO

LNG = Liquefied Natural Gas
HFO = Heavy Fuel Oil

LNG vs HFO

For 1 m^3 of LNG, you get

a. roughly 10% less than the ...

b. roughly the same ...

c. roughly 10% more than the ...

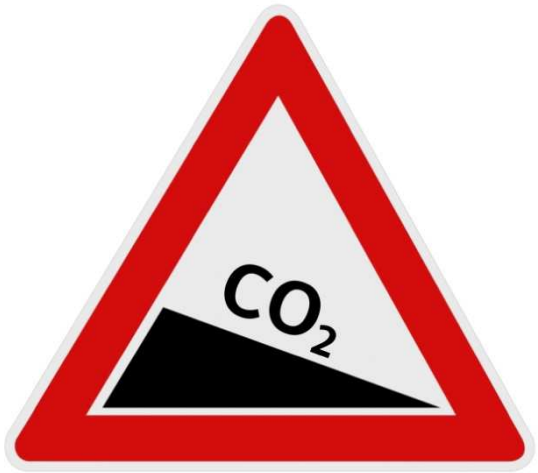
d. roughly 20% more than the ...

... heat for 1 m^3 of HFO

LNG = Liquefied Natural Gas
HFO = Heavy Fuel Oil

LNG vs HFO

Compared to HFO, LNG decreases CO2 emissions by roughly...



a. 10% ...
b. 25% ...
c. 40% ...
d. 90% ...

... for the same work [g CO2/MJ]

LNG = Liquefied Natural Gas
HFO = Heavy Fuel Oil

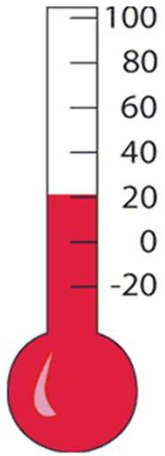
Which fuel has the lowest hydrogen content ?

a. wood
b. coal
c. oil (HFO)
d. natural gas

What is NOT used as fuel for fuel cells ?

a. LNG
b. liquid hydrogen
c. liquid oxygen
d. methanol

Low-temperature fuel cells ...



a. ... have slow start-up

b. ... have high efficiency

c. ... do not use LNG as fuel

d. ... are bulky devices

High-temperature fuel cells ...

a. ... have slow start-up
b. ... have low efficiency
c. ... do not use LNG as fuel
d. ... are used on portable devices

Fuel cells generate ...

a. ... drinking water & electricity

b. ... heat & vibrations

c. ... electricity & vibrations

d. ... phosphoric acid & heat

Coffee break