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 \( (H_2) \)
Calorific value

Place 5
Calorific value

Place 4
Calorific value

Bronze
Calorific value

Silver
Calorific value

Gold
### Calorific values

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Calorific Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>18 kJ/g</td>
<td></td>
</tr>
<tr>
<td>Alcohol</td>
<td>30 kJ/g</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>30 kJ/g</td>
<td></td>
</tr>
<tr>
<td>HFO</td>
<td>41 kJ/g</td>
<td>Heavy Fuel Oil</td>
</tr>
<tr>
<td>MDO</td>
<td>44 kJ/g</td>
<td>Marine Diesel Oil</td>
</tr>
<tr>
<td>MGO</td>
<td>45 kJ/g</td>
<td>Marine Gas Oil</td>
</tr>
<tr>
<td>Butane</td>
<td>50 kJ/g</td>
<td>main component of LPG</td>
</tr>
<tr>
<td>Carbon</td>
<td>53 kJ/g</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>143 kJ/g</td>
<td>good for storing energy (e.g. from wind)</td>
</tr>
</tbody>
</table>

LPG = Liquid Petroleum Gas
# Marine fuels in use

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO (Marine Gas Oil)</td>
<td>Roughly equivalent to No. 2 fuel oil, made from distillate only</td>
</tr>
<tr>
<td>MDO (Marine Diesel Oil)</td>
<td>Blend of gasoil and heavy fuel oil</td>
</tr>
<tr>
<td>IFO (Intermediate Fuel Oil)</td>
<td>Blend of gasoil and heavy fuel oil (less gasoil than MDO)</td>
</tr>
<tr>
<td>MFO (Medium Fuel Oil)</td>
<td>Blend of gasoil and heavy fuel oil (even less gasoil than IFO)</td>
</tr>
<tr>
<td>HFO (Heavy Fuel Oil)</td>
<td>(Nearly) pure residual oil, roughly equivalent to No. 6 fuel oil</td>
</tr>
</tbody>
</table>
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:

\[ \nu = \frac{\mu}{\rho} \]

\(\mu\) = dynamic viscosity [Pa·s]
\(\rho\) = density [kg/m\(^3\)]
\(\nu\) = 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, 1\(^{st}\) 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
honey  2200 cSt
Questions so far?
Fuel types
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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/m³ 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: \( \rho = 425.0 \text{ kg/m}^3 \))
(1 bar, 0°C: \( \rho = 0.7 \text{ kg/m}^3 \))
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
For 1 m³ 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 m³ of HFO?
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
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

Carbon content in fuel

- Wood
- Coal
- Oil
- Gas
- Hydrogen

- Other
- Hydrogen
Different strokes for different fuels

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

19th Century
Different strokes for different fuels

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

19th Century

20th Century
Different strokes for different fuels

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

19th Century

20th Century

21st Century
Questions so far?
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Quiz
What is a fuel cell?

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?

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 \( \sim 1 \) 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

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

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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 CO₂ due to fuel cells alone)

Source: NYK
Mix of technologies for power supply

Source: NYK
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)
Questions so far?
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

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...volume as for 1 t of HFO

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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