The Abdus Salam International Centre for Theoretical Physics

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Joint ICTP-IAEA Workshop on Sustainable Energy Development: Pathways and Strategies after Rio+20

1 - 5 October 2012

Sustainable energy development: the strategy and the local roadmap to meet the goals

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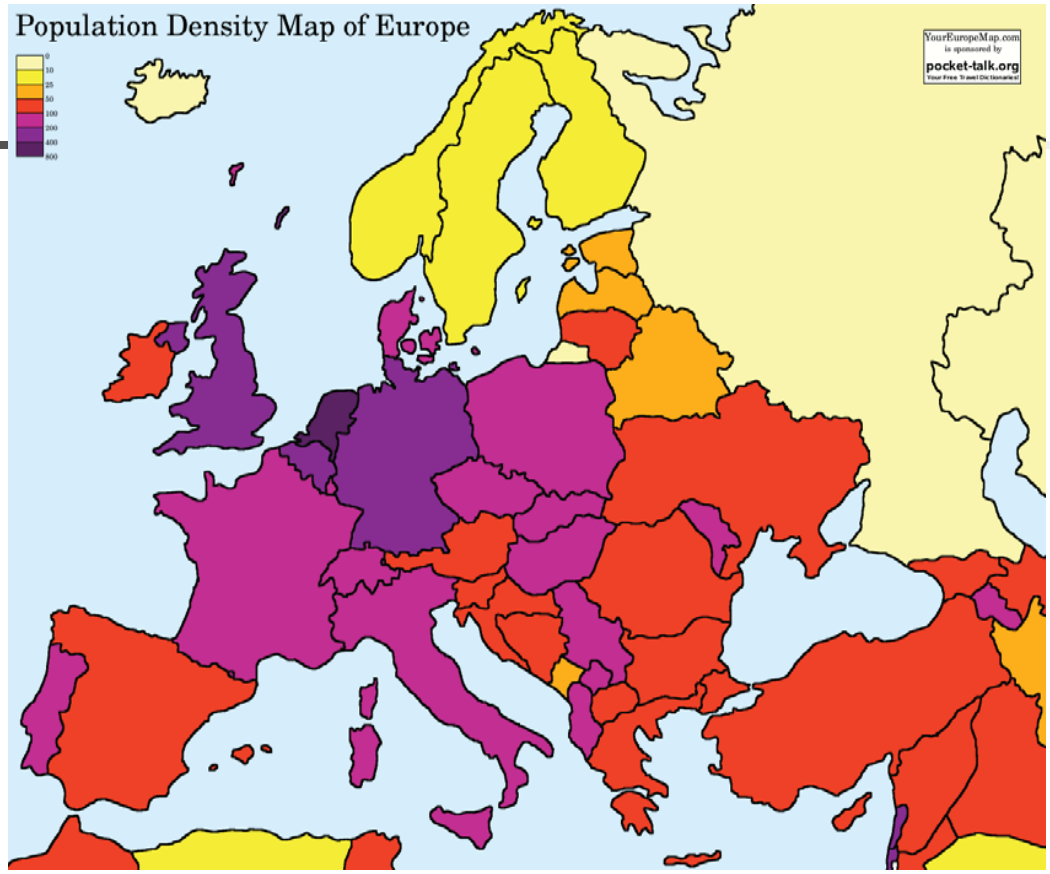
National flag of Moldova

Republic of Moldova is situated in the South-East of Europe

Moldova is a border country for the EU

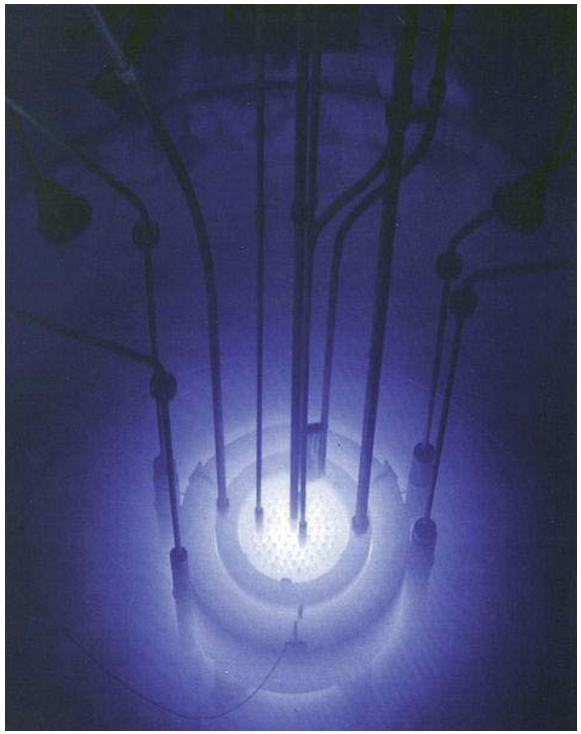
Moldova has fixed as a priority EU integration



Moldova is densely populated, but suffers because of the lack of energy resources (98% of energy resources are imported)

П.А.Черенков: В 1934 году обнаружил специфическое голубое свечение прозрачных жидкостей при облучении быстрыми заряженными частицами. Показал отличие данного вида излучения от флуоресценции. В 1936 году установил основное его свойство — направленность излучения, образование светового конуса, ось которого совпадает с траекторией движения частицы. Теорию излучения Черенкова разработали в 1937 году И. Е. Тамм и *И. М. Франк*.

NRC photo of ***Cherenkov effect*** in the Reed Research Reactor



P.A.Cherenkov – the most "profitable" Nobel Prize Winner…

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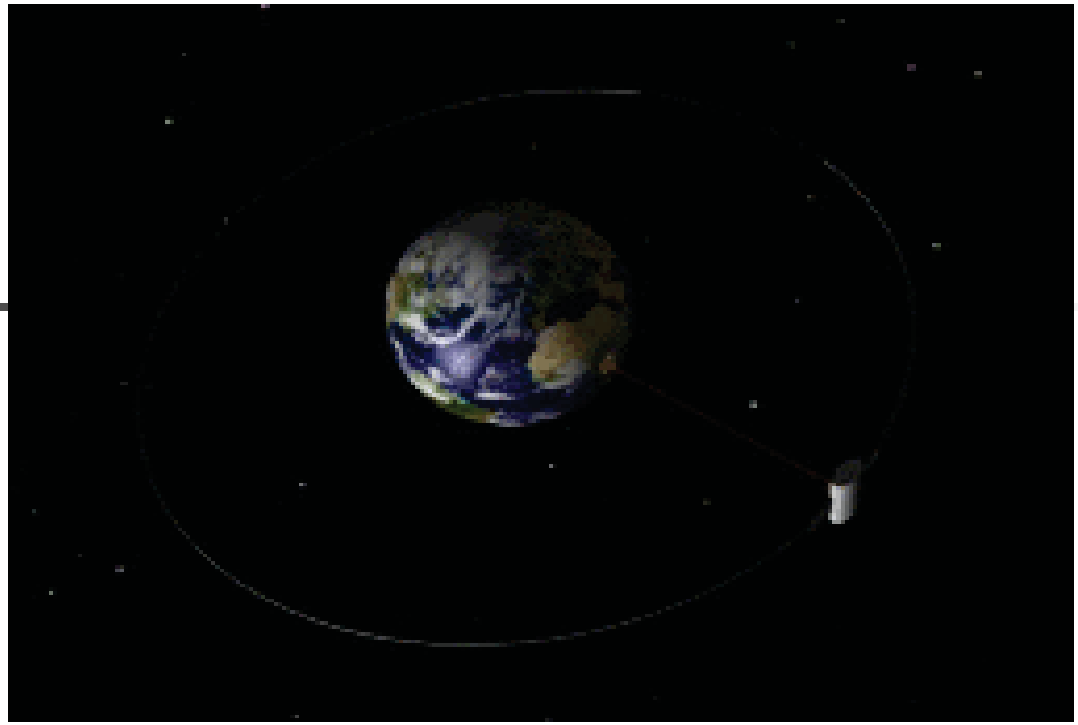
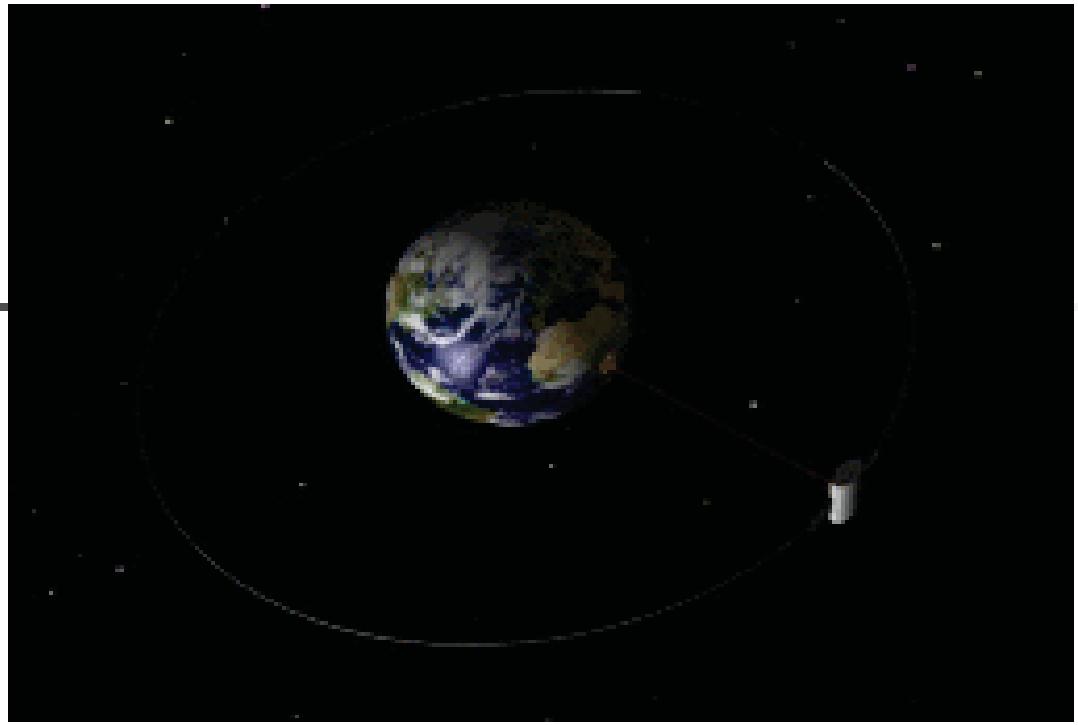
Sustainable energy development: the strategy and the local roadmap to meet the goals

