# Energy, Fusion and IFMIF-DONES

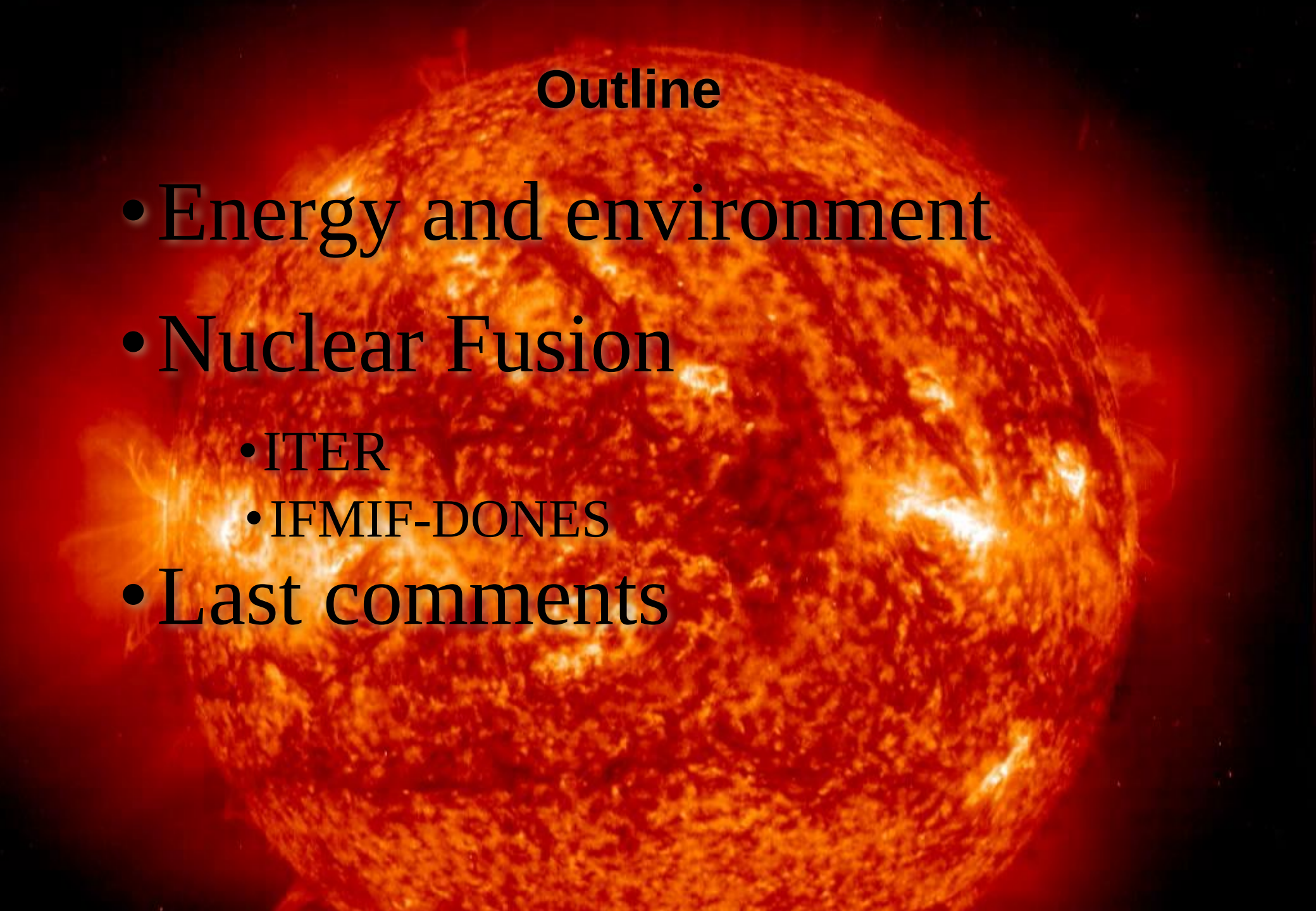

## Carlos Alejaldre

**Director General**

**CIEMAT**

**Former Deputy Director General ITER**

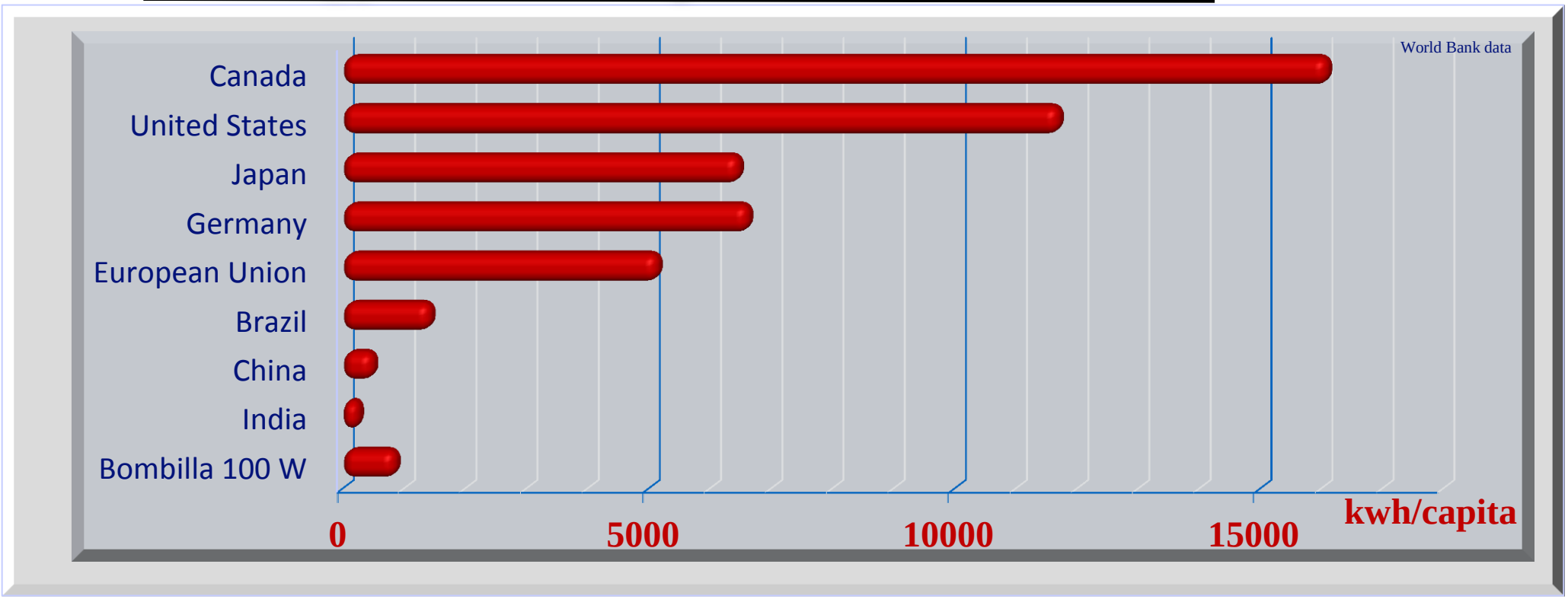

Synchrotron ALBA
Barcelona
13 Noviembre 2019



# Outline

- Energy and environment
- Nuclear Fusion
  - ITER
    - IFMIF-DONES
- Last comments

# Energy Consumption



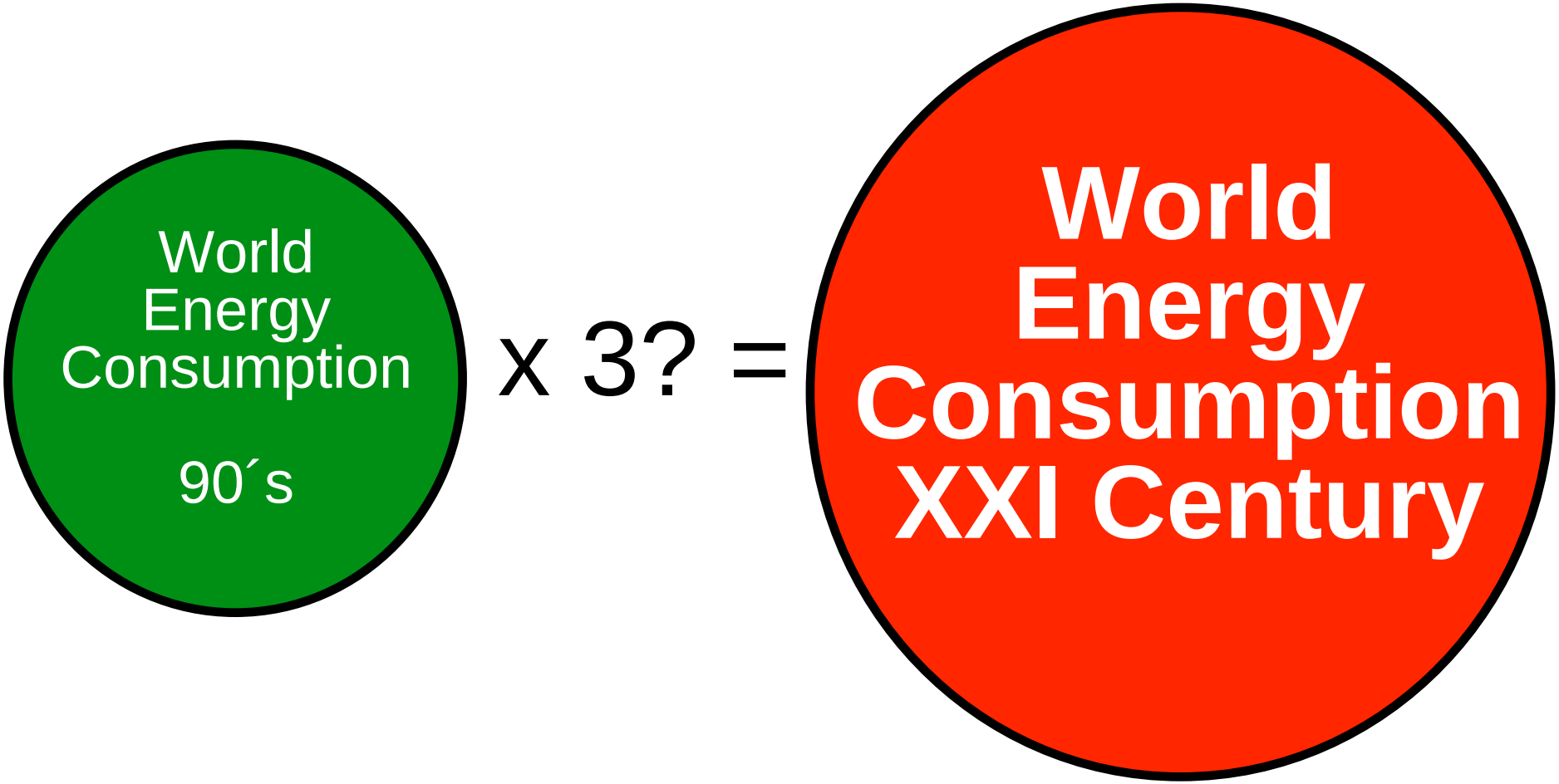

World average: 2000 kWh/persona/año

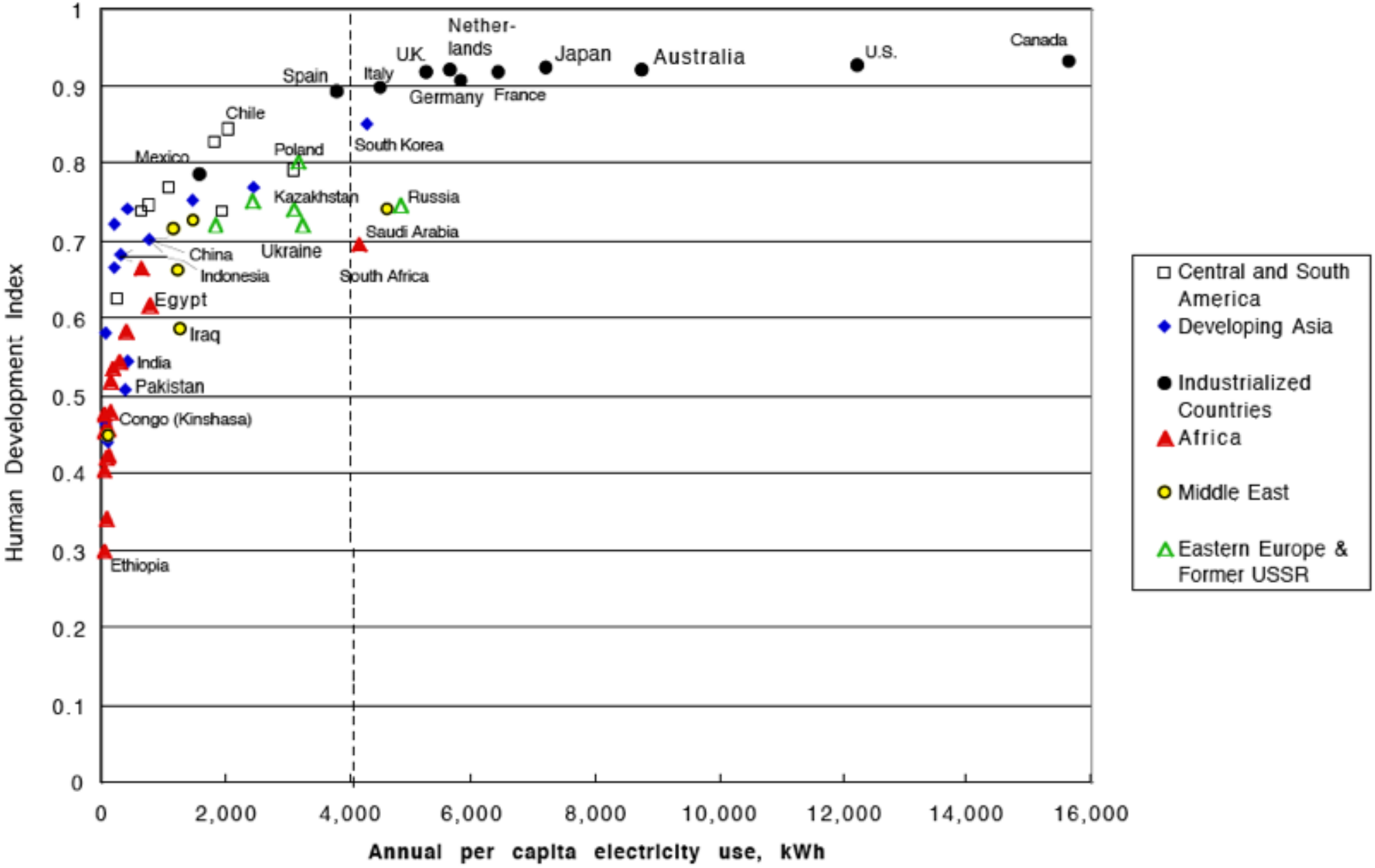
Total Consumption (90´s):5.000 millions x 2.000 = $10^4$ TWh

