The Future of Energy

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MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

OP Vzdělávání pro konkurenceschopnost

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Contents

- Smartgrids
- Virtual Power Plant
- Nuclear Fusion
- Storage of Electricity
- Fuel cells and hydrogen

Smartgrids

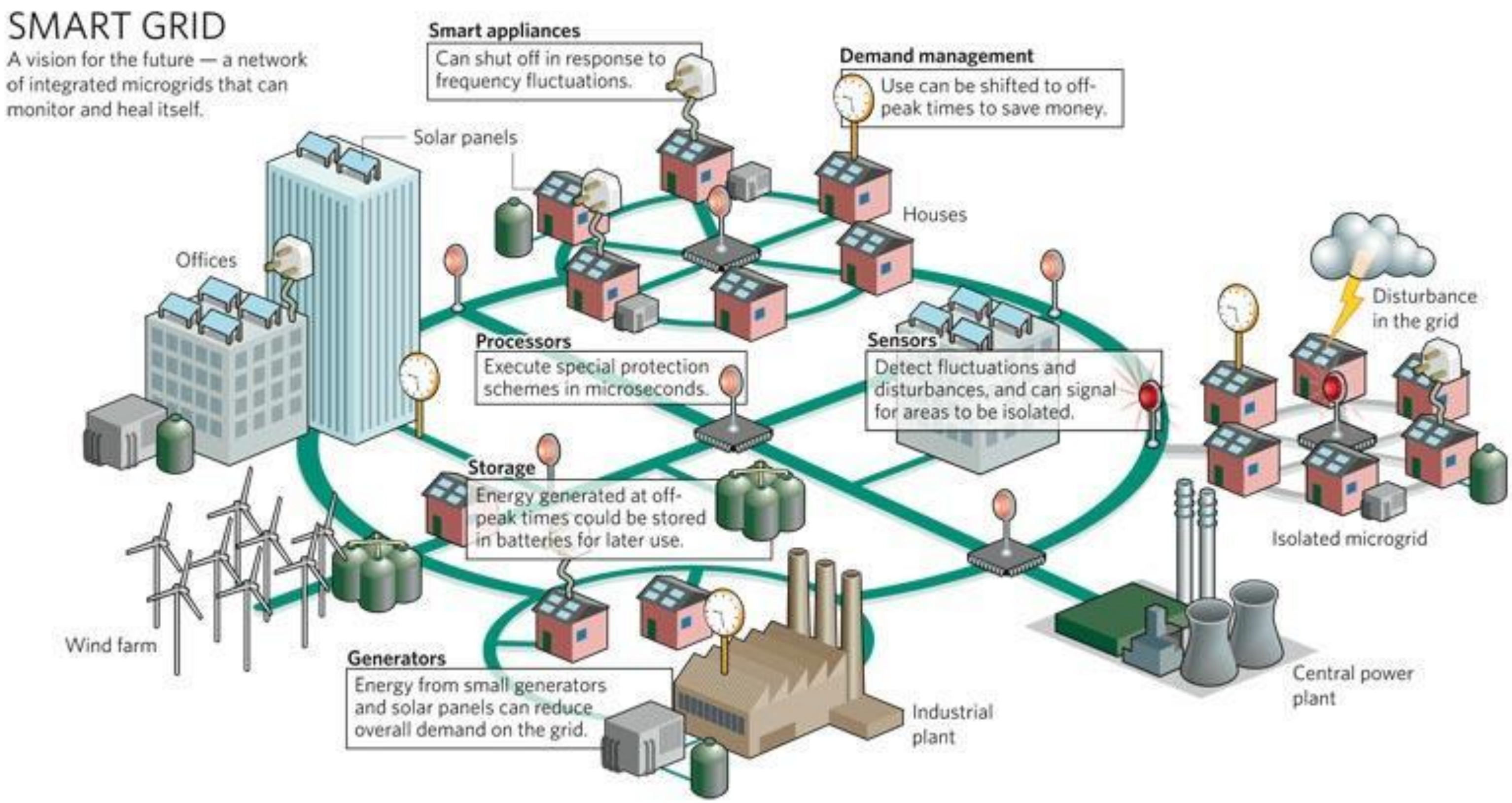
- *„A smart grid is a modernized electrical grid that uses analogue or digital information and communications technology to gather and act on information, such as information about the behaviours of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity. “*

(U.S. Department of Energy.)

Smartgrids

- Goals:
  - More efficient use of energy
  - Limitation of crisis situations in the network
  - Integration of alternative sources
  - Integration of new appliances
  - Providing online information about the price of electricity and the subsequent management of the network