motto

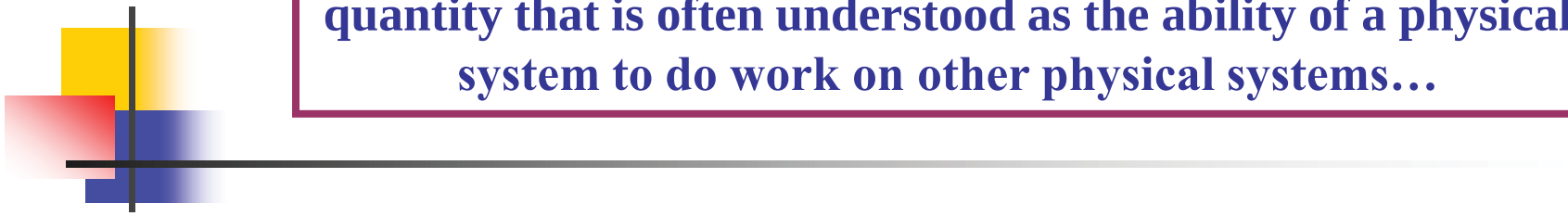
We have the commitment to sustainable development and to ensuring the promotion of an economically, socially and environmentally sustainable future for our planet and for present and future generations



Our planet has become the cradle of the modern civilization – inclusively due to millions of years of evolution…



Only beginning with the 17th century, as a result of the scientific revolution, natural sciences became adequate, "exact". The scientific revolution led to the establishment of several modern sciences (based on **physics**) and gave start to technical (technological) revolution



The notion of "energy" is basic in physics and all natural sciences. In mechanics, energy is an indirectly observed quantity that is often understood as the ability of a physical system to do work on other physical systems…

Energy is subject to a strict *global (universal) conservation law*; that is, whenever one measures (or calculates) the total energy of a system of particles whose interactions do not depend explicitly on time, it is found that the total energy of the system always remains constant

Greek: "activity, operation"

Energy is not a simple scalar physical quantity…

Energy transformations define everything!

Energy is something *sine qua non*

Latin: a condition without which it could not be

In fact, we have a need of high-potential ("free" energy - G)

From thermodynamics (the second law of thermodynamics – Sadi Carnot) comes a limitation – in all transformations, always *only a certain part of energy can be transformed into high-potential energy* (electrical, mechanical), the rest of energy being "waste", or "secondary" energy (low potential thermal energy)...

$$\eta = W/Q_H = (T_H - T_C)/T_H$$

where:
W is the work done by the system (energy exiting the system as work),
Q_H is the heat put into the system (heat energy entering the system),
T_C is the absolute temperate of the cold reservoir, and
T_H is the absolute temperate of the hot reservoir

Sadi Carnot (1796-1832)

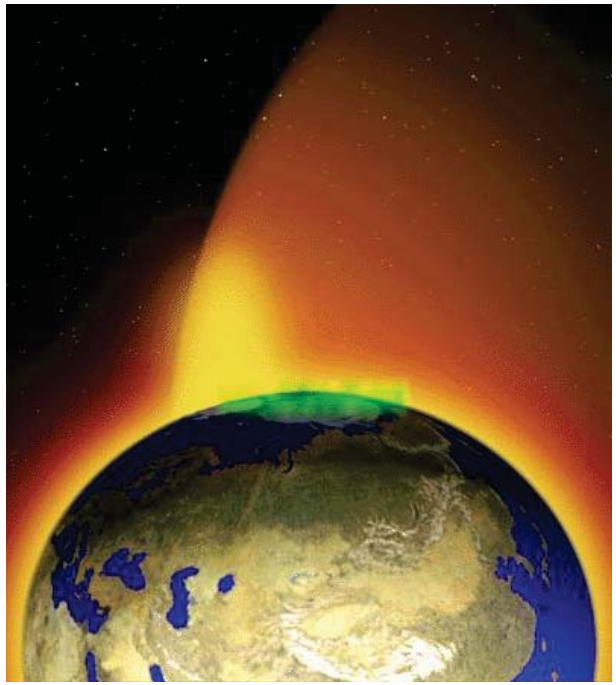
The primary source of energy

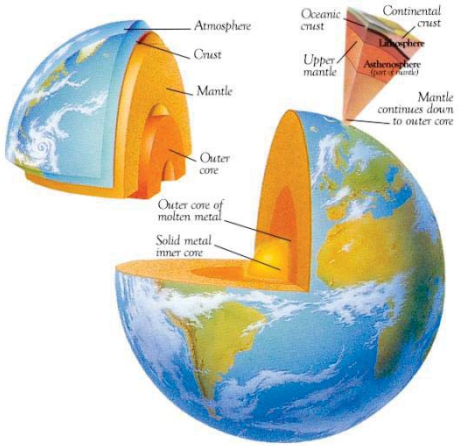
Nuclear energy is characterized by the extreme (maximum) energy intensity and is the only *primary source of energy* in the Universe. On the Earth there is a huge potential of using both nuclear fusion and nuclear fission; all other types of energy derive from nuclear one…

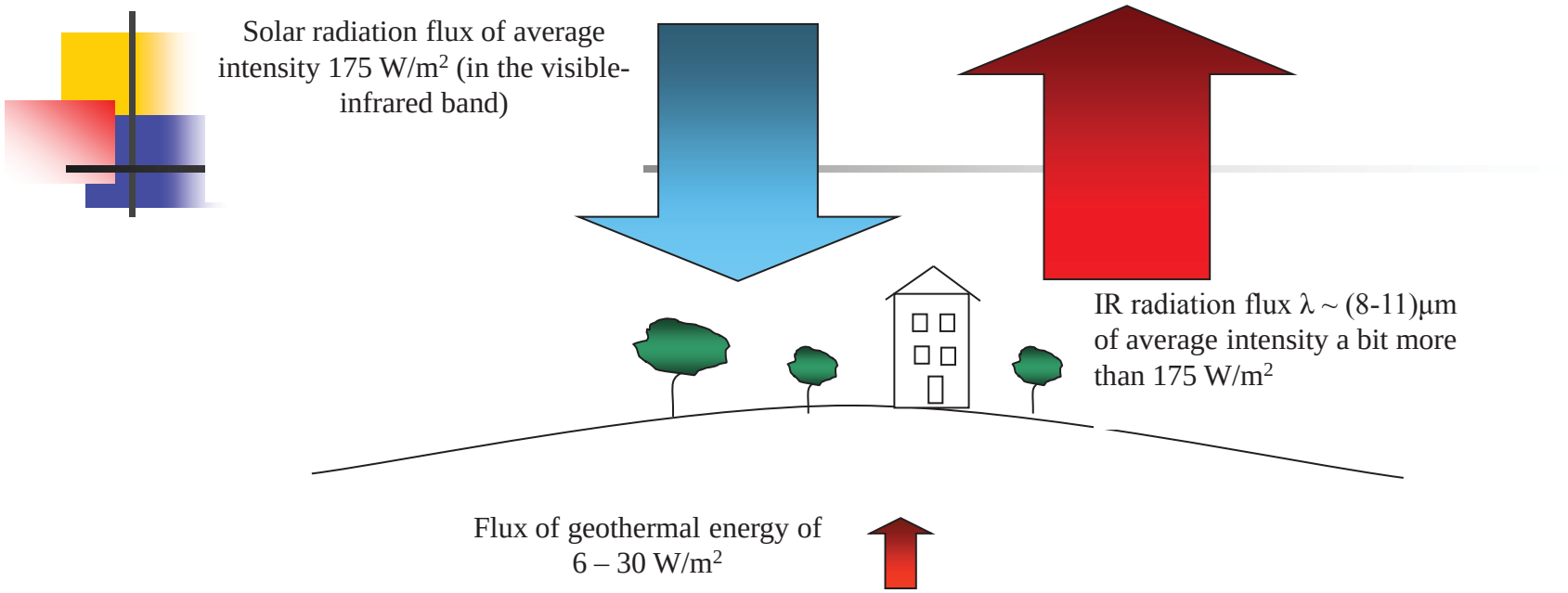
Nuclear energy is characterized by the extreme (maximum) energy intensity and is the only *primary source* of energy in the Universe. On the Earth there is a huge potential of using both nuclear fusion and nuclear fission; other types of energy derive from nuclear one…