*Assume a future: world population doubles and less of 1/3 American consumption allows a satisfactory quality life*

Total Consumption (XXI):10.000 millions x 3.000 = 3 x $10^4$ TWh

# Energy Consumption




Human Development Index
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
Annual per capita electricity use, kWh
Canada
U.S.
Australia
Japan
Nether-lands
UK
Italy
Germany
France
Spain
Chile
Mexico
Poland
South Korea
Kazakhstan
Russia
Saudi Arabia
China
Ukraine
Indonesia
South Africa
Egypt
Iraq
India
Pakistan
Congo (Kinshasa)
Ethiopia
Central and South America
Developing Asia
Industrialized Countries
Africa
Middle East
Eastern Europe & Former USSR

# Energy Consumption



World Energy Consumption

90´s

x 3? =

**World Energy Consumption XXI Century**

| | |
|---|---|
| **Oil** | **43 (32)%** |
| **Coal** | **22 (30)%** |
| **Gas** | **20 (24)%** |
| **Nuclear** | **8 (4)%** |
| **Hydro** | **5 (7)%** |
| **Other** | **2 (3)%** |

BP 2017 ENERGY OUTLOOK

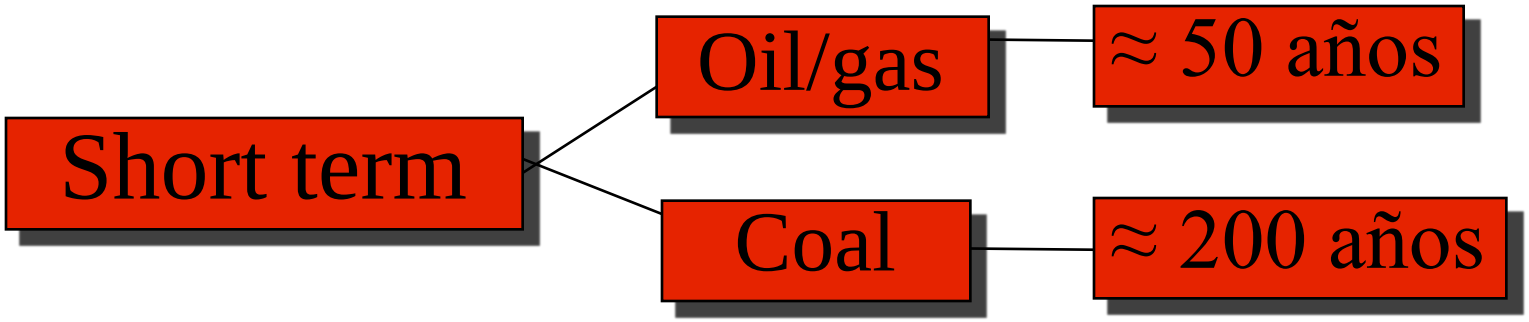
**New Energy Cocktail**

Resources disponibility

Environmental consequences

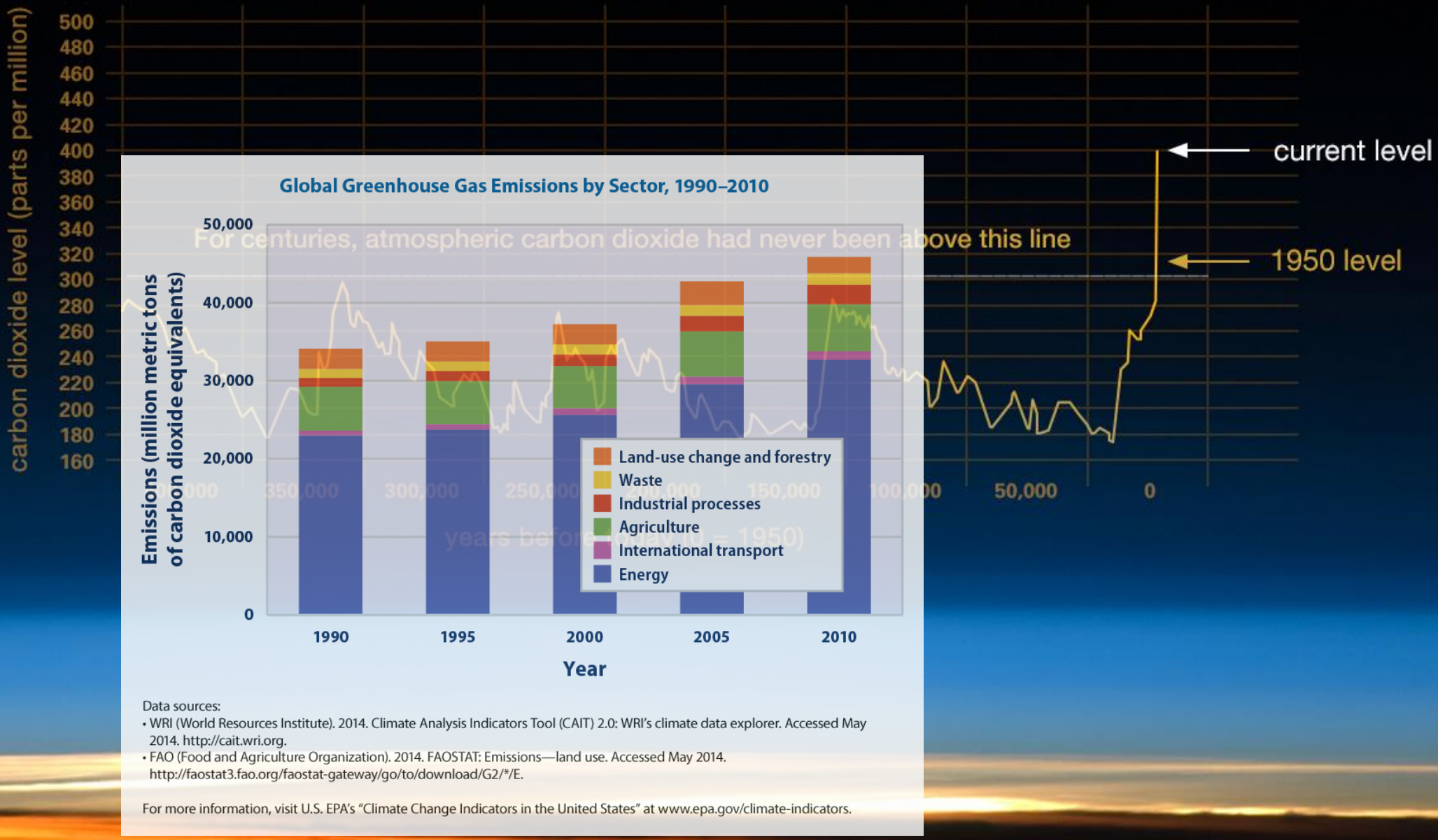
Supply security

# Energy options




Coal production is expected to reach 7.000 Mtons in 2030 – China is currently bringing two additional coal-fired power plants to the electric power grid **every week**.

# $CO_2$ levels in the last 400.000 years




## Global Greenhouse Gas Emissions by Sector, 1990–2010




Data sources:

- WRI (World Resources Institute). 2014. Climate Analysis Indicators Tool (CAIT) 2.0: WRI's climate data explorer. Accessed May 2014. http://cait.wri.org.
- FAO (Food and Agriculture Organization). 2014. FAOSTAT: Emissions—land use. Accessed May 2014. http://faostat3.fao.org/faostat-gateway/go/to/download/G2/*/E.

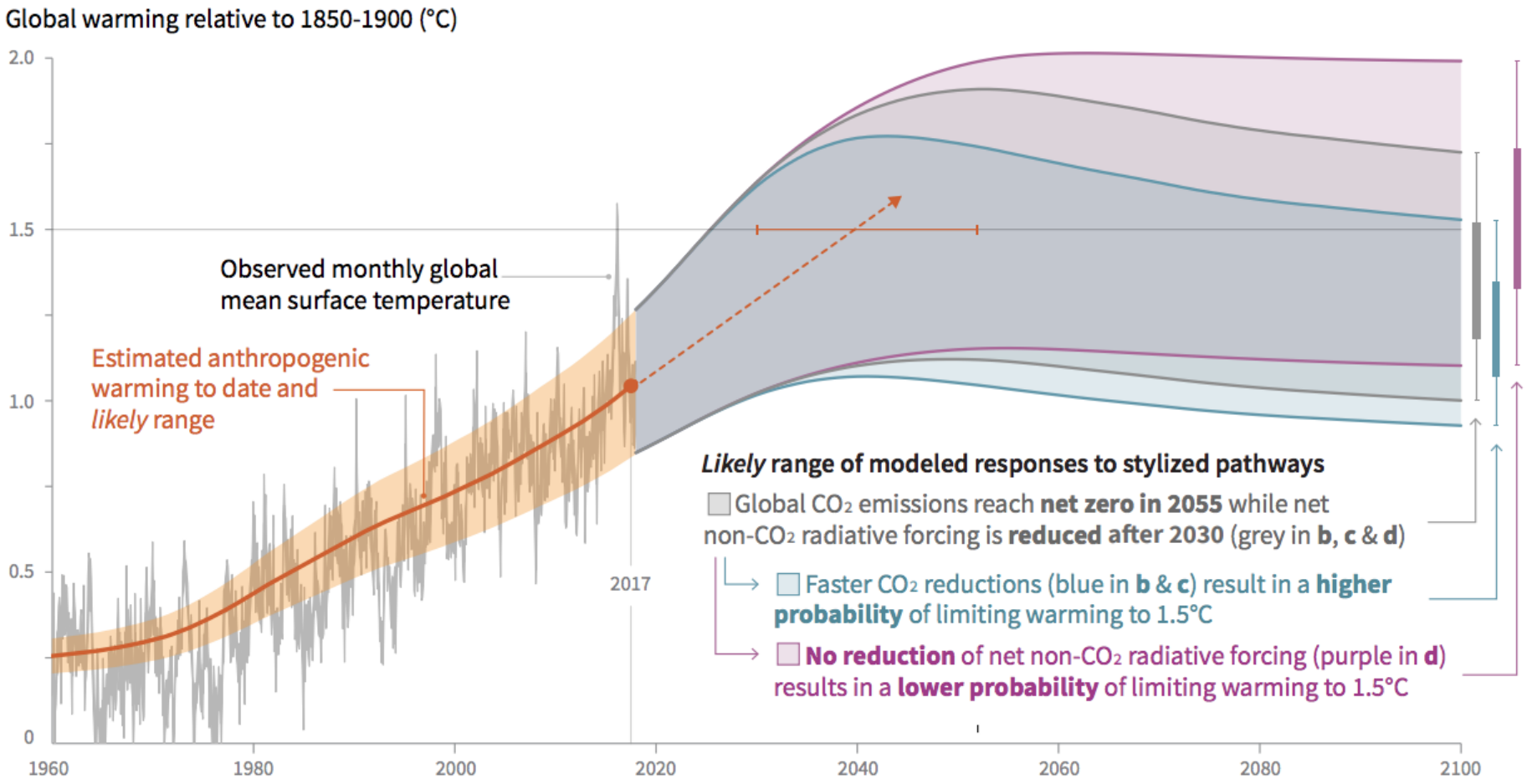
For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.