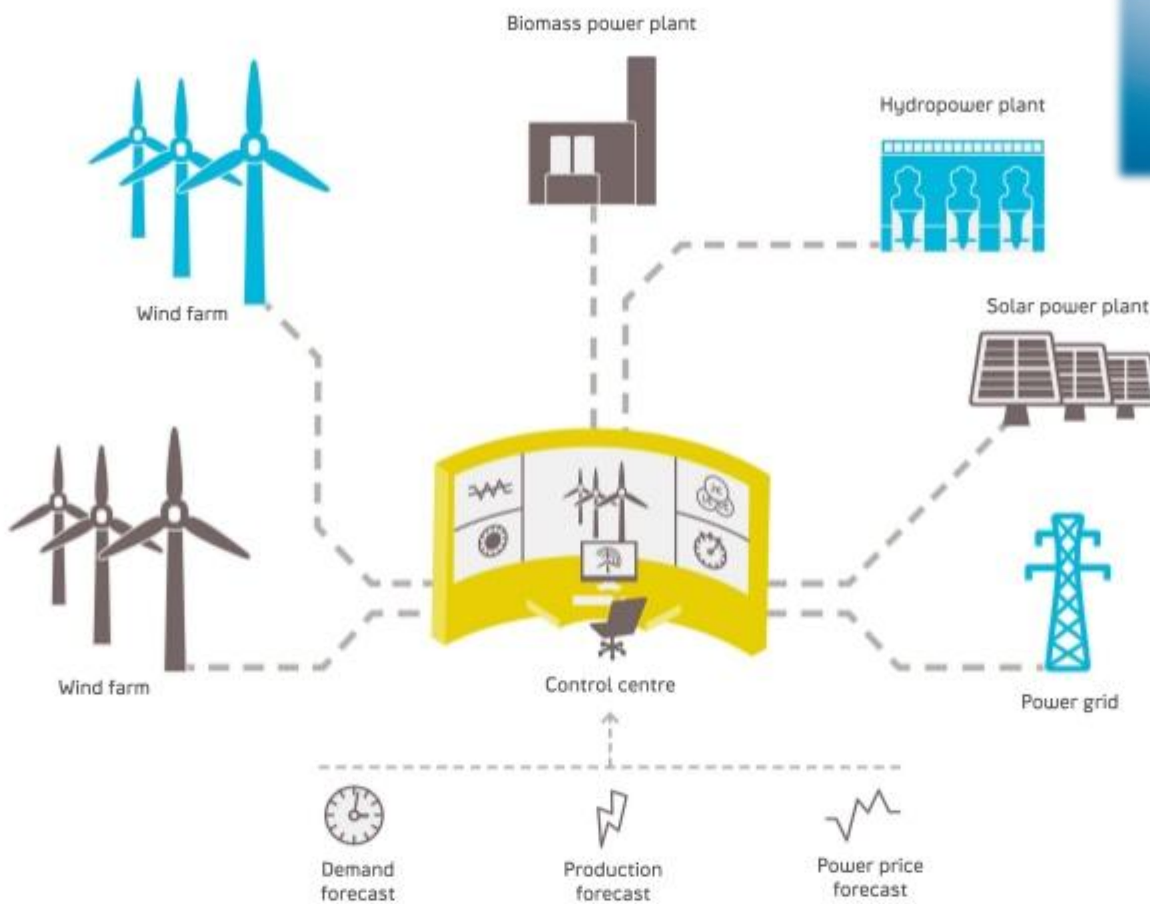
Smartgrids


SMART GRID
A vision for the future — a network of integrated microgrids that can monitor and heal itself.
Smart appliances
Can shut off in response to frequency fluctuations.
Demand management
Use can be shifted to off-peak times to save money.
Solar panels
Houses
Offices
Disturbance in the grid
Processors
Execute special protection schemes in microseconds.
Sensors
Detect fluctuations and disturbances, and can signal for areas to be isolated.
Storage
Energy generated at off-peak times could be stored in batteries for later use.
Isolated microgrid
Wind farm
Generators
Energy from small generators and solar panels can reduce overall demand on the grid.
Industrial plant
Central power plant