On the Earth ***NATURE*** *offers* ***3 major sources of energy***

- *Solar radiation (together with* ***renewables*** *and fossil derivatives)*
- *Nuclear energy (artificial* ***radioactive fission*** *and thermonuclear fusion – ITER****?****)*
- *Geothermal energy*







Thermal equilibrium on the Earth surface

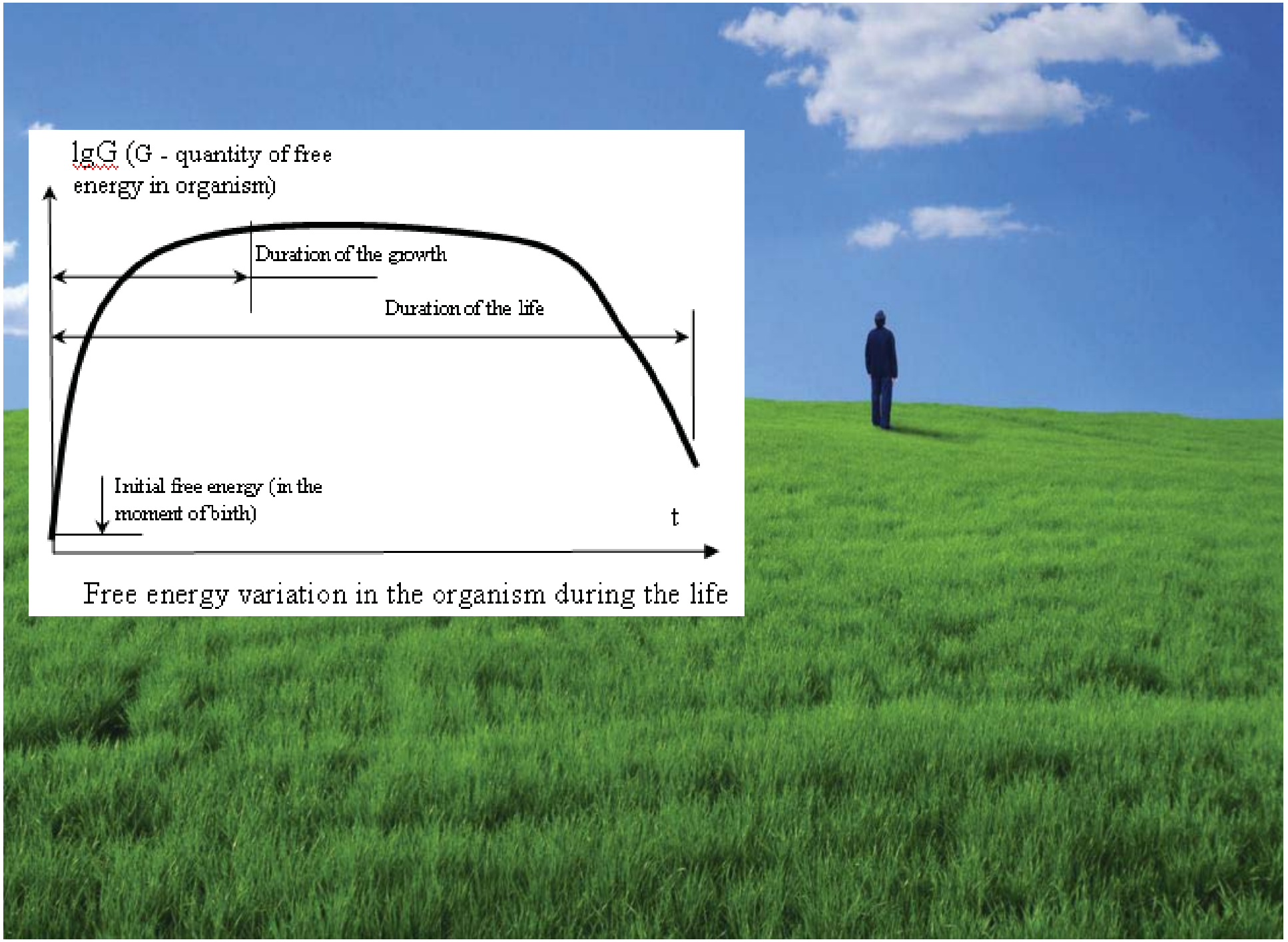
But... *this equilibrium is in danger (!) – mostly because of the irrational use of fossils...*

All organisms (living beings, creatures) need permanent supply (inflow, feeding) of ***free energy*** - in order to maintain dynamic equilibrium with the environment

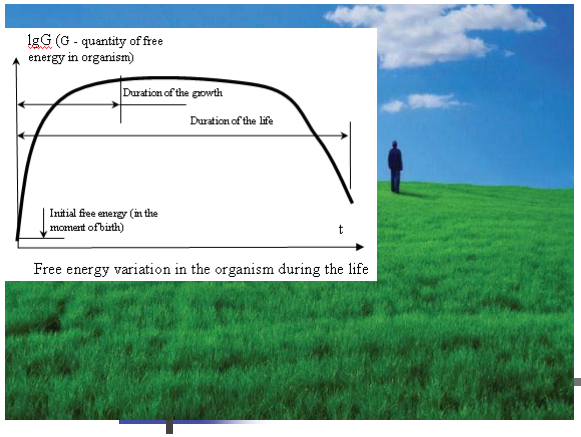
For life we need permanent income (gain) of *free energy*:

$$\Delta G = \Delta H - T\,\Delta S \quad (\Delta G > 0)$$

“extensive” term	“informational” term

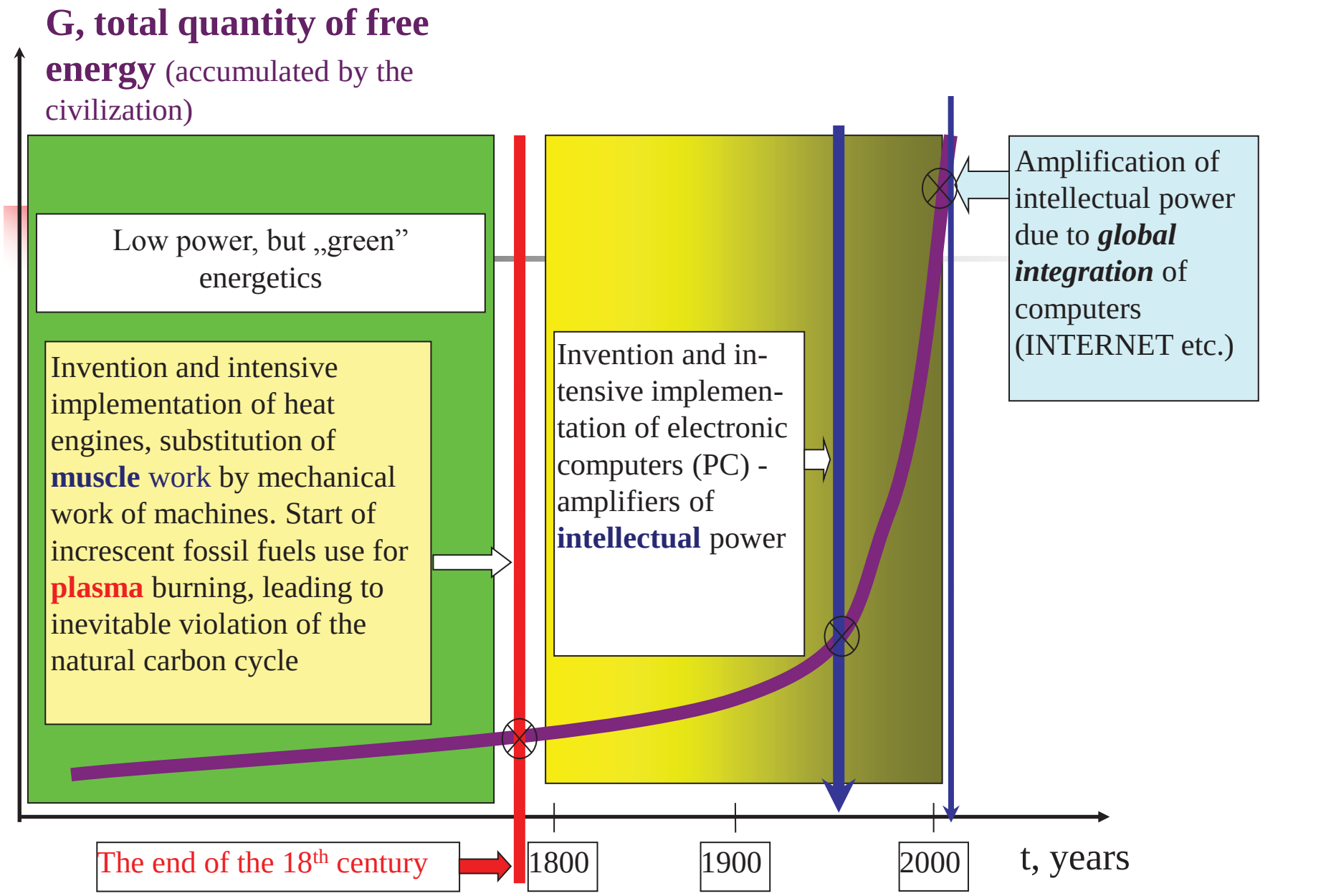


Free energy variation in the organism during the life



Only Human Beings have the privilege of ***deliberated, conscious accumulation of free energy*** in the environment (no other organisms possess such a function!)

Such an "artificial" *accumulation of free energy* in the environment is due to the human beings' *abstract thinking* capability



Even insufficient (slowing) growth of free energy … means degradation of the civilization

Violation of the natural carbon cycle threatens sustainable development

Factors of CO2 emission:

Fossil (non-renewable) fuels burning…
Cement industry (double portion of CO2…)

International Energy Agency:

Global CO_2 emissions set record in 2010 - *30.6 billion tons* (*The world has edged incredibly close to the level of emissions that should not be reached until 2020 - if the two degree C target is to be attained…*)

Violation of the natural carbon cycle threatens sustainable development

Consequences:

Greenhouse effect

Methane is ~25 times stronger as a greenhouse effect than for CO_2

Ocean acidification

Oceans absorb CO_2 from the atmosphere

Clathrate gun hypothesis – substantial ecological limit for "carbon" energetics…

Violation of the natural carbon cycle threatens sustainable development

Nobody knows exactly how close we are to the

POINT OF NO RETURN

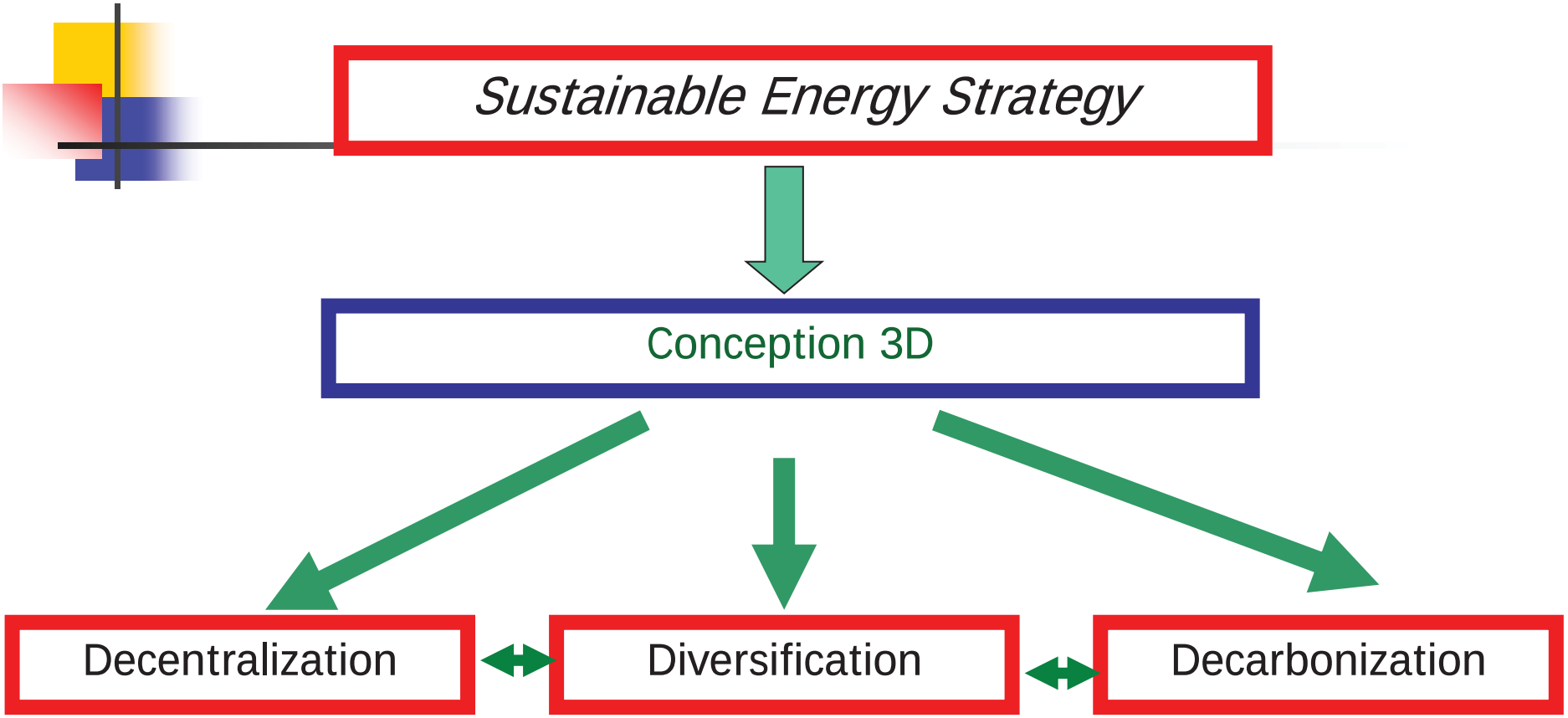
Promotion of low-carbon emission (sustainable) development

Sustainable solutions come from the above analysis

Conclusion:

Sustainable development can be ensured:

- **by the use of renewable (non-carbon) solar energy (*direct solar radiation, wind energy, hydro energy …*)**
- **by the use of nuclear energy**


Sustainable Energy Strategy
Conception 3D
Decentralization
Diversification
Decarbonization

Decentralization

- derives from Thermodynamics (because not-negligible, immanent secondary energy can not be transported for long distances in economically reasonable way), from the nature of alternative energy (it is distributed in space) and from consumer demands (also distributed in space). *Decentralization* means creation of the new (eventually, expensive) distributed infrastructure, but nobody can ignore this principle. A single (relative) exception refers to the Nuclear Power Plants. *Decentralization* is indispensable of *Smart Grid* implementation.

Diversification

-comes mostly from the lack (and non-constancy) of alternative energy resources and concerns of reliability (security).
Diversification means that ***all*** possible energy resources (supplies, technologies of energy production and storage, etc.) must be taken into account (inclusively, of course, nuclear energy).

Decarbonization

-means not only the use of non-carbon technologies, but also extraction (neutralization) of already emitted carbon. We consider irrational sub-terrain storage of carbon: this chemical element is capable to create unique (the strongest) inter-atomic bonds (inclusively, with another atoms), and it is wise carbon to be used largely in (present and future) constructions and technologies (instead of steel, natural diamonds etc.).

The mainstream **is the use of renewable (non-carbon) solar energy (*direct solar radiation, wind energy, hydro energy, biomass…*), but this new technologies need *more investigations, also time and energy for deployment…* Also renewables cannot support long-term *base* capacity…**

Long-term sustainability of nuclear power - can contribute decisively in solving the most important challenges humanity is facing – climate change, food and energy supply...

***Shortage of fossil organic fuels in some countries (in conditions of Nuclear Power utilization) can be treated as a* competitive advantage…**

We rank renewables - as decreasing "energy density" - hydro, wind, solar, biomass.

We consider biomass the most controversial source (kind) of energy, "energetic plantations" being unreasonable.

Biomass is the most controversial item…

In conditions of population growth, we anticipate the energetic use of ***only*** bio-wastes… No energetic plantations!