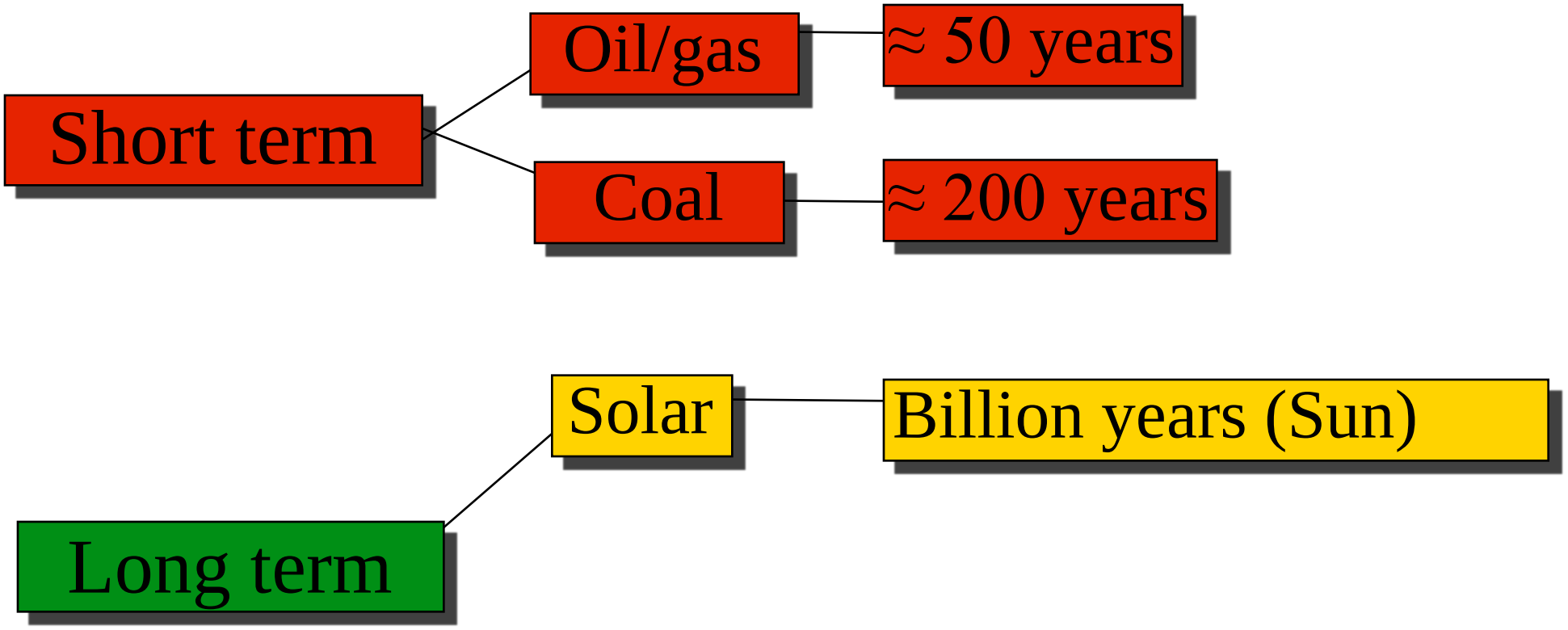
Mount Kilimanjaro, Tanzania, 1912-1998

South Cascade Glacier (Washington State), 1928-20

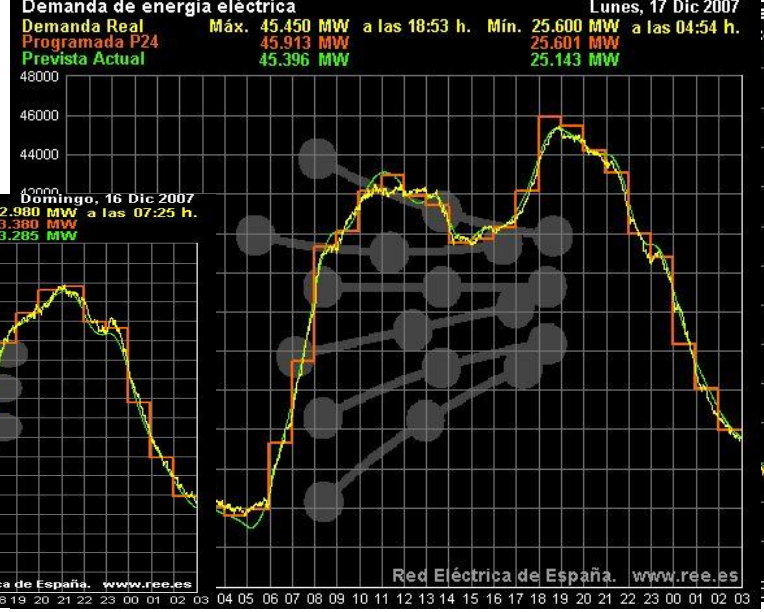
# Reality - Forecast



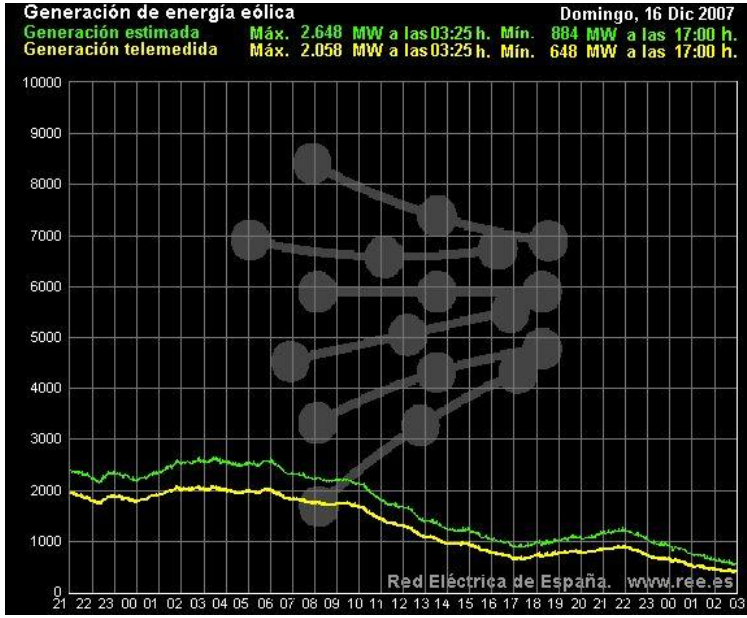
# Energy options

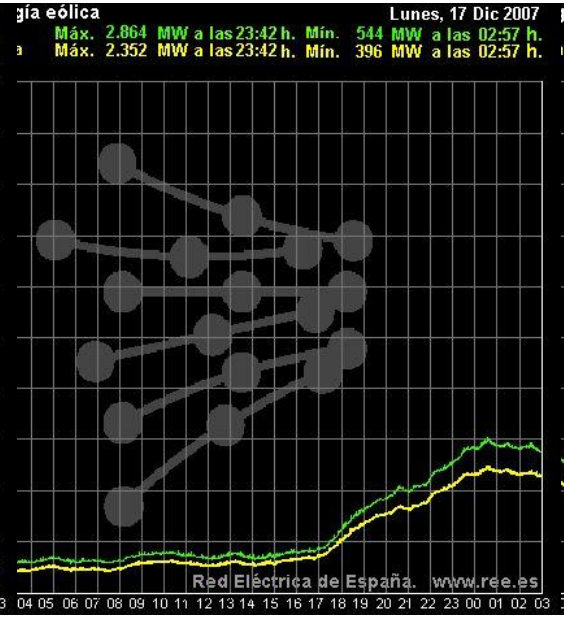


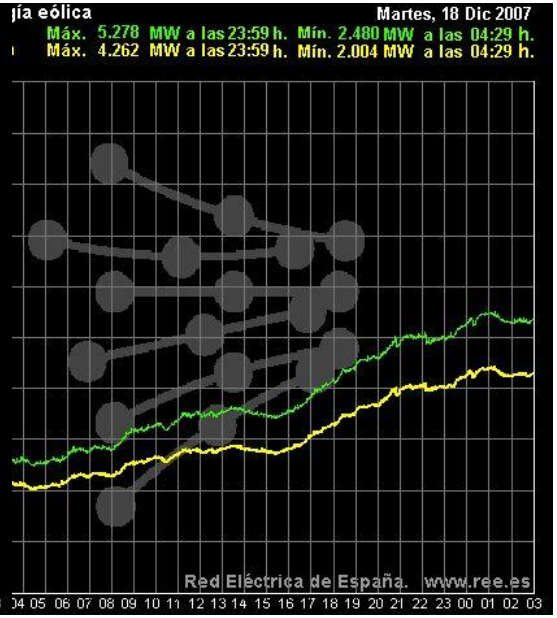

Demanda de energía eléctrica
Domingo, 16 Dic 2007
Demanda Real Máx. 37.910 MW a las 21:08 h. Mín. 22.980 MW a las 07:25 h.
Programada P24 37.804 MW 23.380 MW
Prevista Actual 37.984 MW 23.285 MW
Red Eléctrica de España. www.ree.es


Demanda de energía eléctrica
Lunes, 17 Dic 2007
Demanda Real Máx. 45.450 MW a las 18:53 h. Mín. 25.600 MW a las 04:54 h.
Programada P24 45.913 MW 25.601 MW
Prevista Actual 45.396 MW 25.143 MW
Red Eléctrica de España. www.ree.es

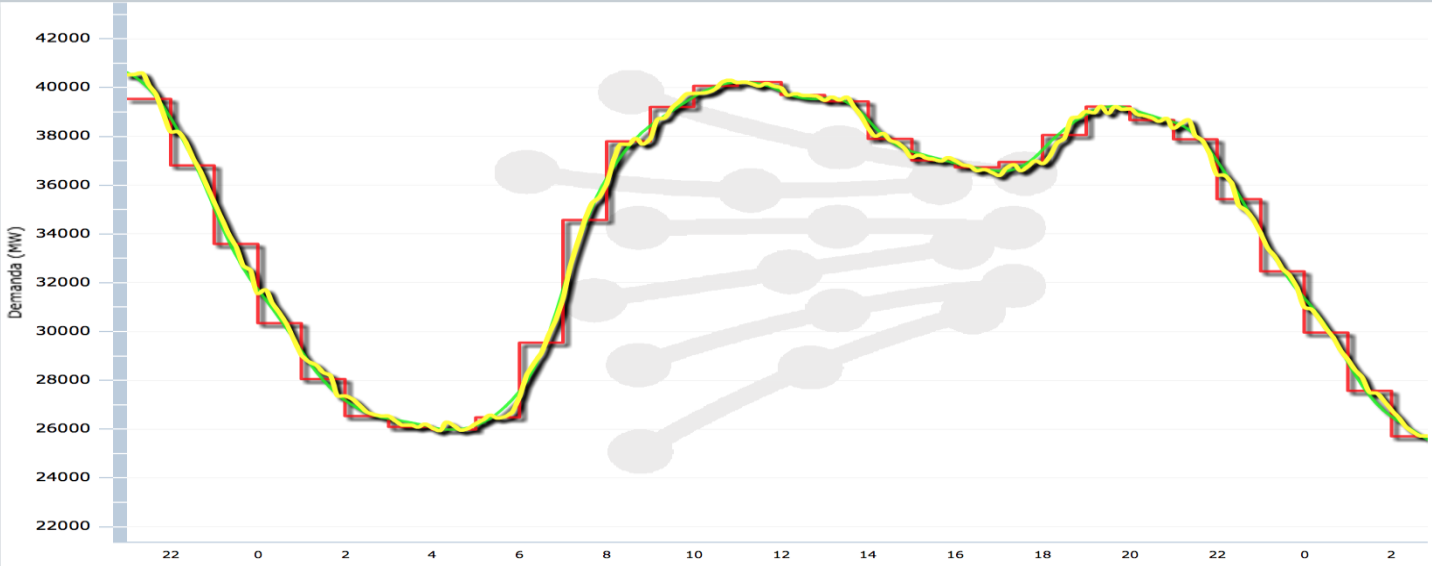

eléctrica
:44:53
38.763 MW
Demanda Real 38.680 MW
Programada P24 38.257 MW
Red Eléctrica de España. www.ree.es


Generación de energía eólica
Domingo, 16 Dic 2007
Generación estimada Máx. 2.648 MW a las 03:25 h. Mín. 884 MW a las 17:00 h.
Generación telemedida Máx. 2.058 MW a las 03:25 h. Mín. 648 MW a las 17:00 h.
Red Eléctrica de España. www.ree.es

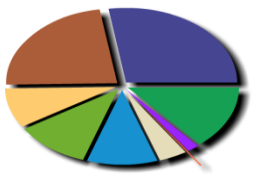

gía eólica
Lunes, 17 Dic 2007
Máx. 2.864 MW a las 23:42 h. Mín. 544 MW a las 02:57 h.
Máx. 2.352 MW a las 23:42 h. Mín. 396 MW a las 02:57 h.
Red Eléctrica de España. www.ree.es


gía eólica
Martes, 18 Dic 2007
Máx. 5.278 MW a las 23:59 h. Mín. 2.480 MW a las 04:29 h.
Máx. 4.262 MW a las 23:59 h. Mín. 2.004 MW a las 04:29 h.
Red Eléctrica de España. www.ree.es

## Demanda de energía eléctrica en tiempo real, estructura de generación y emisiones de CO2

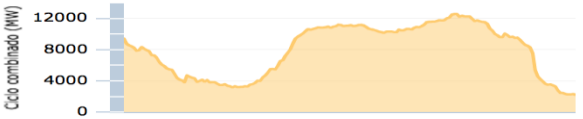



Estructura de generación a las 03:00



- Nuclear
- Fuel + gas
- Carbón
- Ciclo combinado
- Eólica
- Hidráulica (+)
- Intercambios int. (+)
- Enlace balear (-)
- Solar térmica
- Fotovoltaica
- Térmica renovable
- Cogeneración y resto

Generación | CO2 asociado a generación

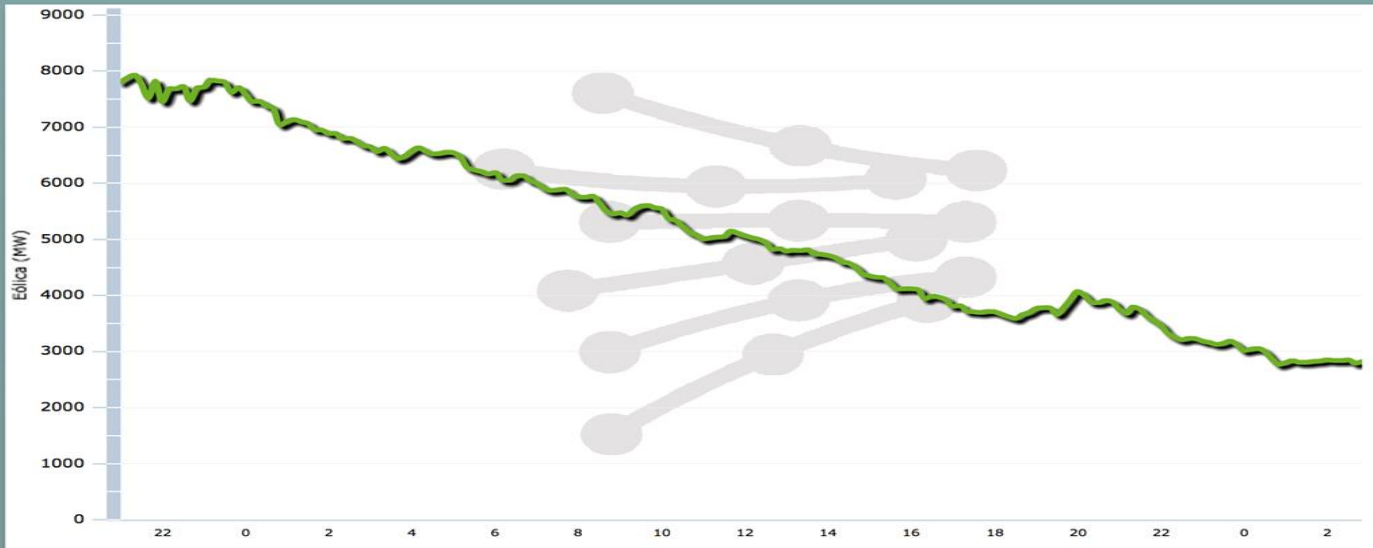


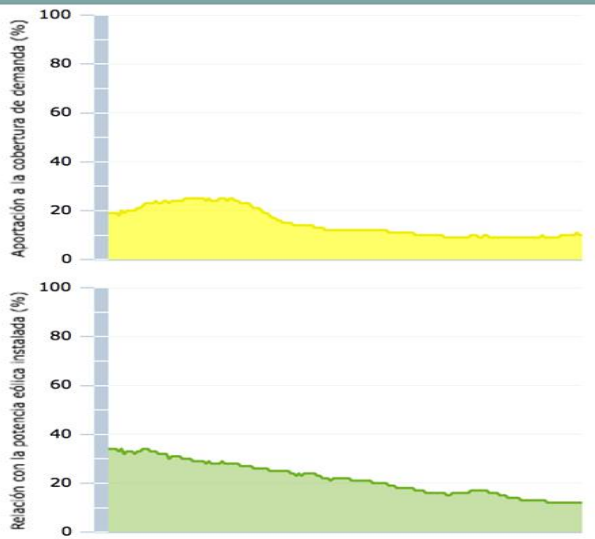

**Demanda (MW) a las 03:00 de 21/01/2017 Real = 25122 Prevista = 25389 Emisiones CO2 (t/h) = 7487**



2017-01-20 Ver fecha Máximo diario 40448 a las 20/01/2017 10:46 Mínimo diario 25821 a las 20/01/2017 04:47 Ayuda