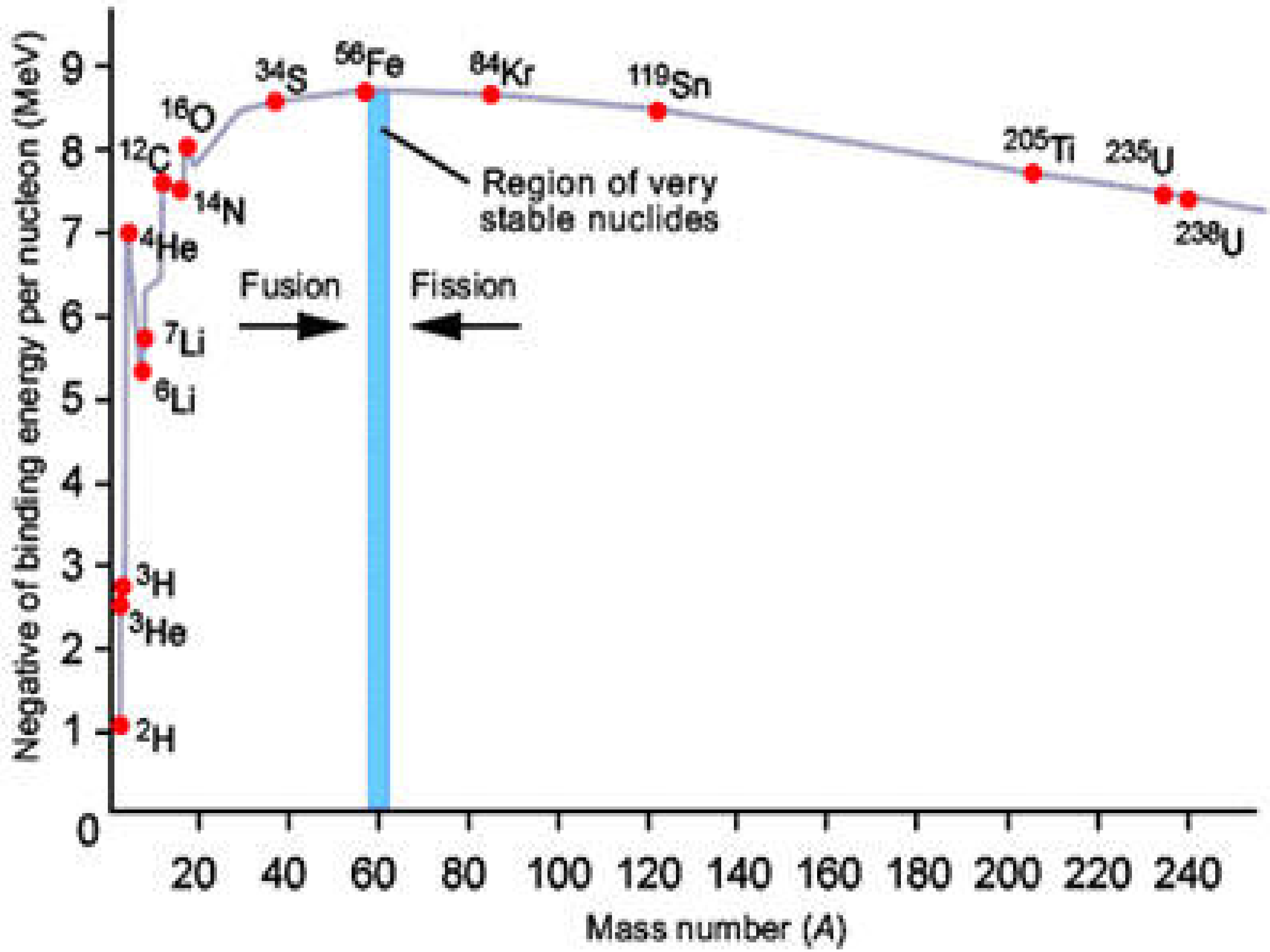
Smartgrids

- Critique
  - High pressure on both the supply (joining the production units to the so-called virtual power plants) and demand (consumers programming appliances for time or cost)
  - Ensuring a sufficient number of actors
  - Investment costs for operators and traders (benefits tends to rest with customers)
  - The modernization of the electricity grid
  - The potential to monitor and susceptibility to abuse the technology by thieves
  - Privacy protection
  - Relinquishing control over the use of electricity in favor of the operator

Virtual Power Plant



Nuclear Fusion



Nuclear Fusion

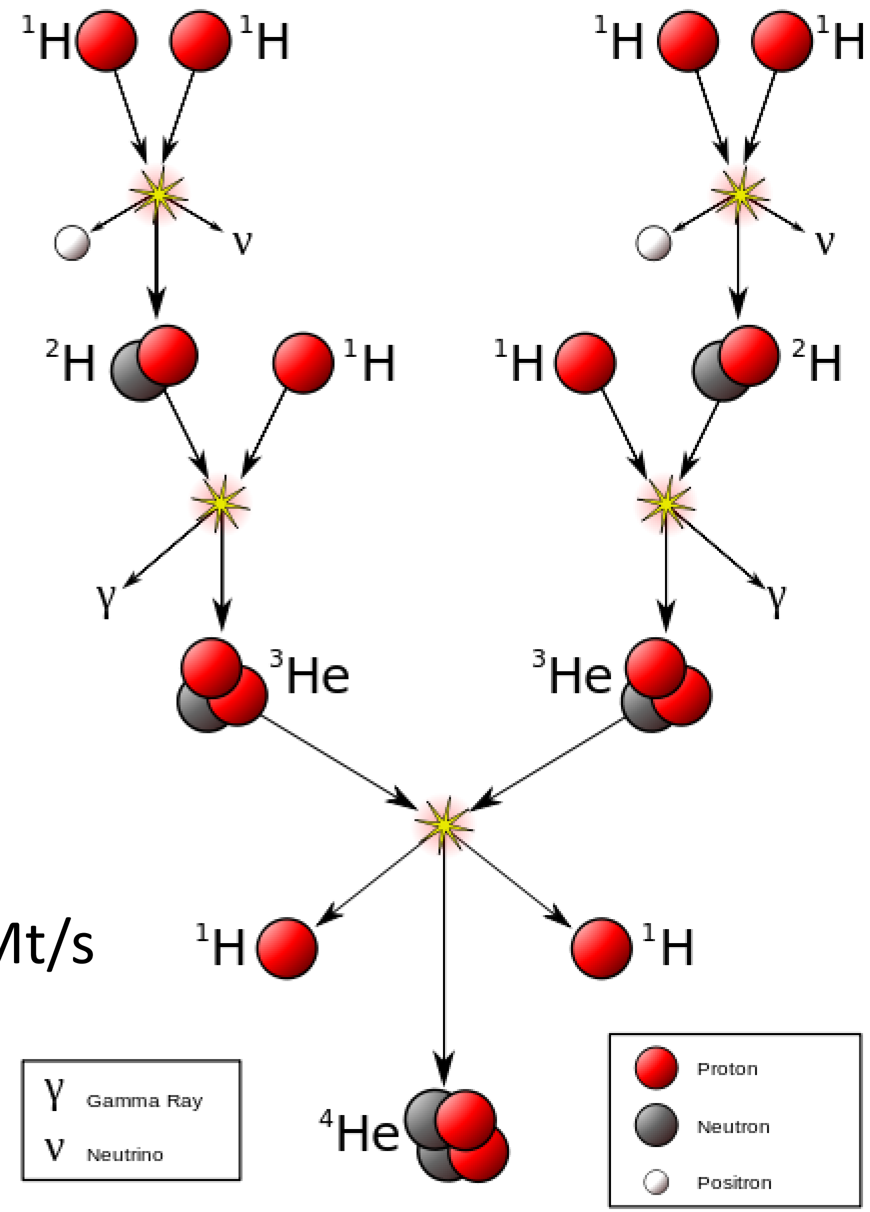
A process, during which lighter atomic nuclei are fused and energy is released

<u>The Sun</u>:

15 M °C

1H + 1H => He + energy

Hydrogen consumption: 600 Mt/s



Nuclear Fusion

- One way of achieving fusion is by using high temperature and pressure, which causes the nucleus collide with sufficient energy to overcome the Coulomb barrier. In this case we are talking about thermonuclear fusion.