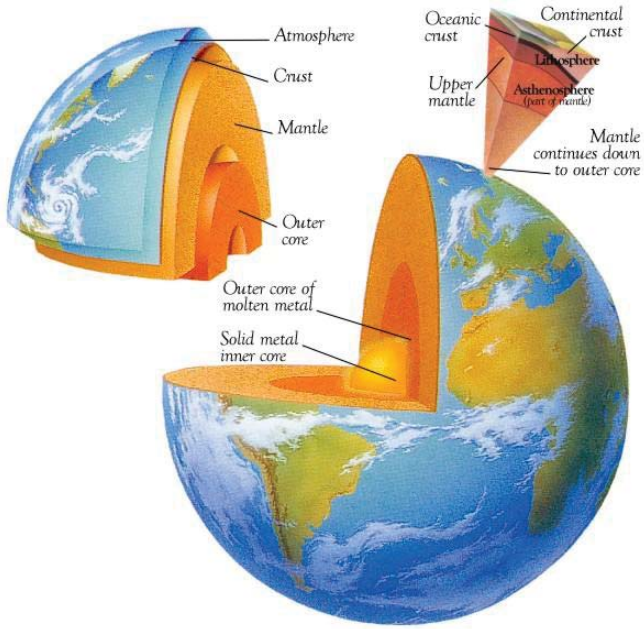
Biomass briquettes are an example fuel for production of dendrothermal energy

Wood is a typical source of biomass

Regulatory measures with respect to "energetic plantations"...

Geothermal energy

Unused commercial potential of the geothermal energy is relatively small and refers to only special regions (on the edges of tectonic plates)



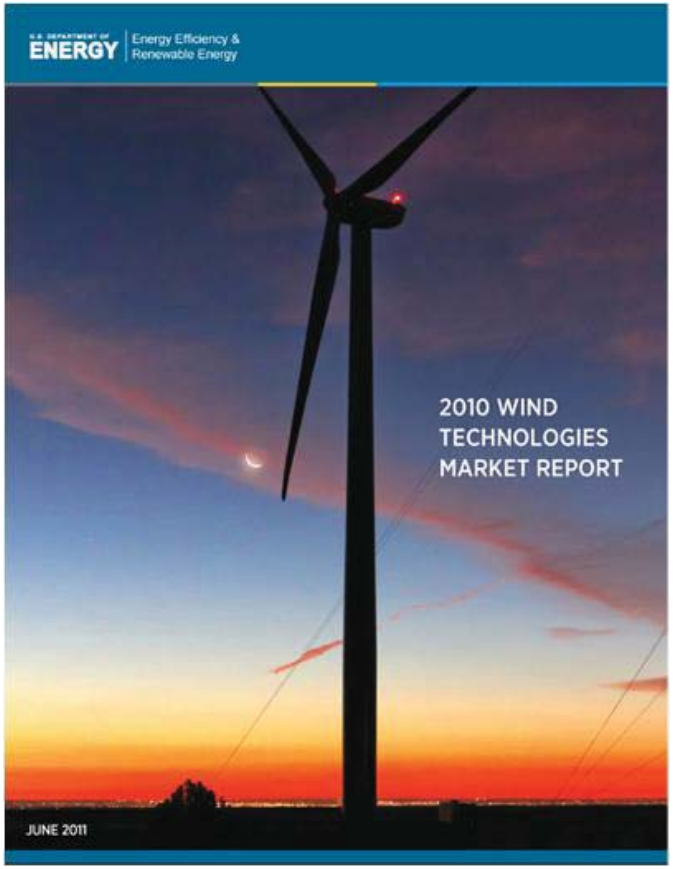
Wind energy

Unused potential of the wind energy:

high-altitude installations;

sail installations;

MHD installations



Hydroelectric power (water power plants)

Unused potential of the **hydroelectric** *energy is relatively small:*

damless stations;

buildings;

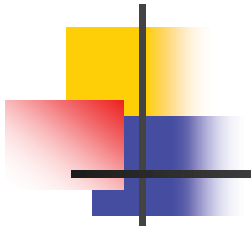
combined hydro-accumulation and irrigation

Solar radiation

Unused potential of the solar radiation (solar energy):

multifunctional installations;

high-altitude installations independent of whether conditions (in troposphere and higher)



In each case, implementation of non-traditional (decentralized, non-carbon energetic) means creation of the *new economy (a global redesign!)*, with the respective consumption of resources, time,… and carbon emissions. The problem is - *how to avoid the enormous additional emissions of carbon dioxide…*

The local (regional) roadmap for transition to the sustainable energy

Promotion of low-carbon and non-carbon technologies of energy production (renewables), inclusively of nuclear power – together with the encouragement of energy efficiency...

Examples:

LNG as the fuel of transition

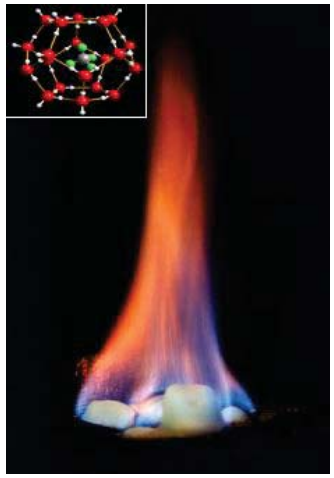
green transport

plus-energy houses (green buildings)

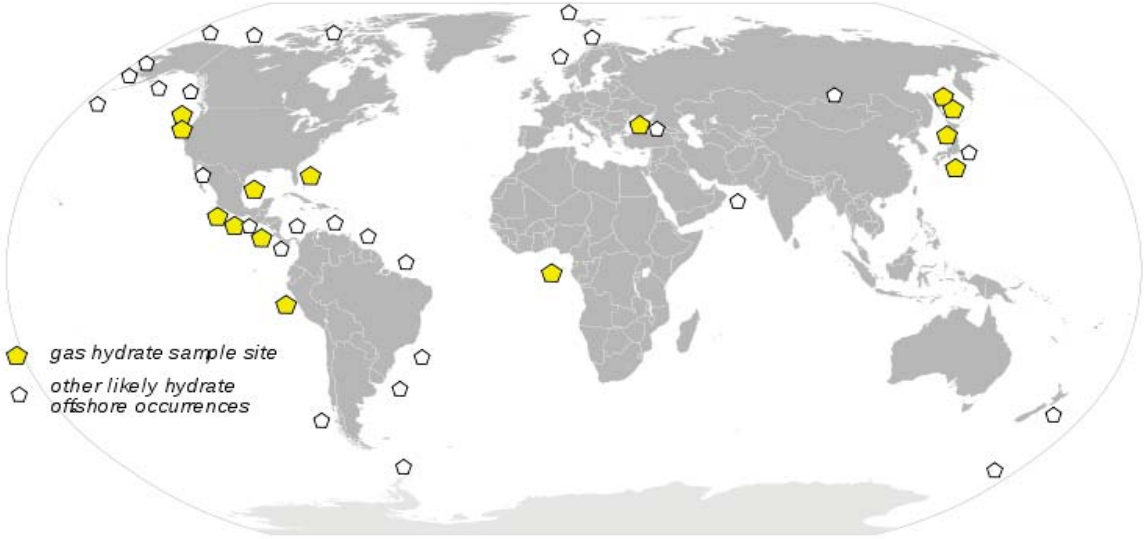
LNG as the fuel of transition

Natural gas (methane) is a low-carbon fuel, with a clear perspective of transformation in non-carbon fuel. Predominantly should be used "clathrate gun " reserves of methane (*methane is a powerful greenhouse gas*).

Note. *The worldwide amounts of carbon bound in gas hydrates is conservatively estimated to total twice the amount of carbon to be found in all known fossil fuels on Earth*



"Burning ice". Methane, released by heating, burns; water drips



Worldwide distribution of confirmed or inferred offshore gas hydrate-bearing sediments

LNG as the fuel of transition

In our opinion, the conception of natural gas (methane) utilization should be changed:

Our conception foresees (provides) ***obligatory liquefaction*** on a certain stage (LNG) – with the utilization of the cryogenic and transportation pressure ***potentials***. This also solves the problems of storage, transportation and distribution (no need of additional gas pipe-lines).

Natural gas (methane) ***burning without electricity (mechanical work) production should be excluded***

LNG carrier

Dominion Cove Point LNG is located on the Chesapeake Bay in Lusby, Maryland, south of Baltimore. It is one of the nation's largest liquefied natural gas (LNG) import facilities.

Green transport

Hybrids, especially of V2G type…

LNG and CNG as the fuel of transition and, eventually, post-transition period…

Gyrobuses – for “homo urbanus”, but not only …

Plus-energy houses (green buildings)

The main features:

energy-active thermoisolation, complex use of all possible alternative energy recourses, decentralized energetic autonomy...