## Generación de energía eólica en tiempo real, relación con la potencia eólica instalada y aportación a la demanda.

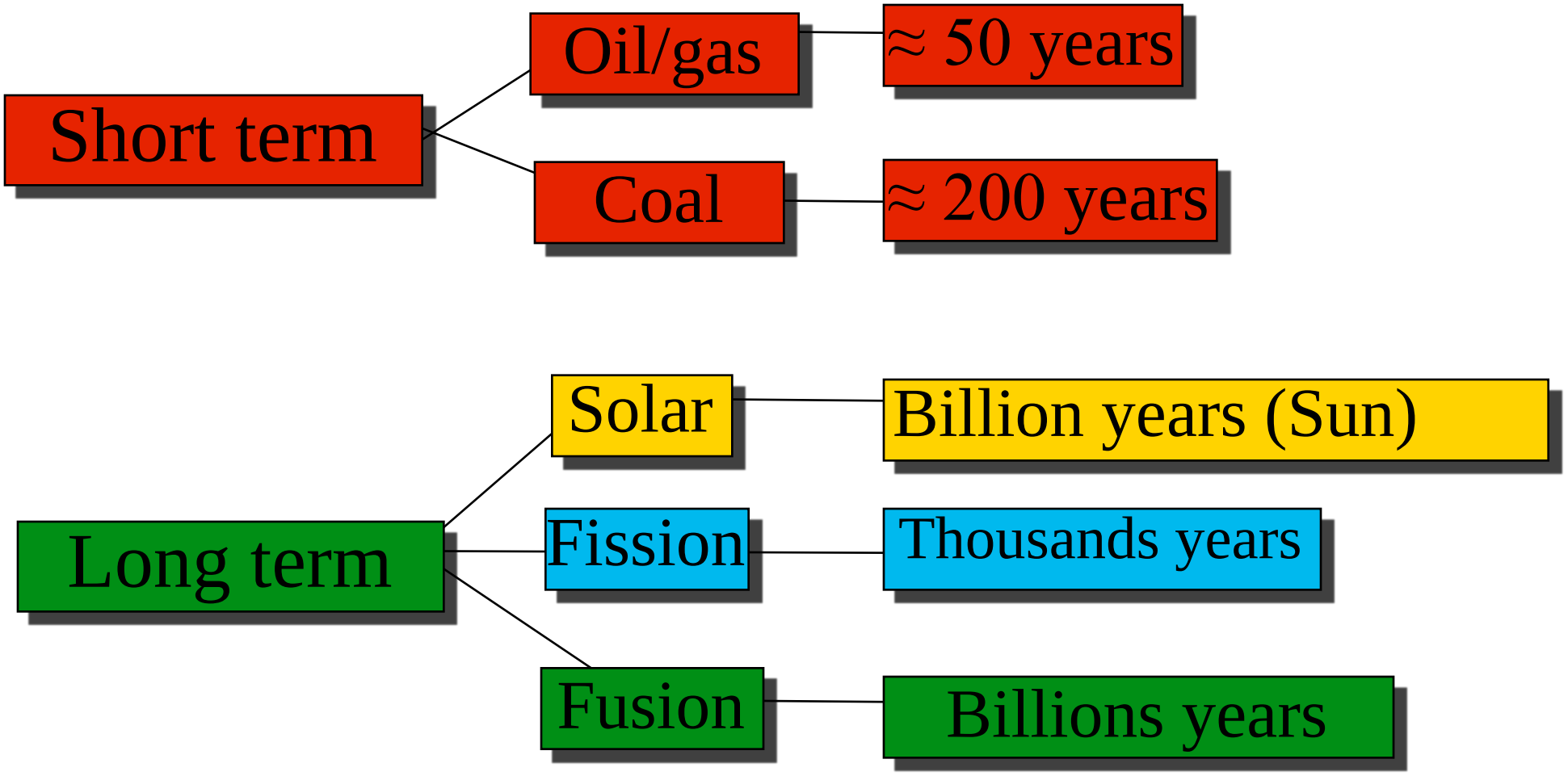



**Valor estimado de generación eólica a las 03:00 del 21/01/2017 : 2833(MW).**

**Supone un 12 % de la potencia total eólica instalada y una aportación del 11 % a la cobertura de la demanda.**

# Energy options



# Fusion Fuel

Primary fuel of a Fusion Power Plant is water and lithium*


≈

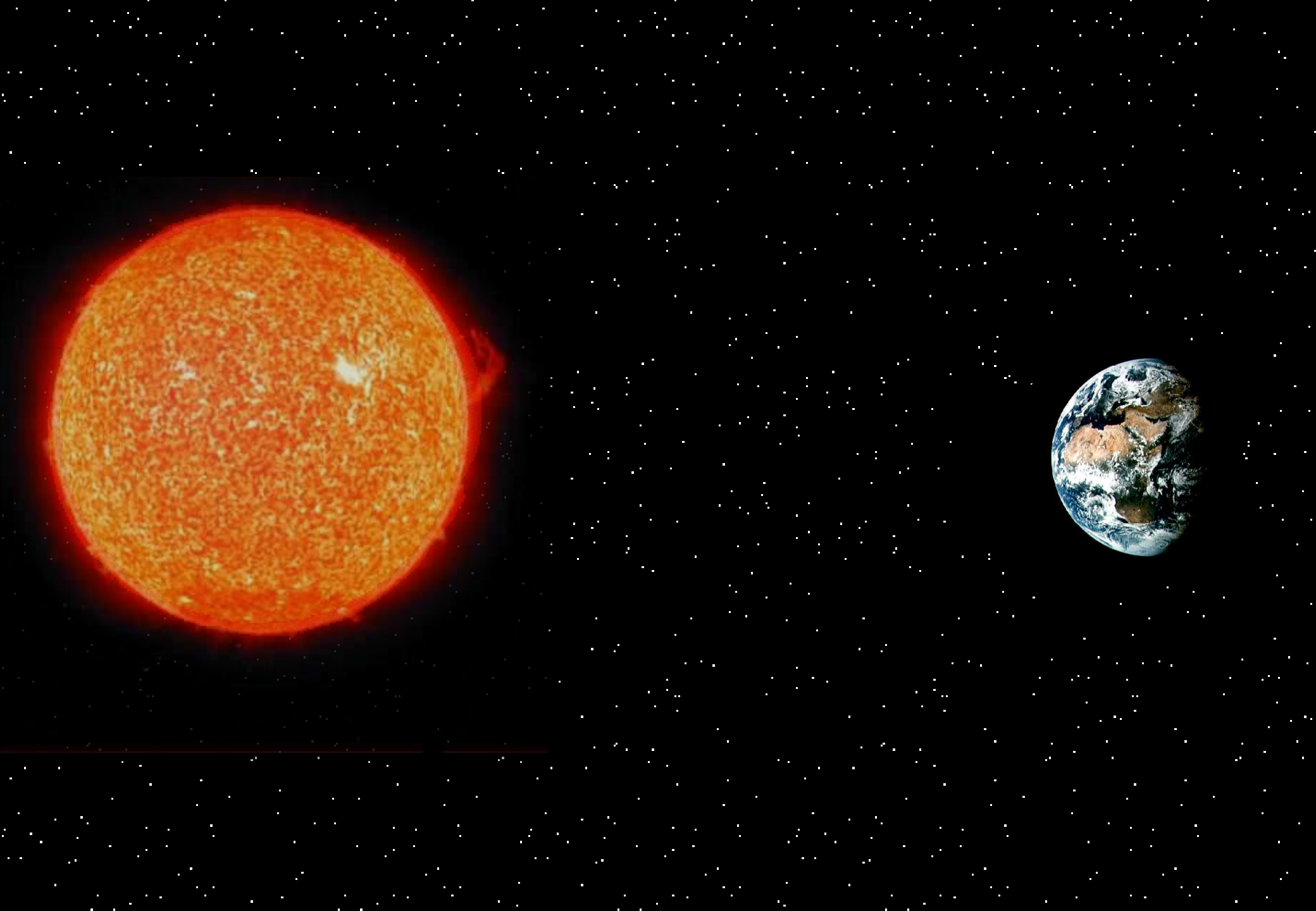
45 liters of water

+

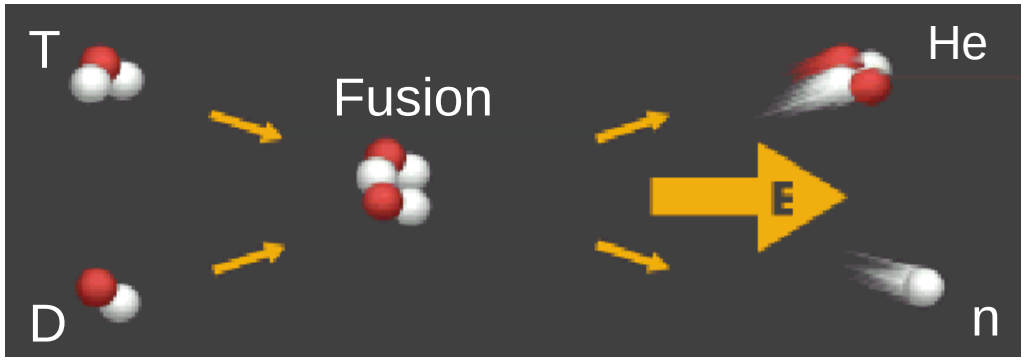
Computer battery

Lithium from a portable battery + half bathtub water **(-> a thimble of heavy water) can produce** 200,000 kW-hour
≈ average consumption of one spaniard during 45 years

* ***Deuterium/hydrogen = 1/6700***
***+ tritium from: neutron (from fusion) + lithium □ tritium + helium***



# Fusión in our Planet *"... Is not the same as in the Sun"*




+ 20% de Energy (3.5 MeV)

+ 80% de Energy (14.1 MeV)

- **The most "suitable" fusion reaction for energy production in our planet:**

$$^2D + ^3T \Rightarrow ^4He\ (3.5\ MeV) + ^1n\ (14.1\ MeV)$$

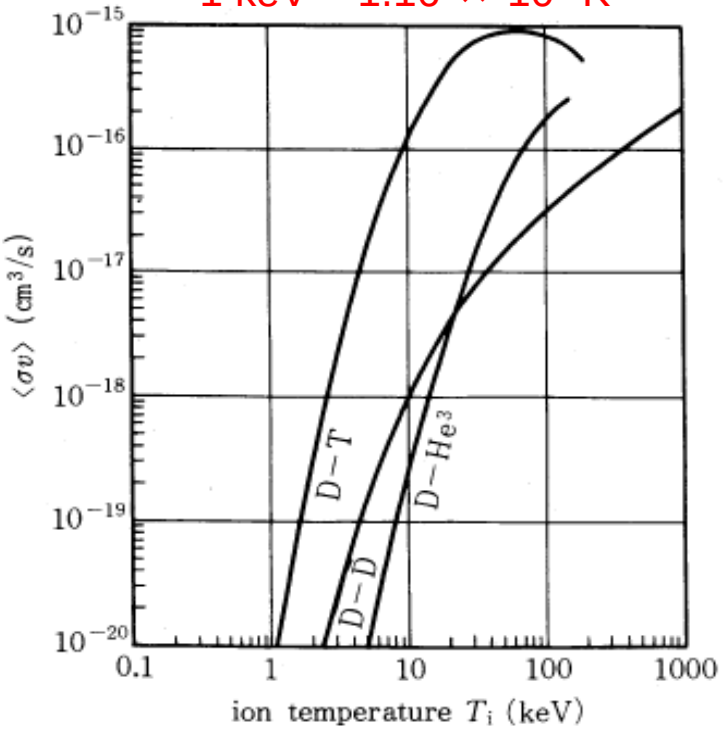
- **Two other reactions are very important for DT fusión:**