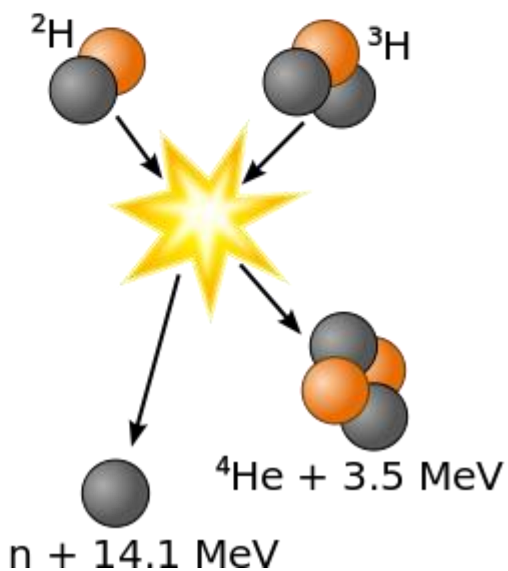
- There are also many ways of performing fusion without the use of high temperatures, but none of them will probably be able to be used as an energy source.

- One-off nuclear fusion reaction is not difficult to recall (it can be achieved by electrical discharge), but it is difficult to keep it in the reactor for a longer time and ensure a positive balance of energy obtained to energy delivered.

Nuclear Fusion

The most easy to apply reaction is a synthesis of deuterium and tritium:

150 M°C 2H (D) + 3H (T) => He + n + energy



Nuclear Fusion

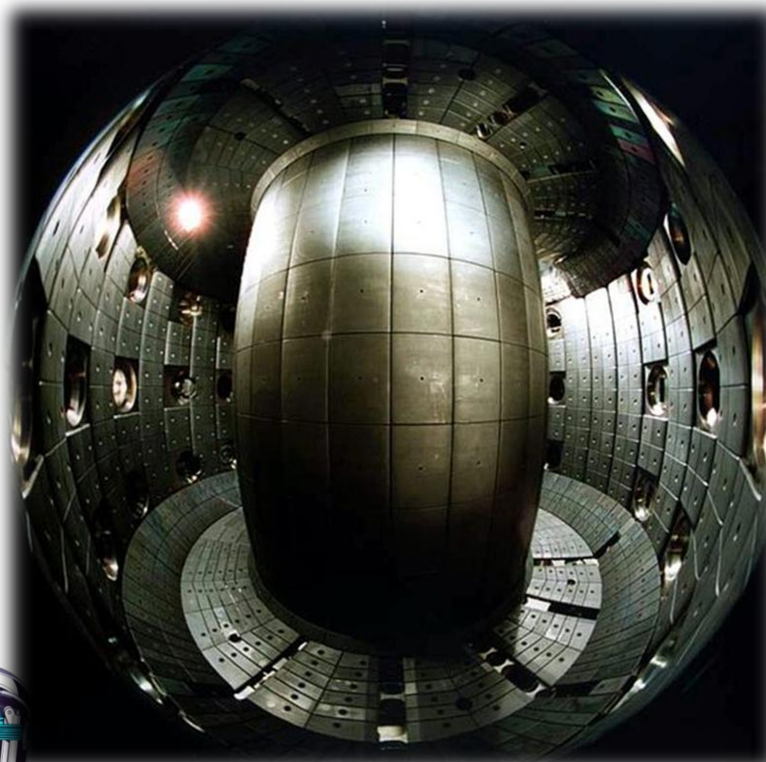
- Jamie Edwards, thirteen year old schoolboy at Priory Academy in the British Penwortham is the youngest person in history who was able to induce nuclear fusion.