The *deployment* of renewables needs *time and energy* …

Also renewables cannot support long-term *base* capacity…

Also *some regions have limited renewable resources*

Long-term sustainability of the ***Nuclear Power*** -
can contribute decisively in solving the most important challenges humanity is facing – climate change, food and energy supply…

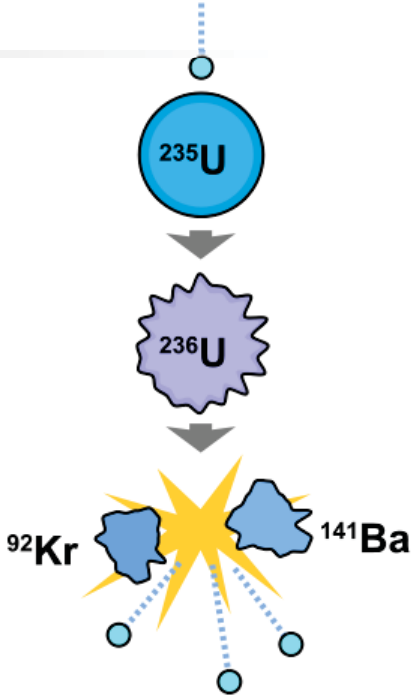
In conditions of Nuclear Power utilization - Shortage of fossil organic fuels in some countries (territories) can be treated as a **competitive advantage…**

Natural uranium: 99.27% - ^{238}U

0.72% - ^{235}U

0.01% - ^{234}U

An induced fission reaction. A slow-moving neutron is absorbed by a uranium-235 nucleus turning it briefly into a uranium-236 nucleus; this in turn splits into fast-moving lighter elements (fission products) and releases three free neutrons:



Energy release in nuclear fission reaction :

$$^{235}U_{92} + {}^{1}n_{0} \rightarrow {}^{92}Kr_{36} + {}^{141}Ba_{56} + 3\ {}^{1}n_{0} + E\ (\sim 236\ MeV)$$

For comparison – energy release in the reaction of burning :

$$C + O_2 \rightarrow CO_2 + E\ (\sim 5\ eV)$$

The mass of (**non-carbon!**) wastes in nuclear energy cycle is

~ 10 million times less than in conventional fuel burning (as per unit of energy produced)

The mass of wastes (non-carbon!) in nuclear energy cycle is **~ 10 million times less** than in conventional fuel burning (as per unit of energy produced):

After Fukushima I nuclear power became more controversial and there is an ongoing debate about the use of nuclear energy. Proponents, such as the World Nuclear Association and IAEA, contend that nuclear power is a sustainable energy source that reduces carbon emissions. Opponents, such as Greenpeace International and NIRS, believe that nuclear power poses many threats to people and the environment

Nuclear power plant accidents include the Chernobyl disaster (1986), Fukushima I nuclear accidents (2011), and the Three Mile Island accident (1979).

Three Mile Island accident - is the result of the ***technical defect*** (malfunction plus its wrong indication). The next, modern generations of Nuclear Power Plants (*not also Fukushima I* ***!***) **practically exclude** such accidents...

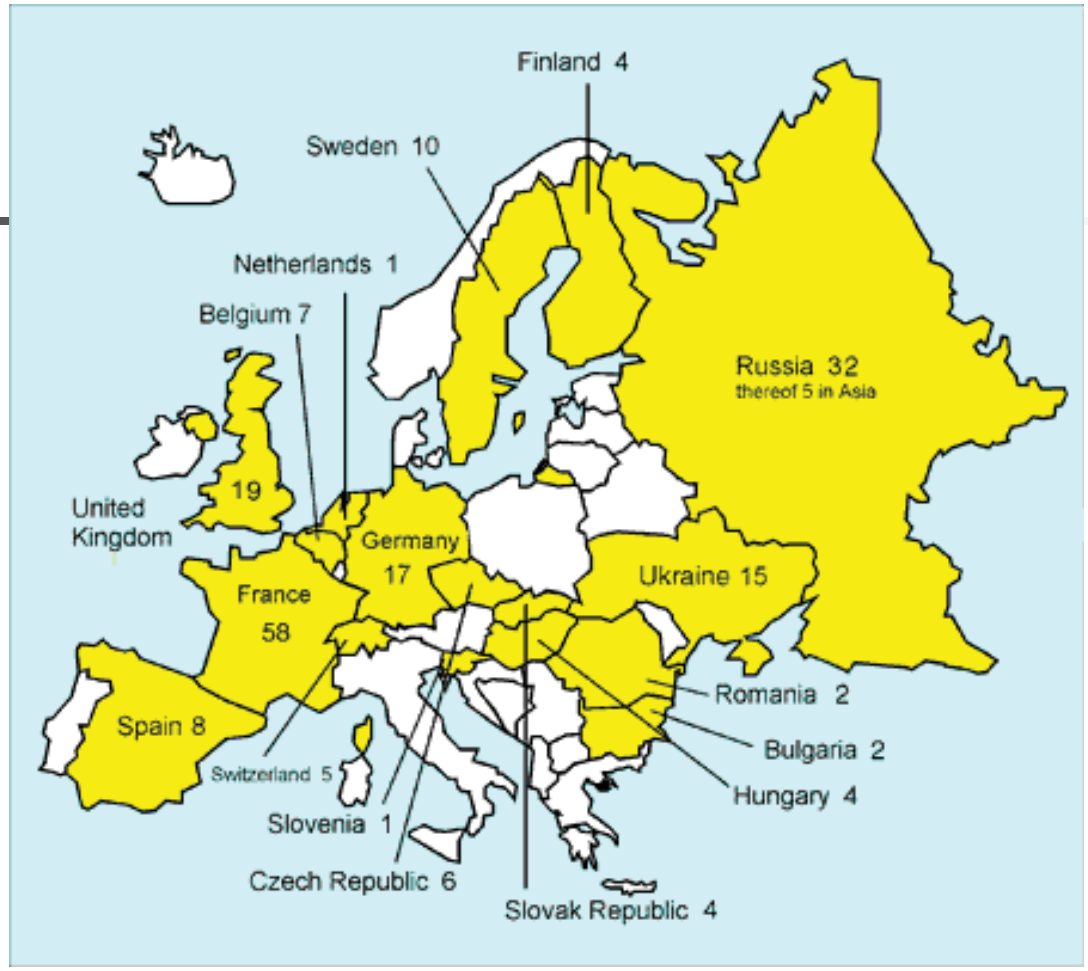
Chernobyl accident – is the ***purely man-made (artificial one)*** - the result of ***operation rules flagrant violation*** (in the reactor with ***dangerously high*** positive **"void coefficient of reactivity"**).

Note. A positive void coefficient means that the reactivity increases as the void content inside the reactor increases (due to increased boiling or loss of coolant)

Fukushima I accident – is the result ***of the unique natural disaster*** *(tsunami of more than 40 m height,* in Fukushima I region - about*14 m height), but* ***finally*** ***human factor is decisive****...*

Fukushima I Nuclear Power Plant was designed for only 4.5 m height tsunami resistance (exceding estimation -1.5m - 3 times!), but there came ... more than 14 m height tsunami...