$$^1n + ^6Li \Rightarrow ^4He + ^3T + 4.8\ MeV$$

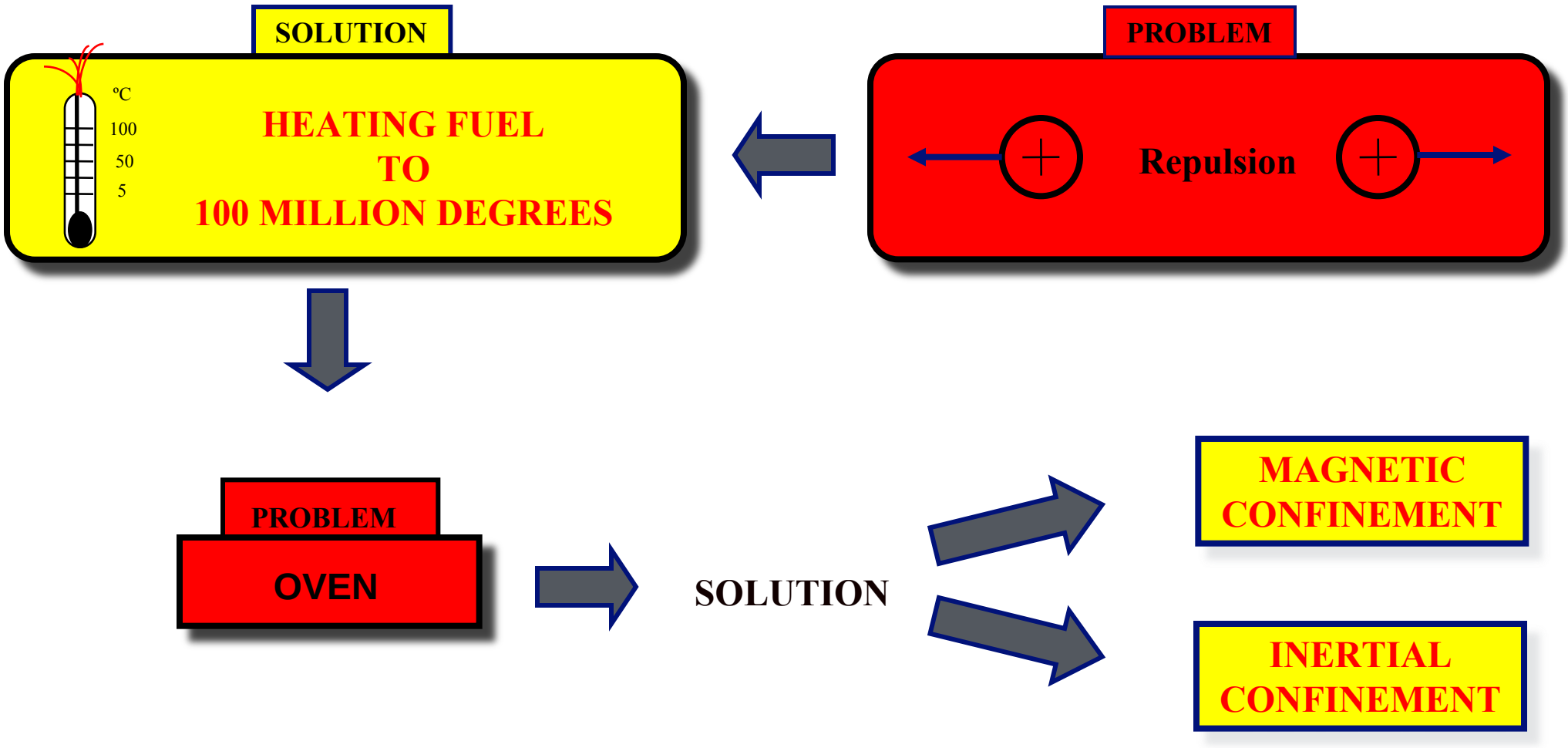
$$^1n + ^7Li \Rightarrow ^3He + ^3T + ^1n - 2.5\ MeV$$

  - These reactions will permit to generate tritium in a fusion power plant.

1 keV = 1.16 × $10^7$ K

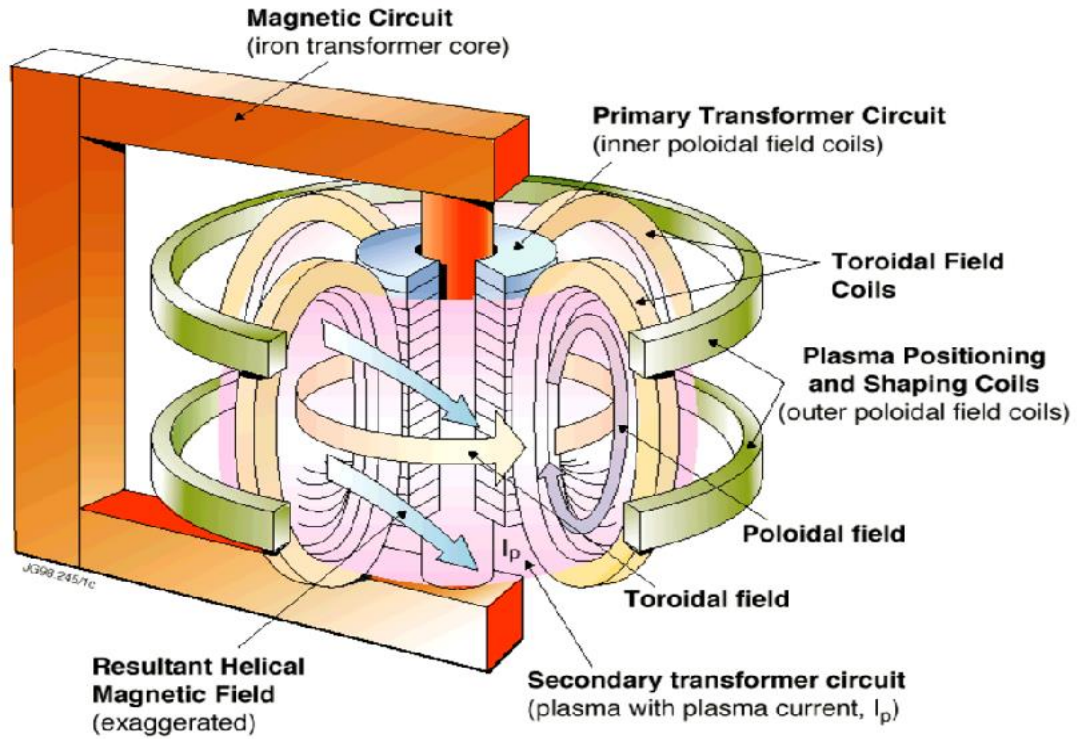


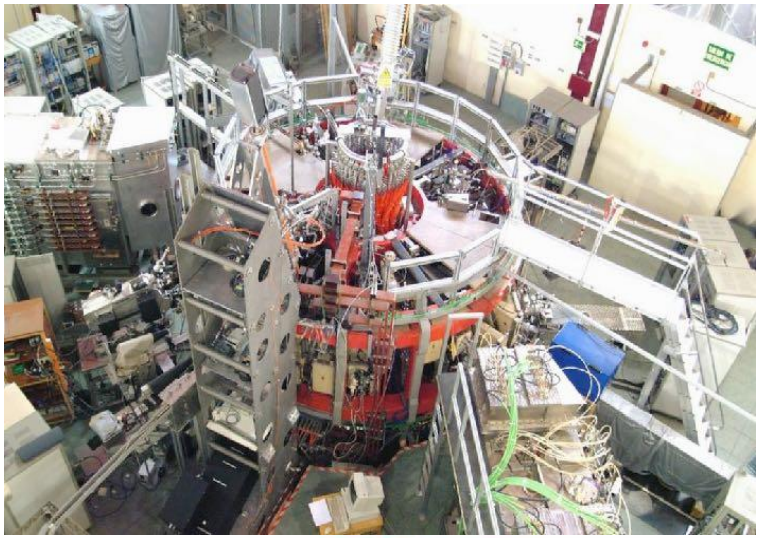
# Problem-Solution



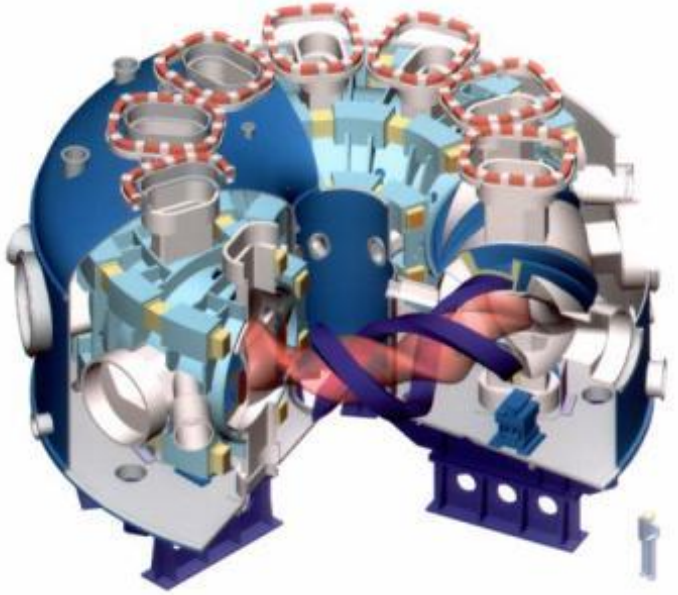
# THE BOTTLES: Tokamak and Stellarator

**"тороидальная камера в магнитных катушках" (*toroidal'naya kamera v magnitnykh katushkakh*) — toroidal chamber in magnetic coils (Tochamac)).**