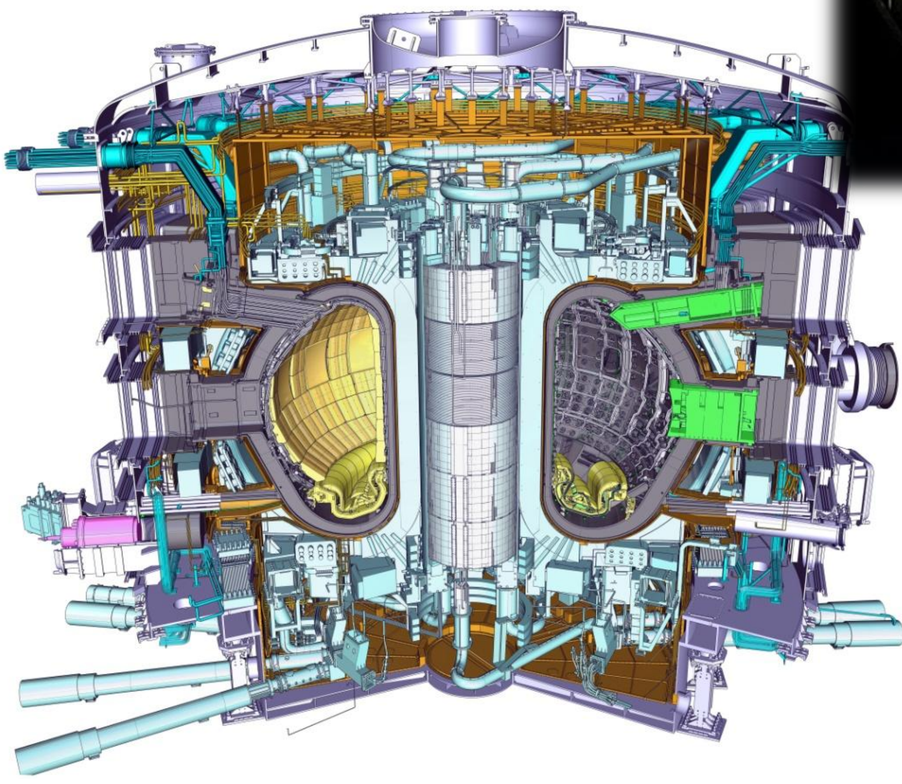
Nuclear Fusion

- One of the ways to achieve nuclear fusion is the tokamak, a device that prevents contact with the plasma with the wall of the chamber by a magnetic field.

- тороидальная камера с магнитными катушками
- Thoroid Chamber in Magnetic Coils
- **TOKAMAK**

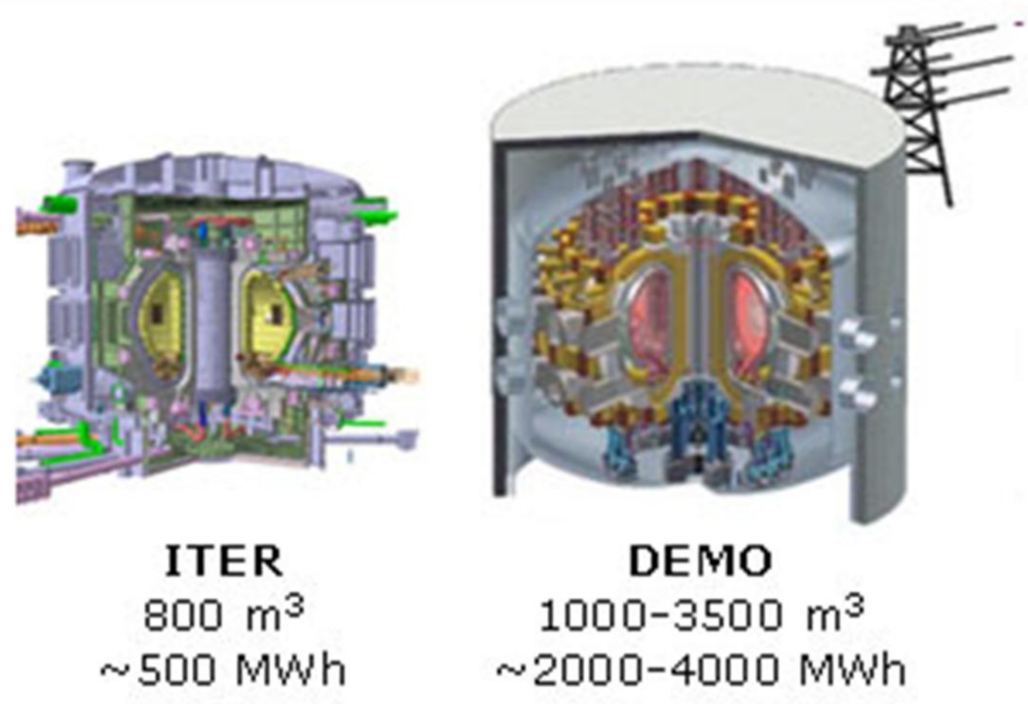
Nuclear Fusion





Nuclear Fusion

- The idea of tokamak was born in the '50s by Igor Yevgenevich Tamm and Andrei Sakharov
- At present, the international project ITER in Cadarache, France, is the most advance



1960s: TM1-MH (since 1977 Castor; since 2007 Golem) in Prague, Czech Republic. In operation in Kurchatov Institute since early 1960s but renamed to Castor in 1977 and moved to IPP CAS, Prague; in 2007 moved to FNSPE, Czech Technical University in Prague and renamed to Golem.

1975: T-10, in Kurchatov Institute, Moscow, Russia (formerly Soviet Union); 2 MW

1978: TEXTOR, in Jülich, Germany

1983: Joint European Torus (JET), in Culham, United Kingdom

1983: Novillo Tokamak, at the Instituto Nacional de Investigaciones Nucleares,in Mexico City, Mexico

1985: JT-60, in Naka, Ibaraki Prefecture, Japan; (Currently undergoing upgrade to Super, Advanced model)

1987: STOR-M, University of Saskatchewan; Canada; first demonstration of alternating current in a tokamak.

1988: Tore Supra, at the CEA, Cadarache, France

1989: Aditya, at Institute for Plasma Research (IPR) in Gujarat, India

1980s: DIII-D, in San Diego, USA; operated by General Atomics since the late 1980s

1989: COMPASS, in Prague, Czech Republic; in operation since 2008, previously operated from 1989 to 1999 in Culham, United Kingdom

1990: FTU, in Frascati, Italy

1991: Tokamak ISTTOK, at the Instituto de Plasmas e Fusão Nuclear, Lisbon, Portugal;

Outside view of the NSTX reactor

1991: ASDEX Upgrade, in Garching, Germany

1992: H-1NF (H-1 National Plasma Fusion Research Facility) based on the H-1 Heliac device built by Australia National University's plasma physics group and in operation since 1992

1992: Alcator C-Mod, MIT, Cambridge, USA

1992: Tokamak à configuration variable (TCV), at the EPFL, Switzerland

1994: TCABR, at the University of São Paulo, São Paulo, Brazil; this tokamak was transferred from Centre des Recherches en Physique des Plasmas in Switzerland

1995: HT-7, in Hefei, China

1999: MAST, in Culham, United Kingdom

1999: NSTX in Princeton, New Jersey

1999: Globus-M in Ioffe Institute

1990s: Pegasus Toroidal Experiment at the University of Wisconsin-Madison; in operation since the late 1990s

2002: HL-2A, in Chengdu, China

2006: EAST (HT-7U), in Hefei, China (ITER member)

2008: KSTAR, in Daejon, South Korea (ITER member)

2010: JT-60SA, in Naka, Japan (ITER member); upgraded from the JT-60.