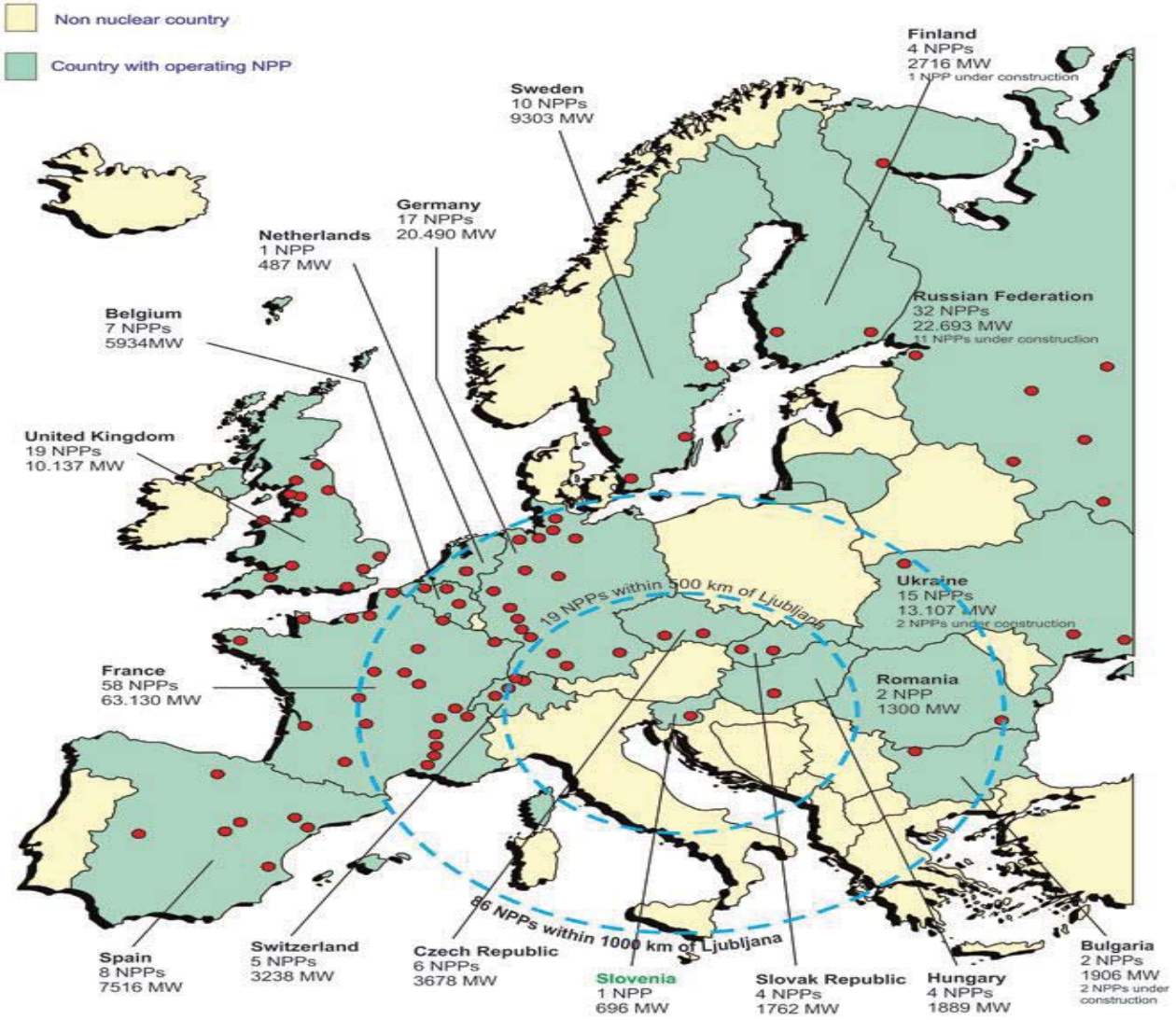
The **radiation effects from the Fukushima I nuclear accidents** are the results of release of radioactive isotopes. The total amount of iodine-131 and caesium-137 released into the atmosphere has been estimated to exceed **10% of the emissions from the Chernobyl accedent**. The accidents were rated at level 7 rating on the International Nuclear Event Scale



Nuclear Power Plants in Operation in Europe, January, 2011

(***Note.*** Ukraine plans to add 2 new reactors at Khmel'nitskyi power station – mainly for export …)

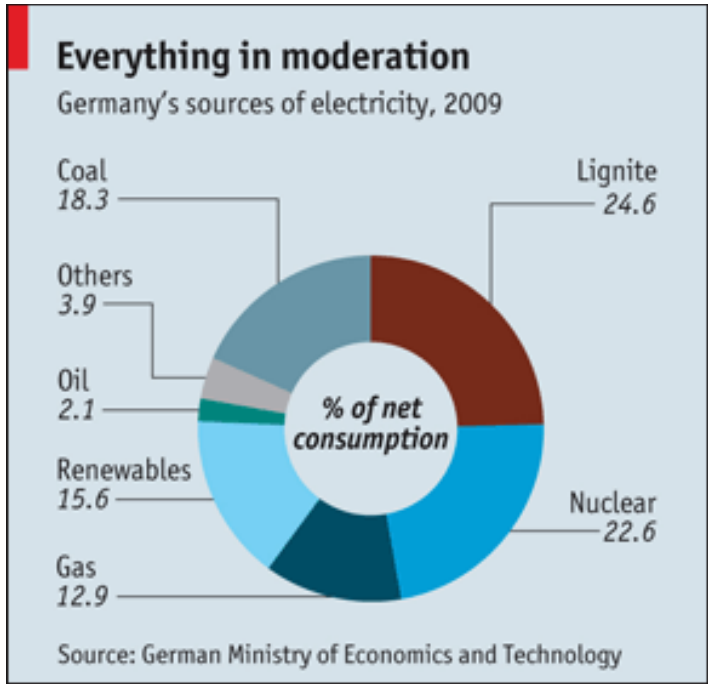
Nuclear Power Plants in Europe



Status as of September 2010 as reported to IAEA.

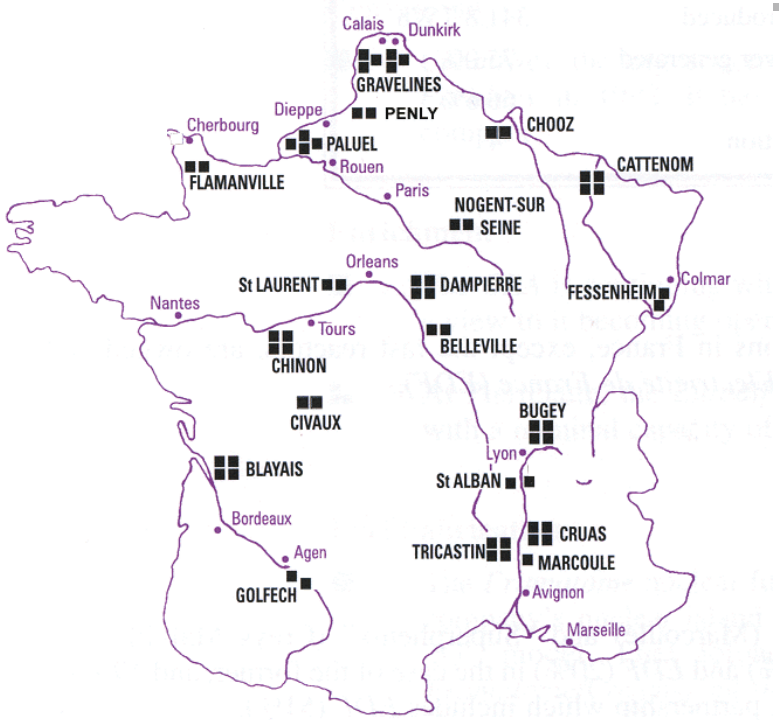
Each indicated location can represent several reactors.

Germany's dilemma is like coming up with a menu that pleases both carnivores and herbivores...



It could be fatal for Germany as an industrial powerhouse to give up ***a source of energy that is cheap, domestic and emits little carbon***... but... nuclear power is unpopular...

Nuclear Power in France



- France derives over 75% of its electricity from nuclear energy. This is due to a long-standing policy based on energy security.
- France is the world's largest net exporter of electricity due to its **very low cost of generation**, and gains over EUR 3 billion per year from this.
- France has been very active in developing nuclear technology. Reactors and fuel products and services are a major export.
- It is building its first Generation III reactor and planning a second.
- About 17% of France's electricity is from recycled nuclear fuel.

Environmental Performance Index (EPI) ranks 163 countries on 25 performance indicators tracked across ten policy categories covering both environmental public health and ecosystem vitality.

*France is **first** among the main industrial countries!*

Japan Government: 40 years more of nuclear power usage….

"Armenia Syndrome"…

Nuclear continues to be fastest growing energy sector…

Three main options of Nuclear Project implementation for the Republic of Moldova:

- *European light water PWR*
- *Russian light water PWR*
- *Pressurized heavy water reactor (CANDU PHWR)*

The main advantages of the proposed Regional Nuclear Project (integrated energy-technological complex):

- The rational use of the secondary (waste) energy, with the possibility of total elimination of thermal pollution (**for low temperature dehydration**, complex use of sea water potential (not only nuclear desalination!), tailing neutralizing and utilization...)
- Secondary use of spent nuclear fuel
- Utilization of nuclear warheads
- Perspective of "nuclear wastes" utilization
- Heavy water production, tritium H^3 production, He^3 production ...
- Combined nuclear-alternative cycle, with heat accumulation...