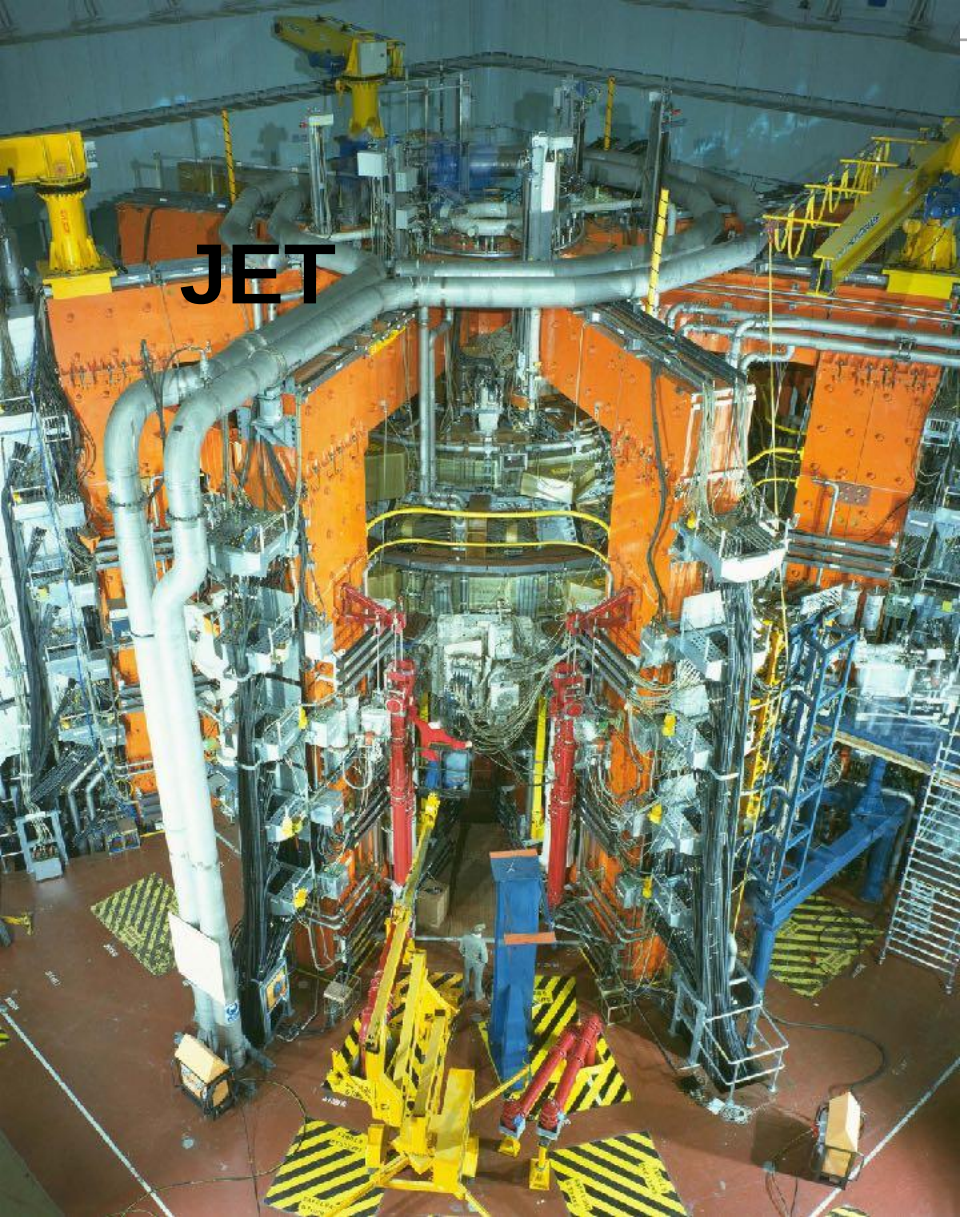


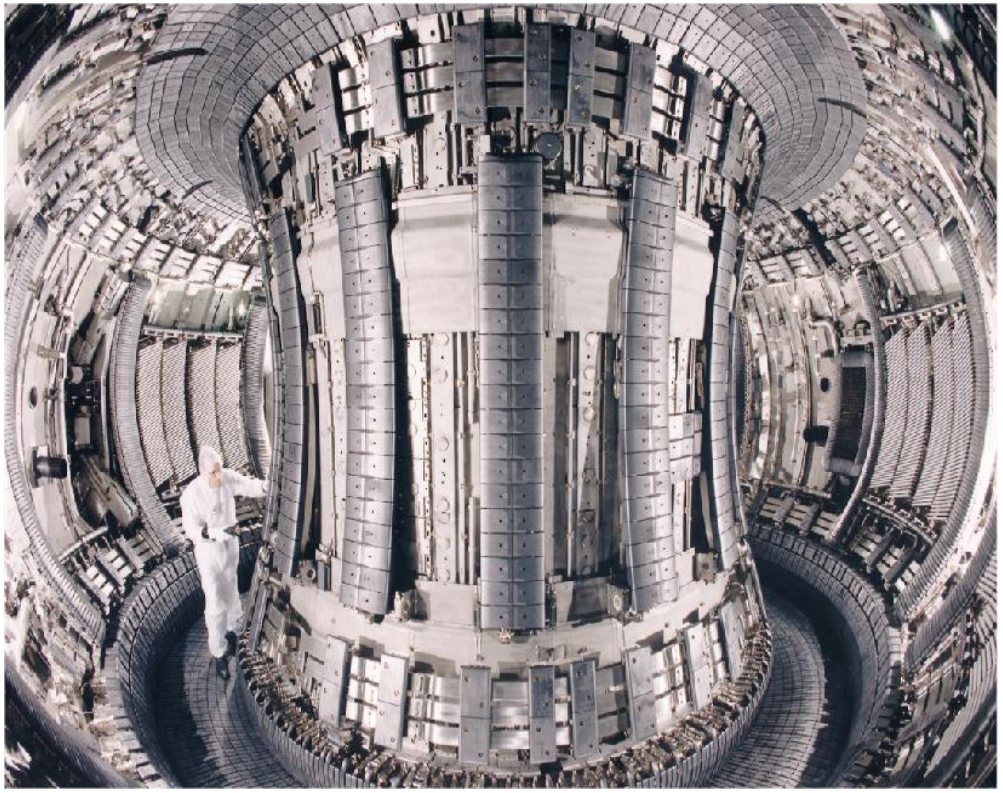



TJ-II
CIEMAT



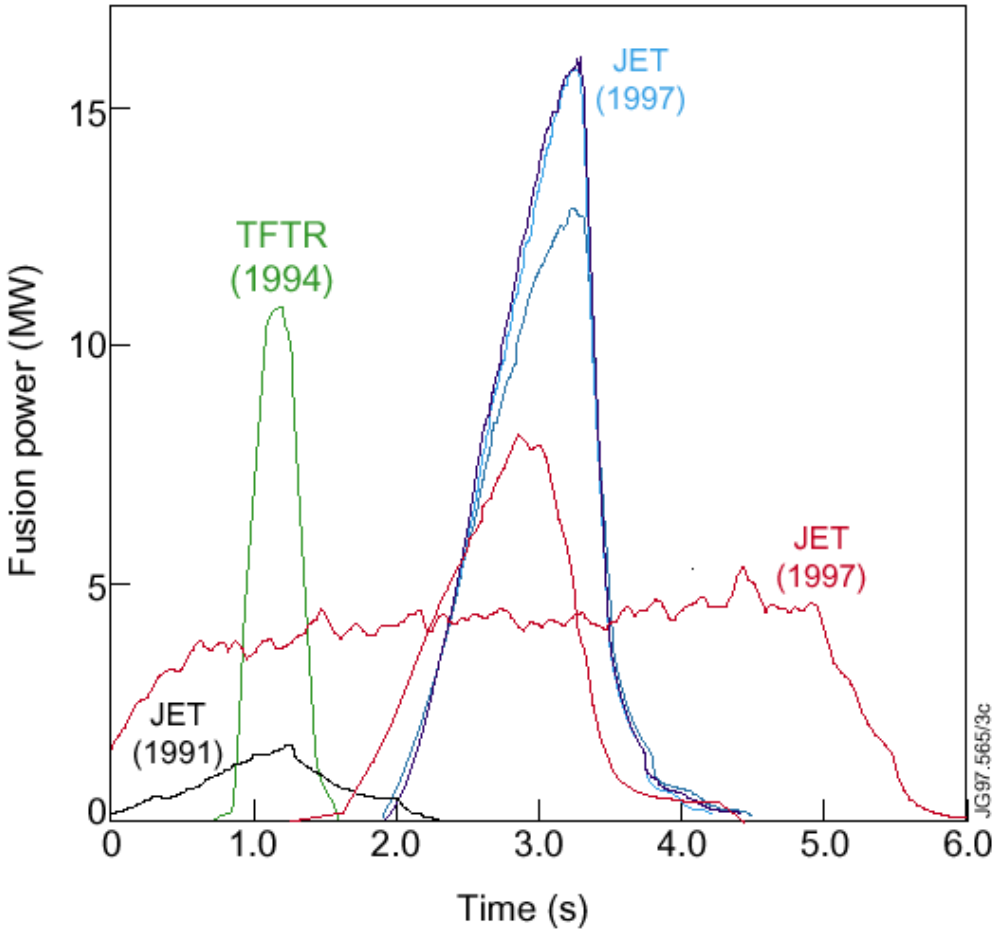
LHD
Japón



# JET: The world biggest nuclear fusion “bottle”

# Achievements




# Plasma fusion performance

*Temperature - $T_i$:* *1-2 $\times 10^8$ K (10-20 keV)*
*(~10 $\times$ temperature at Sun center)*

*Densidad - $n_i$:* *1 $\times 10^{20}$ $m^{-3}$*
*(~$10^{-6}$ atmospheric density)*

*Energy confinement time - $\tau_E$: few segundos ($\propto$ corriente $\times$ radius$^2$)*
*(plasma pulse duration ~1000s)*

***Fusion power amplificación:*** $Q = \dfrac{\text{Fusion Power}}{\text{Input Power}} \sim n_i T_i t_E$

***⇒ Today's facilities : Q ≤ 1***

***⇒ ITER: Q ≥ 10***

***⇒ "Controlled ignition": Q ≥ 30***

"All the News That's Fit to Print"

# The New York Times

**Late Edition**
Weather: Rain likely today, strong easterly winds; rain ending late tonight. Partly cloudy and warmer tomorrow. Temperatures: today 43-47, tonight 40-45; yesterday 38-62. Details, page C30.

VOL. CXXXV . . No. 46,601  NEW YORK, FRIDAY, NOVEMBER 22, 1985

80 cents beyond 75 miles from New York City, except on Long Island. 30 CENTS

# ext of the Joint U.S.-Soviet Statement: 'Greater Understanding Achieved'

Special to The New York Times

*EVA, Nov. 21 — Following is t of the joint Soviet-American ent at the end of the summit today, as made public by the louse:*

utual agreement, the Presi- the United States, Ronald , and the General Secretary of tral, Committee of the Com- Party of the Soviet Union, Mi- Gorbachev, met in Geneva -21. Attending the meeting on side were Secretary of State P. Shultz; chief of staff, Don- egan; Assistant to the Presi- obert C. McFarlane; Ambas- the U.S.S.R., Arthur A. Hart- ecial adviser to the President Secretary of State for Arms Paul H. Nitze; Assistant Sec- f State of European Affairs, e L. Ridgway; Special Assist- he President for National Se- ffairs, Jack F. Matlock.

ding on the Soviet side were r of the Politburo of the Cen- mmittee of the C.P.S.U., r of Foreign Affairs Eduard ardnadze; First Deputy For- ister Georgi M. Korniyenko; ador to the United States, F. Dobrynin; head of the De- t of Propaganda of the Cen- mmittee of the C.P.S.U., Alek- . Yakovlev; head of the De- t of International Informa- he Central Committee of the ., Leonid M. Zamyatin; t to the General Secretary of ntral Committee of the , Andrei M. Aleksandrov.

comprehensive discussions the basic questions of U.S.- lations and the current inter- situation. The meetings were d useful. Serious differences n a number of critical issues. acknowledging the differ- their systems and ap- to international issues, eater understanding of each ew was achieved by the two They agreed about the need ve U.S.-Soviet relations and national situation as a whole.

In this connection the two sides have confirmed the importance of an ongoing dialogue, reflecting their strong desire to seek common ground on existing problems.

They agreed to meet again in the nearest future. The General Secretary accepted an invitation by the President of the United States to visit the United States of America, and the President of the United States accepted an invitation by the General Secretary of the Central Committee of the C.P.S.U. to visit the Soviet Union. Arrangements for the timing of the visits will be agreed upon through diplomatic channels.

In their meetings, agreement was reached on a number of specific issues. Areas of agreement are registered on the following pages.

## Security

The sides, having discussed key security issues, and conscious of the special responsibility of the USSR and the U.S. for maintaining peace, have agreed that a nuclear war cannot be won and must never be fought. Recognizing that any conflict between the U.S.S.R. and the U.S. could have catastrophic consequences, they emphasized the importance of preventing any war between them, whether nuclear or conventional. They will not seek to achieve military superiority.

## Nuclear and Space Talks

The President and the General Secretary discussed the negotiations on nuclear and space arms.

They agreed to accelerate the work at these negotiations, with a view to accomplishing the tasks set down in the Joint U.S.-Soviet Agreement of Jan. 8, 1985, namely to prevent an arms race in space and to terminate it on earth, to limit and reduce nuclear arms and enhance strategic stability.

Noting the proposals recently tabled by the U.S. and the Soviet Union, they called for early progress, in particular in areas where there is common ground, including the principle of 50 percent reductions in the nuclear arms of the U.S. and the U.S.S.R. appropriately applied, we well as the idea of an interim I.N.F. agreement.

During the negotiation of these agreements, effective measures for verification of compliance with obligations assumed will be agreed upon.

## Risk Reduction Centers

The sides agreed to study the question at the expert level of centers to reduce nuclear risk taking into account the issues and developments in the Geneva negotiations. They satisfaction in such recent step this direction as the modernizati the Soviet-U.S. hot line.

## Nuclear Nonproliferati

General Secretary Gorbachev President Reagan reaffirmed commitment of the U.S.S.R. and U.S. to the Treaty on the Nonprol ation of Nuclear Weapons and t interest in strengthening toge with other countries the nonprolif tion regime, and in further enhan the effectiveness of the treaty, i alia by enlarging its membershi

The U.S.S.R. and the U.S. reaff their commitment, assumed by t under the Treaty on the Nonprolif tion of Nuclear Weapons, to pu negotiations in good faith on mat of nuclear arms limitation and di mament in accordance with Art VI of the treaty.

The two sides plan to continu promote the strengthening of the ternational Atomic Energy Age and to support the activities of agency in implementing safegua as well as in promoting the peac uses of nuclear energy.

They view positively the practic regular Soviet-U.S. consultations nonproliferation of nuclear weapc which have been businesslike constructive, and express their int to continue this practice in the futu

## Chemical Weapons

In the context of discussing curity problems, the two sides r firmed that they are in favor of a general and complete prohibition of chemical weapons and the destruction of existing stockpiles of such weapons. They agreed to accelerate efforts to conclude an effective and verifiable international convention on this matter.

The two sides agreed to intensify bilateral discussions on the level of experts on all aspects of such a chemical weapons ban, including the question of verification. They agreed to initiate a dialogue on preventing the proliferation of chemical weapons.

ministries and departments in such fields as agriculture, housing and protection of the environment have been useful.

Recognizing that exchanges of views on regional issues on the expert level have proven useful, they agreed to continue such exchanges on a regular basis.

The sides intend to expand the programs of bilateral cultural, educational and scientific-technical exchanges, and also to develop trade and economic ties. The President of the United States and the General

— a global task — through joint research and practical measures. In accordance with the existing U.S.-Soviet agreement in this area, consultations will be held next year in Moscow and Washington on specific programs of cooperation.

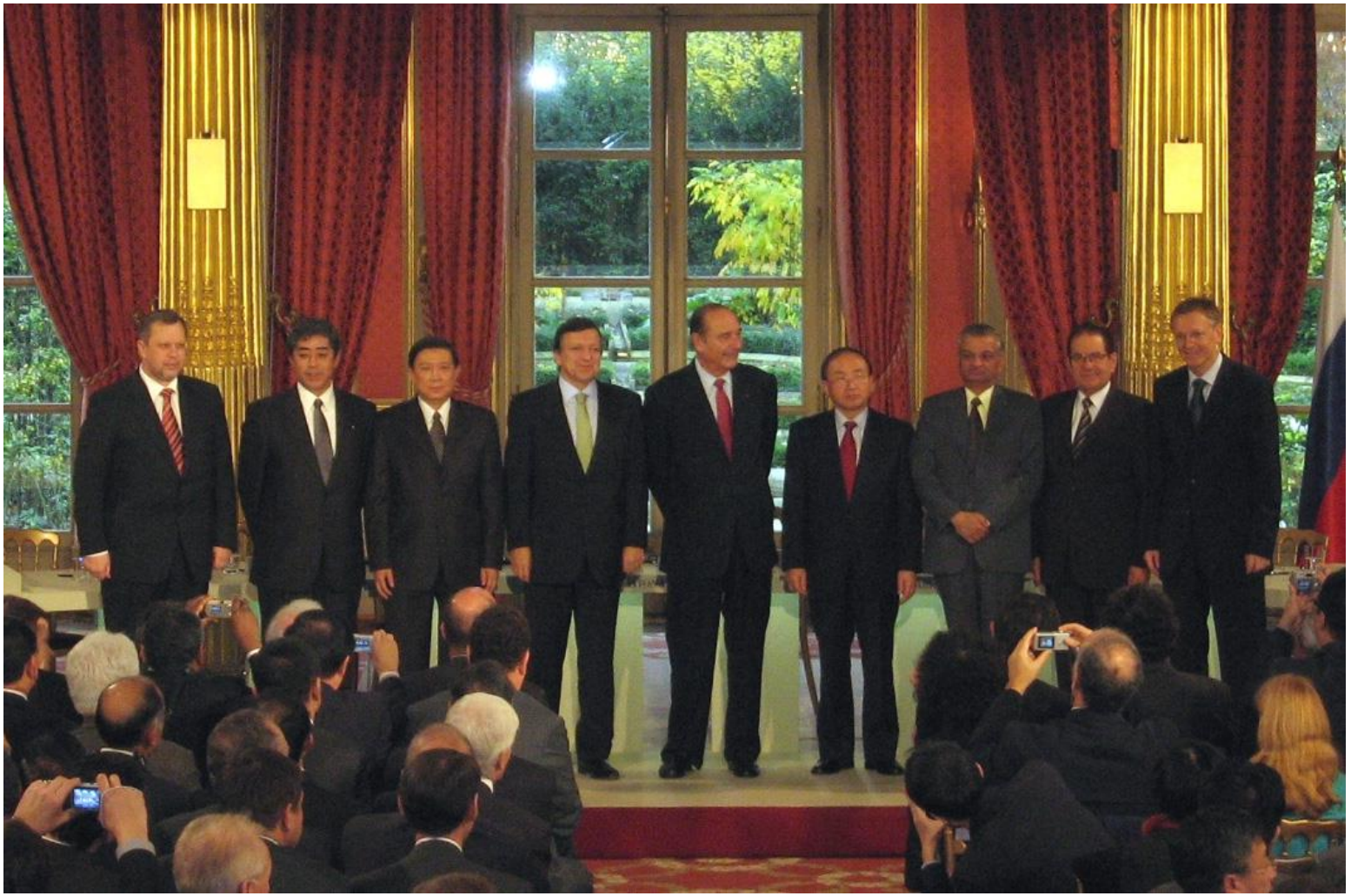
## Exchange Initiatives

The two leaders agreed on the utility of broadening exchanges and contacts including some of their new forms in a number of scientific

## Fusion Research

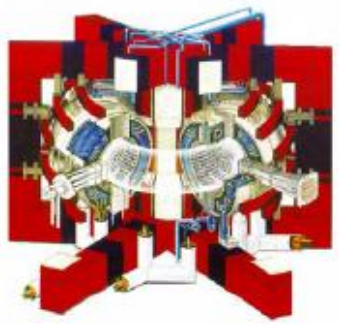
The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentialy inexhaustible, for the benefit for all mankind.