2012: SST-1, in Gandhinagar, India (ITER member); the Institute for Plasma Research reports 1000 seconds operation.

2012: IR-T1, Islamic Azad University, Science and Research Branch, Tehran, Iran

2012: ST25 at Tokamak Energy at Culham, Oxfordshire, UK (now at Milton Park)

2014: ST25 (HTS) the first tokamak to have all magnetic fields formed from high temperature superconducting magnets, at Tokamak Energy based in Oxfordshire, UK

Storage of Electricity

- Options:
  - Electromechanical (flywheels, compressed air, pumping hydro stations…)
  - Electrochemical (fuel cells, batteries)
  - Chemical (hydrogen, biofuels)
  - …

Storage of Electricity

Storage is reflected in all parts of the electric chain:

Production, nature of the system:

- optimization of production capacity (quantity, economics) involvement of RES
- planning of transmission networks

Transmission and Distribution:

- portable storage systems (optimization of network capacity)
- dispersed systems (strengthen operational reliability)

Customers:

-reduction of price fluctuations over time

-backup in case of failure (services, industry, households)

Game changer?

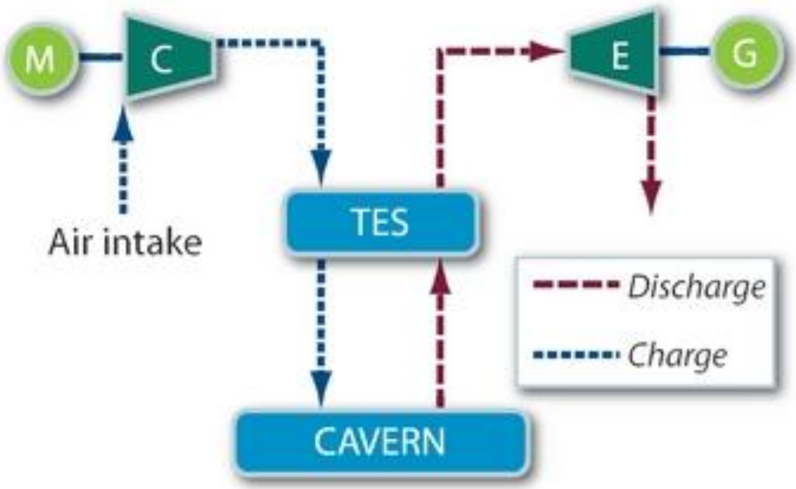
Current System	With Storage
Costs	Costs
Capacity	Capacity
Startup Speed	
Capacity Variablity	

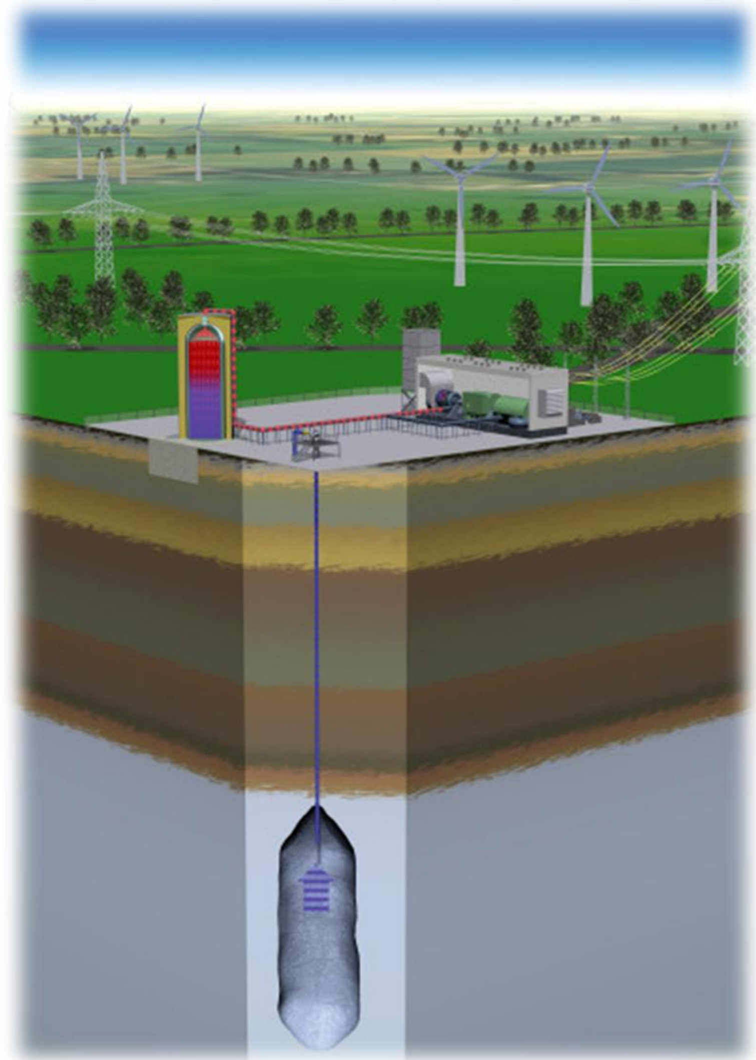
Pumping Hydro Stations

- Dinorwig, Scotland

Electromechanical Storage (flywheels)