Note. Cost of tritium: Present Canada price is ~$30,000/g, Expected cost for future US production: $100,000 to $200,000/g

Usage of Tritium

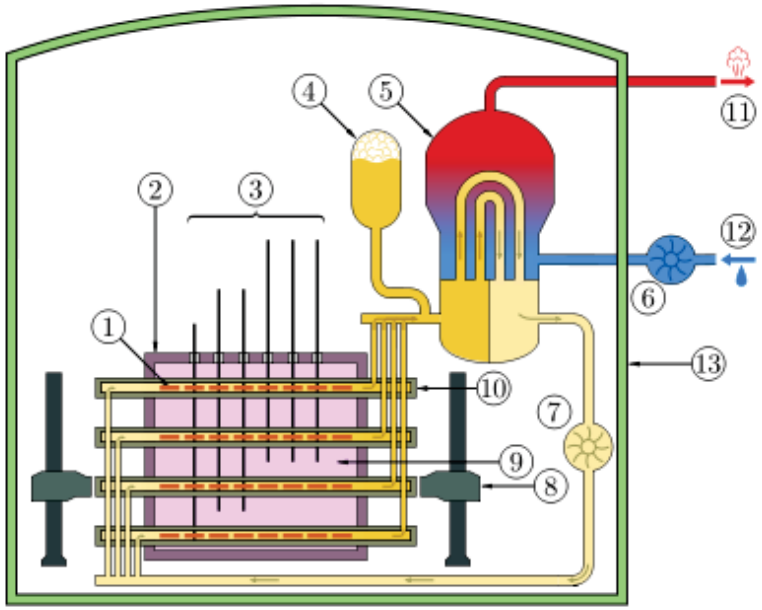
The emitted electrons from the radioactive decay of small amounts of tritium cause phosphors to glow so as to make self-powered lighting devices called betalights, which are now used in firearm night sights, watches, exit signs, map lights, and a variety of other devices

Nuclear weapons

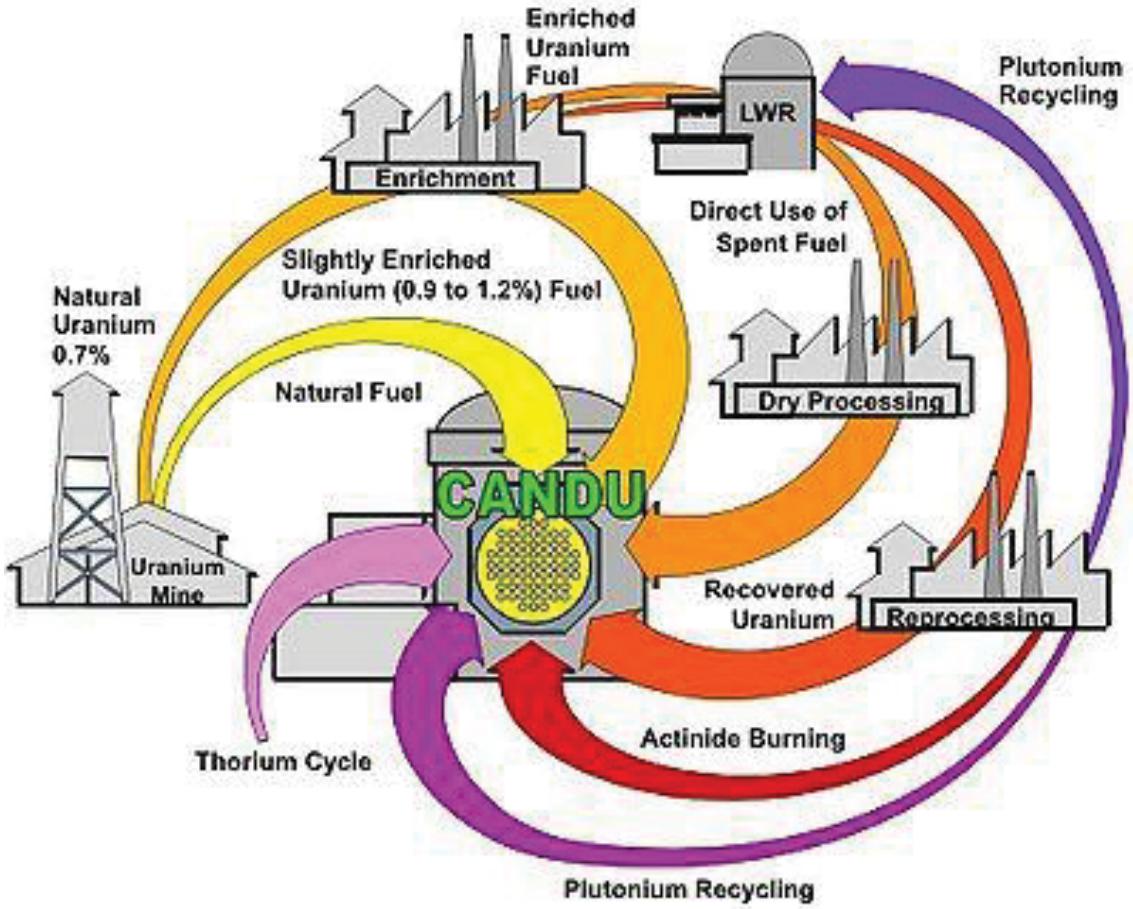
Tritium is widely used in multi-stage hydrogen bombs for boosting the fission primary explosion of a thermonuclear weapon (it can be similarly used for fission bombs)

Schematic Diagram of a CANDU reactor: The primary loop is in yellow and orange, the secondary in blue and red. The cool heavy water in the calandria can be seen in pink, along with partially-inserted shutoff rods.

1	Fuel bundle	8	Fueling machines
2	Calandria (reactor core)	9	Heavy water moderator
3	Adjuster rods	10	Pressure tube
4	Heavy water pressure reservoir	11	Steam going to steam turbine
5	Steam generator	12	Cold water returning from turbine
6	Light water pump	13	Containment building made of reinforced concrete
7	Heavy water pump		



Range of possible CANDU fuel cycles: CANDU reactors can accept a variety of fuel types, including the used fuel from light-water reactors:



Cattenom Nuclear Power Plant, France

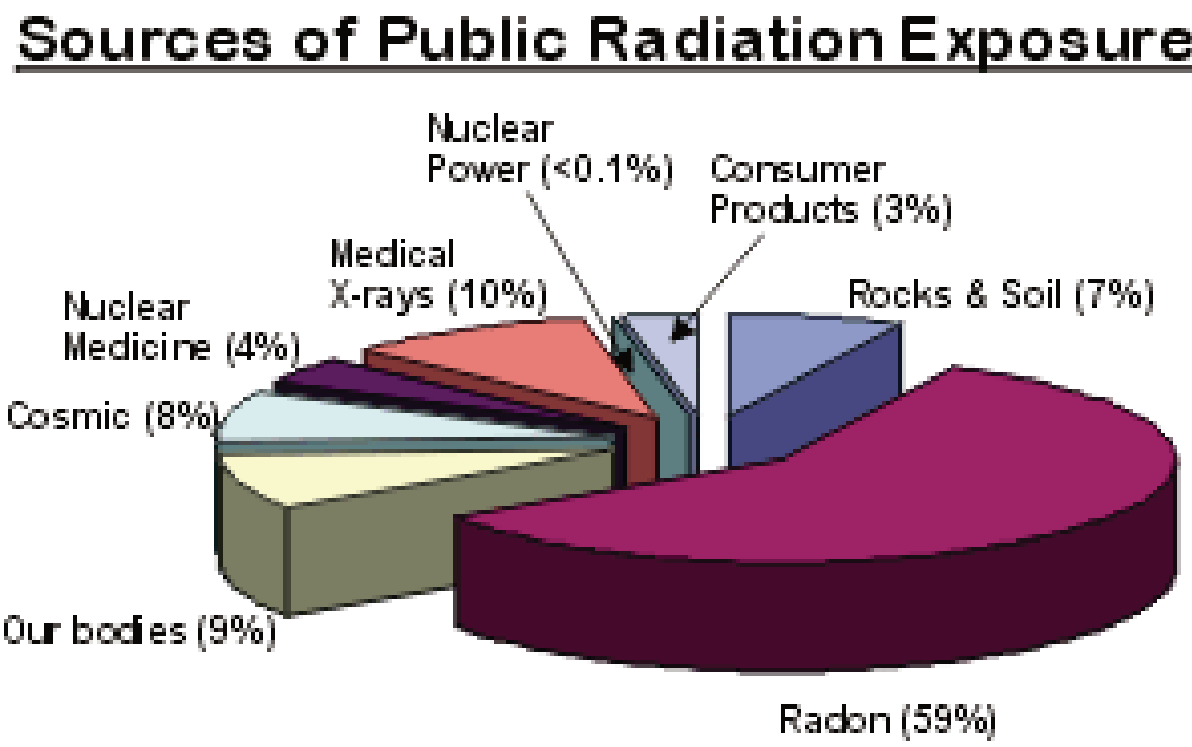
The "global warming" shortage which we overcome:

In the 2006 France, normally an electricity exporter, had to buy electricity on European spot market to meet demand. In 2009 in Germany, eight nuclear reactors had to be shut down simultaneously on hot summer days for reasons relating to the overheating of equipment or of rivers.

CNCAN NATIONAL COMMISSION FOR NUCLEAR ACTIVITIES CONTROL

URANIUM MINES - MAP

How much radiation do nuclear plants expose (the Canadian) public to?



Conclusion:

Sustainable development can be ensured - in the case of optimal combination of renewables with nuclear power !

Thanks !!!

Special gratitude to the Audience!!!