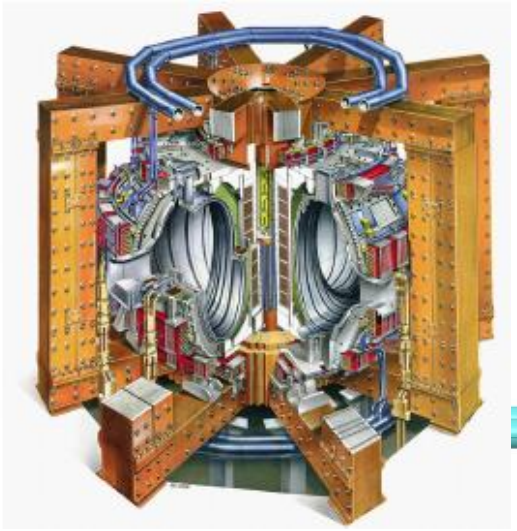
# Collaboration is our greatest asset

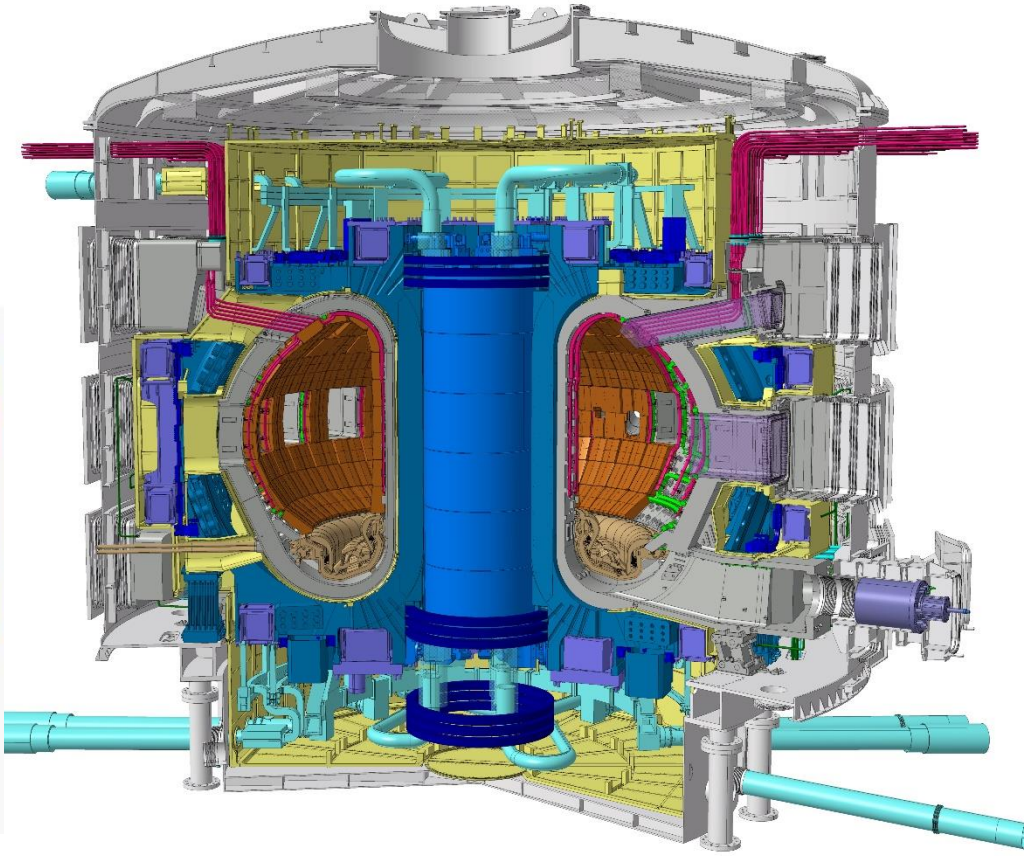


Ceremony ITER Agreement Signature, Elysee Palace, 21 November 2006

# The size of ITER is double the size of the largest actual experiment.







*Tore Supra*
$V_{plasma}$ 25 $m^3$
$P_{fusion}$ ~0
$T_{plasma}$ ~400 s

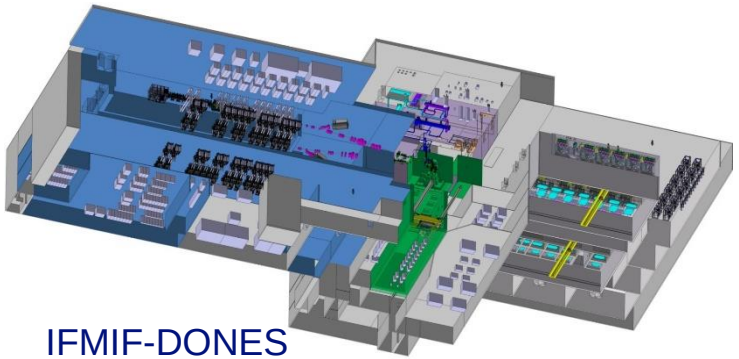
*JET*
$V_{plasma}$ 80 $m^3$
$P_{fusion}$ ~16 MW, 2 s
$T_{plasma}$ ~30 s

*ITER*
$V_{plasma}$ 830 $m^3$
$P_{fusion}$ ~500 MW, ~400 s
$T_{plasma}$ ~700 s

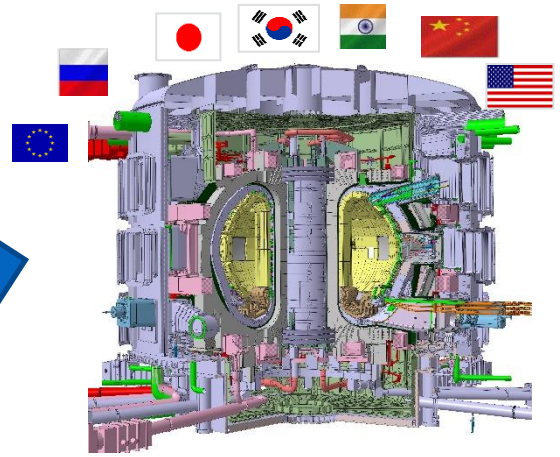
# Tokamak Complex

Resting on 493 seismic pads, the 440 000-ton Tokamak Complex comprises 7 levels (2 underground).

# ROADMAP TO NUCLEAR FUSION ENERGY

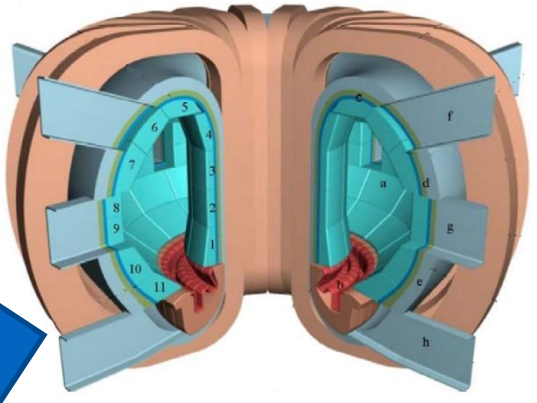


IFMIF-DONES
2 D+ beams, 40 MeV, 125 mA on a Li target



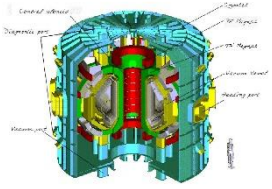
ITER – 500 $MW_{th}$

300– 500 segs

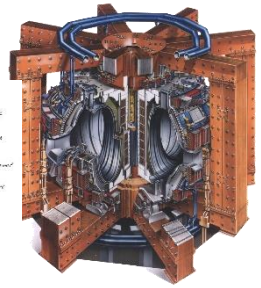


DEMO ≥ 500 $MW_{el}$

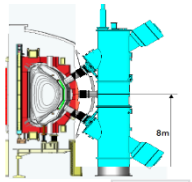
1 – 2 Horas



K-STAR



JET

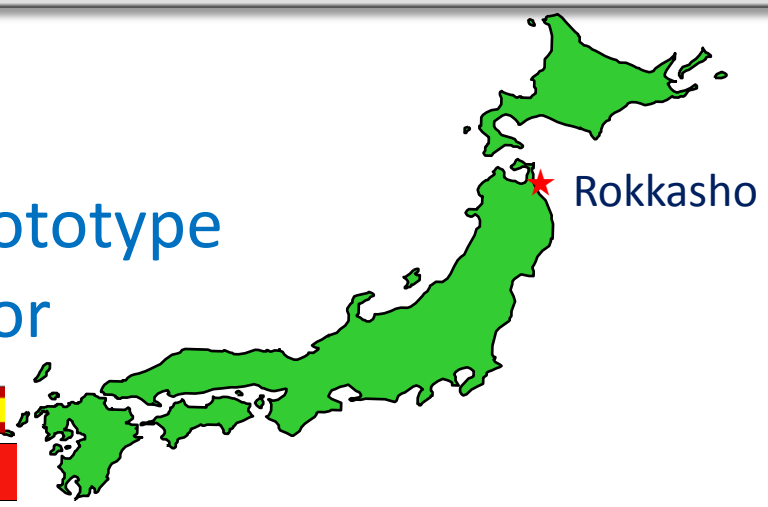


JT-SU

# Current accelerator design validation

## (ongoing part of IFMIF/EVEDA Project)

## LIPAc
## Linear IFMIF Prototype Accelerator

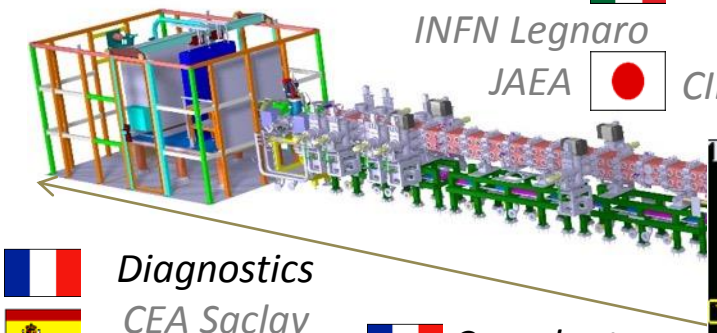



*Injector + LEBT*
*CEA Saclay*

*RFQ*
*INFN Legnaro*
*JAEA*

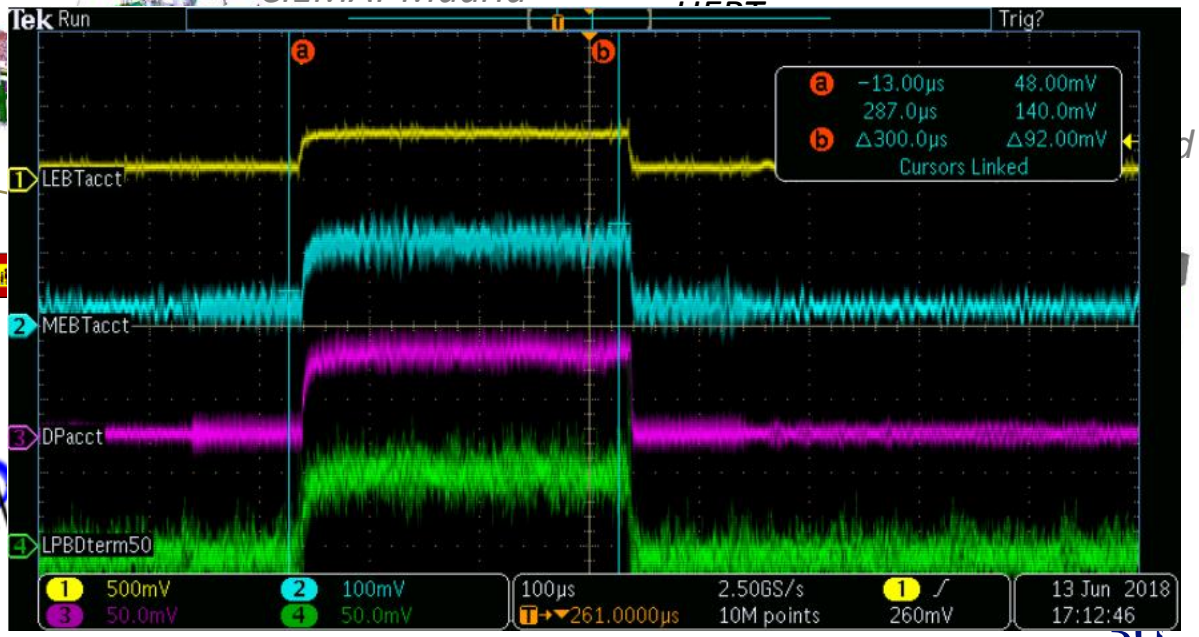
*MEBT*
*CIEMAT Madrid*

*SRF Linac*
*CEA Saclay*
*CIEMAT Madrid*



*Diagnostics*
*CEA Saclay*
*CIEMAT Madrid*

*Cryoplant*
*CEA Saclay*



# Spanish components of IFMIF- EVEDA in Rokkasho


Ceremony of arrival of RF power supplies


Beam diagnostics


Middle Energy Beam Transport


Radio Frequency power system

# Comisión para la Implementación de IFMIF-DONES en España

Presidente

Rafael Rodrigo, Secretario General de Coordinación de Política Científica

Vicepresidenta

Lina Gálvez Muñoz, Consejera de Conocimiento, Investigación y Universidades

Carlos Alejaldre
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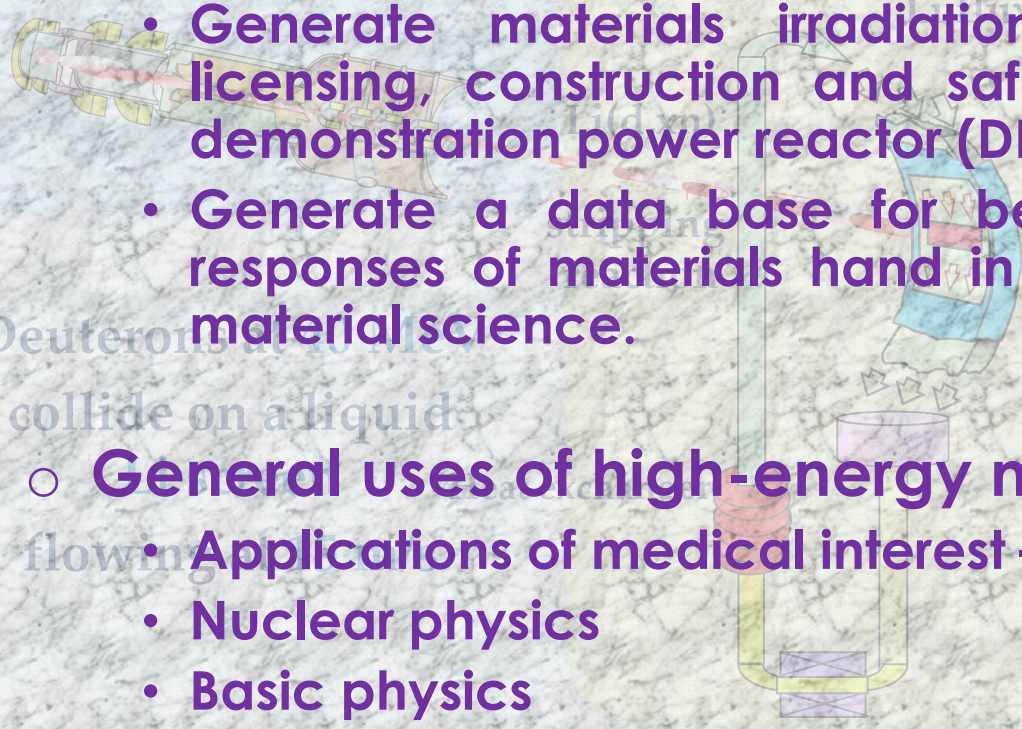
  - Diputacion de Granada
  - Ayuntamiento de Granada
- CIEMAT
  - Laboratorio Nacional de Fusión
- CDTI
- Universidad de Granada
- INEUSTAR Asociación Española de Industria de la Ciencia
- INDUCIENCIA Plataforma Tecnológica
- Ongranada Tech City