Compressed Air



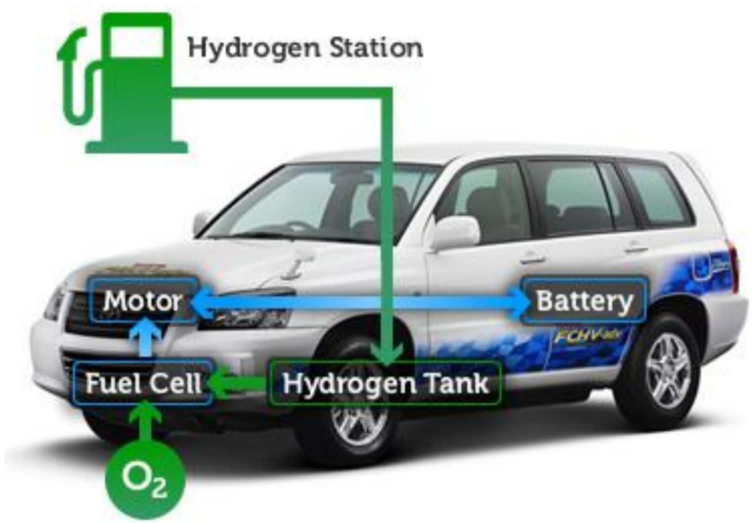


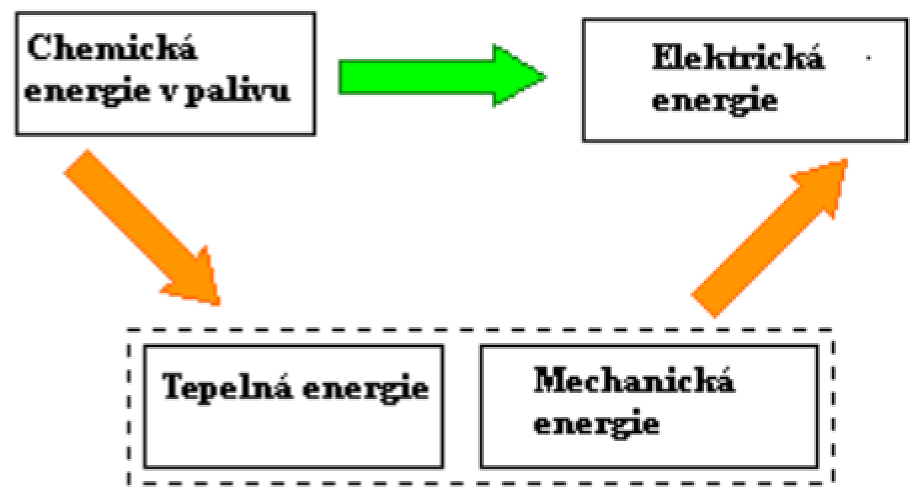
Fuel Cells and Hydrogen

- The principle has been known since the mid-19th century, their commercial deployment is still at the planning stage
- They are an alternative to the current small and medium sources of fossil fuels; gas engines, dieselaggregates, gas microturbines, small cogeneration units, it is counted with their deployment in the automotive industry
- In the future, it should replace the larger electricity supply units. It can be used also as a replacement for batteries and accumulators.
- For some special applications (space projects, undersea research) they are already widely used.

Fuel Cells and Hydrogen

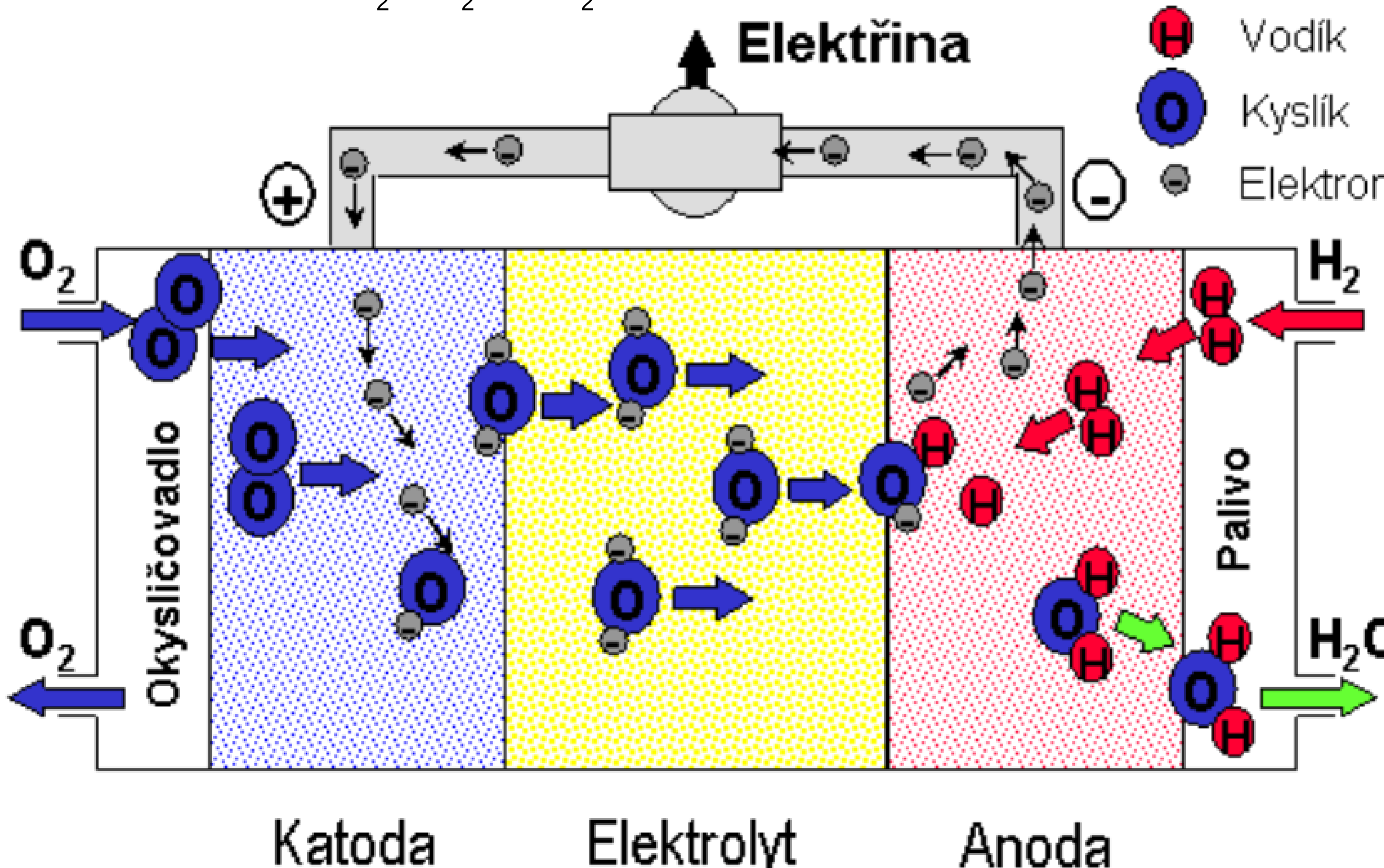
- A fuel cell is an electrochemical device directly converting chemical energy of fuel and oxidant into electrical energy.