# IFMIF-DONES Main Systems

## Mission

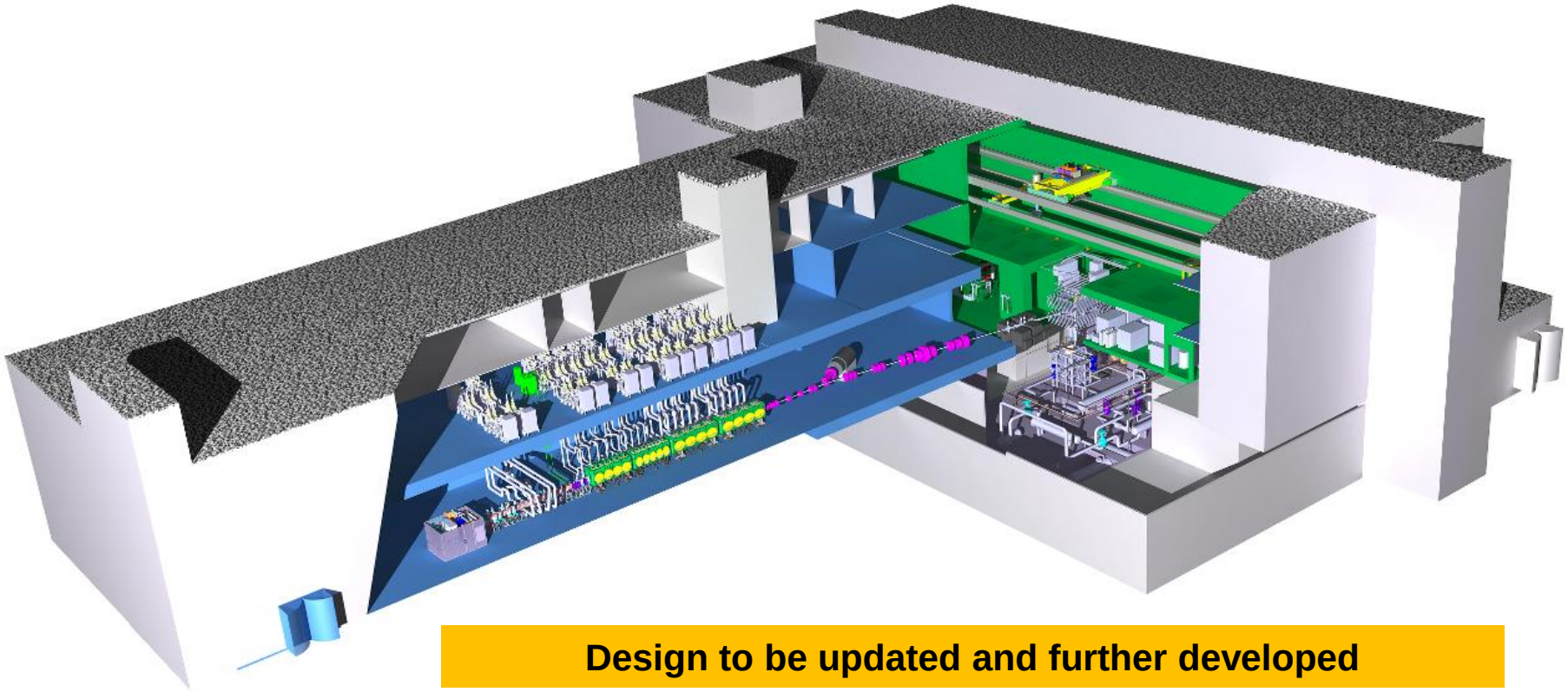
- **Fusion - oriented**
  - Generate materials irradiation test data for design, licensing, construction and safe operation of the fusion demonstration power reactor (DEMO)
  - Generate a data base for benchmarking of radiation responses of materials hand in hand with computational material science.
- **General uses of high-energy neutrons**
  - Applications of medical interest – isotope production
  - Nuclear physics
  - Basic physics
  - Industrial application of neutrons




A neutron flux of ~ $10^{14}$ $cm^{-2}s^{-1}$ is generated with neutron spectrum up to 50 MeV energy

# Technical description

Based on the IFMIF IIEDR a **preliminary conceptual design is available**, including facility configuration, systems design, preliminary safety evaluation, 3D CAD,…



**Design to be updated and further developed**

# DONES SITE LOCATION

It is located in the Granada province (Andalusia region – southern Spain), 18 km southwest from Granada city in the Granada Metropolitan park (Escúzar ).


# Granada: University City



- >300 research groups,
- Top research : Computer Science, Health, Engineering, Physical, Mathematics, Sport Science, Chemistry, Materials, Geology..
- >12 research institutes
- **More than 50 spin-offs**, 27 of them TIC.

- **High degree of internacionality**: >4.000 ERASMUS students per year (Leader in Erasmus Program)

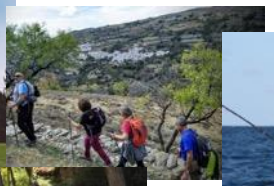
- **High Reputation with high quality research**:
  - **TOP 300 Shangai Ranking**
  - **2nd university in Spain**
  - 1st University **in TIC in Spain**
  - **TOP 50 in TIC Shangai Ranking**

# Granada: Living Conditions

-one of the most **historic** and **culturally rich** urban centers in the world

-**Its geography is extremely rich and varied**: the maritime coast and the valleys and mountains offer **many recreational Opportunities.**

NATIONAL PARK OF SIERRA NEVADA: Biosphere Reserve



UNIVERSIDAD DE GRANADA

# Site Evaluation

Two European Union member state countries, Croatia and Spain, filed in a technical proposal to host the facility.

- F4E report conclusions:

***"The Spanish proposal entirely fulfils all requirements and assumption.****The Granada site present unique characteristics and is fully operational: construction works could start immediately.* ***The national experience*** *in building and operating nuclear facilities, the presence of waste management and storage facilities, the national scientific and technological competences both on particle accelerators and nuclear installations,* ***is at the highest international standard****."*

- European Council conclusions on the reformed ITER project (adopted on 12/04/2018) :

"*The Council TAKES NOTE WITH SATISFACTION of the candidacy of Spain and Croatia for the site of the future IFMIF-DONES project and, at the same time EMPHASISES the need to maintain the successful cooperation with Japan within a Broader Approach and its follow-up."*

Safari Archivo Edición Visualización Historial Marcadores Ventana Ayuda 81 % Mié 19 sept 18:44:34 Carlos Alejaldre Losilla

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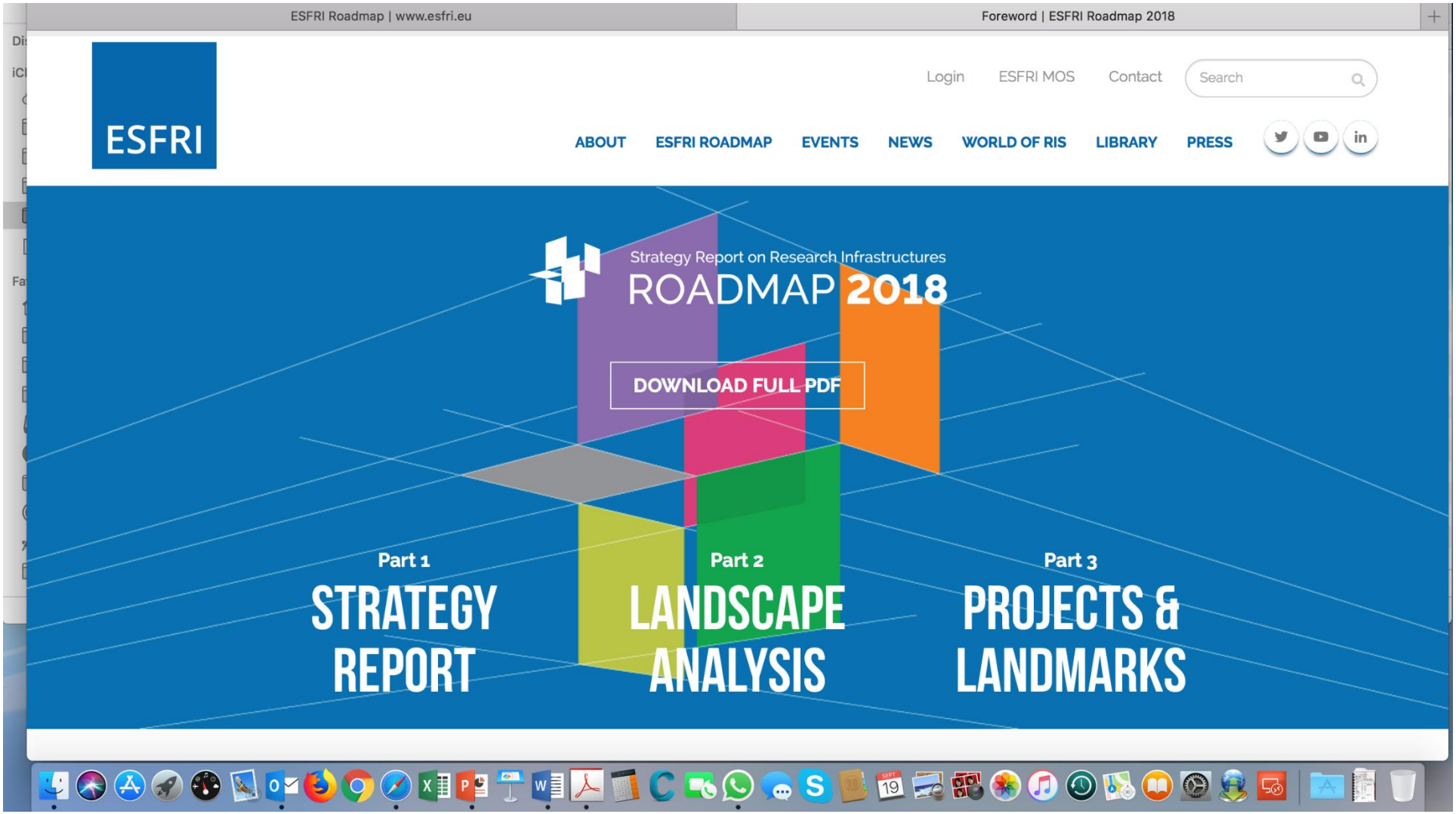
España y Croacia impulsan la candidatura de Granada para albergar el IFMIF-Dones

# ESFRI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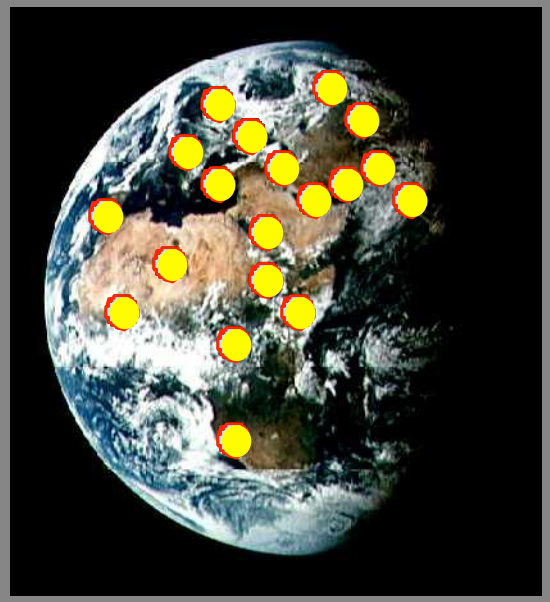
# Last comments



- There is not an easy nor probably unique solution, to the energy problema facing our Planet. To intensify R&D in Energy is a must!
- Scientific viability of fusion has already been proven (16 MW en JET).
- The project ITER, the scientific and tecnological proof of nuclear fusion is been constructed in Europa (Cadarache). Barcelona hosts the European Agency responsable for the in kind contribution.
- IFMIF-DONES is essential to build the future Fusion Power Plants. Granada is the site to do it.
- Spain is an important part of the European Fusion Strategy and our Fusion Programme a good example that a change in the prodcutive model is possible.

**Nuclear Fusion is a reality and it could be the inexhaustible , cheap and environmentally friendly energy source of the future.**

# Welcome to the new Fusion Era


Continuará… (Próximo capítulo en Granada)


Questions?
Comments?