Fuel Cells and Hydrogen (Polymer Electrolyte Membrane)

Anode Reaction: $2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-$
Cathode Reaction: $O_2 + 4e^- \rightarrow 2O^{2-}$
Overall Cell Reaction: $2H_2 + O_2 \rightarrow 2H_2O$



Fuel Cells and Hydrogen - advantages

- High efficiency power conversion due to direct conversion of chemical energy of fuel into electrical energy (total efficiency in automobiles 50-60%)
- Modular concept - the possibility to construct fuel cells in a wide range of performances with nearly the same efficiency.
- The possibility of using a variety of gaseous fuels (after adjustments)
- Almost silent operation due to the absence of moving parts (except the accompanying equipment - blowers, compressors, ...).
- Low wear
- Efficiency for power plant electricity production is 40-45%

Fuel Cells and Hydrogen - disadvantages

- High investment costs
- Still too low service life
- The effectiveness decreases with time
- The necessity of continuously removing fumes from chemical reactions whose quantity depends on the size of the current drawn (for H2-O2 cells pumping out of water or water vapor, other cells oxidation products)
- Commissioning (PEM operating temperature is 70-85 C, it may take a few minutes and the cell must be warmed up to operating temperature, likely from an external source)

Fuel Cells and Hydrogen Production

Hydrogen is produced in large thermal decomposition of methane (natural gas) at 1000 °C.

$$CH_4 \rightarrow C + 2\ H_2$$

In the future, the production of hydrogen using nuclear energy is likely, either thermochemically (high temperatures) or by means of electric current (nuclear power plants could then be used at the times, when demand is low)

Fuel Cells and Hydrogen Production

- Steam reforming

Reforming reaction: $CH_4 + H_2O \rightarrow CO + 3H_2$

CO conversion: $CO + H_2O \rightarrow CO_2 + H_2$

Effectivity 80 %

- Electrolysis

$2H_2O \rightarrow 2H_2 + O_2$

Effectivity 80-92 %

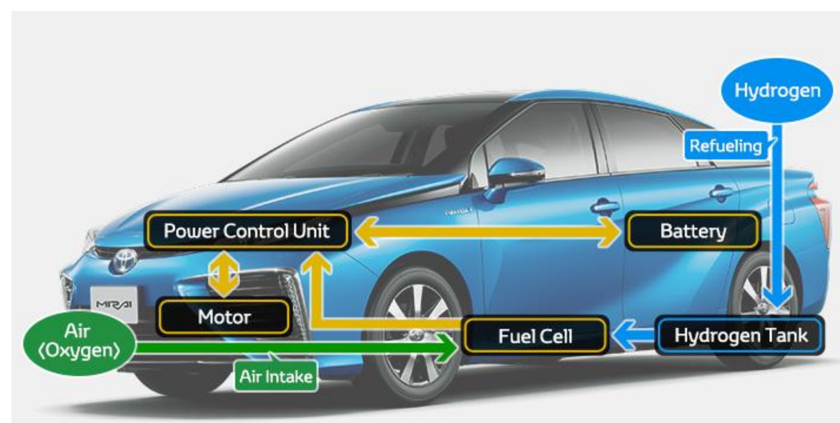
- High-temperature electrolysis

Effectivity up to 45 %

Fuel Cells and Hydrogen

Barcelona
Hydrogen buses

Toyota Mirai Fuel Cell Sedan
12/2014 in Japan; 8/2015 in USA; 6/2016 in EU



Fuel Cells

Honda FCX Clarity Fuel Cell

Hyundai ix35 FCEV

Alstom Coradia iLint

Mercedes-Benz F-Cell

In the Meantime the Clash Goes on…