Energía, Fusion y el Proyecto IFMIF-DONES

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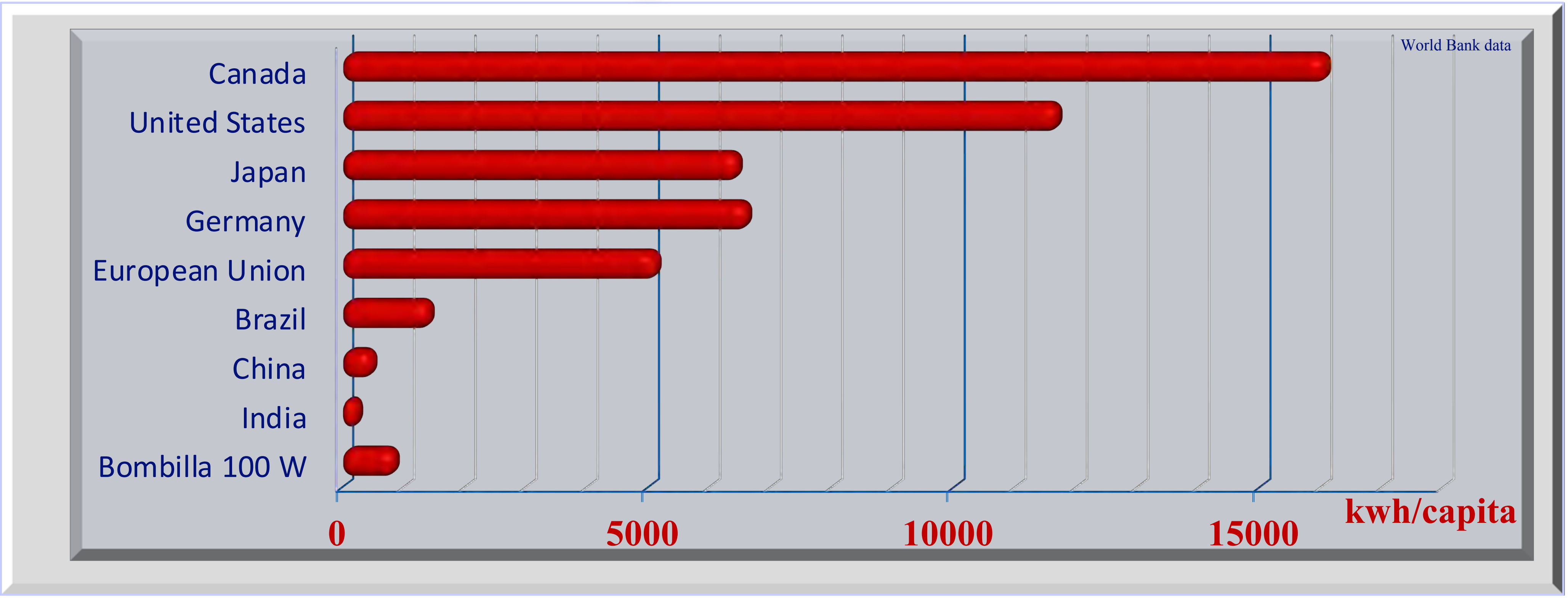
Director General
CIEMAT
Director Ejecutivo de la Comisión para la Implementación de IFMIF-DONES en España

Diálogos con la Sociedad
Universidad de Granada
30 Enero 2019

Resumen

- Energía y medioambiente
- Fusión Nuclear
  - Situación actual:
    - Proyecto ITER
    - IFMIF-DONES
- Ultimos comentarios

Consumo Energético



Promedio Mundial: 2000 kWh/persona/año

Consumo Total (90´s):5.000 millones x 2.000 = 10^4 TWh

Supongamos un futuro: La Población se dobla y menos de 1/3 del consumo Americano permite una calidad de vida satisfactoria

Consumo Total (XXI):10.000 millones x 3.000 = 3 x 10^4 TWh

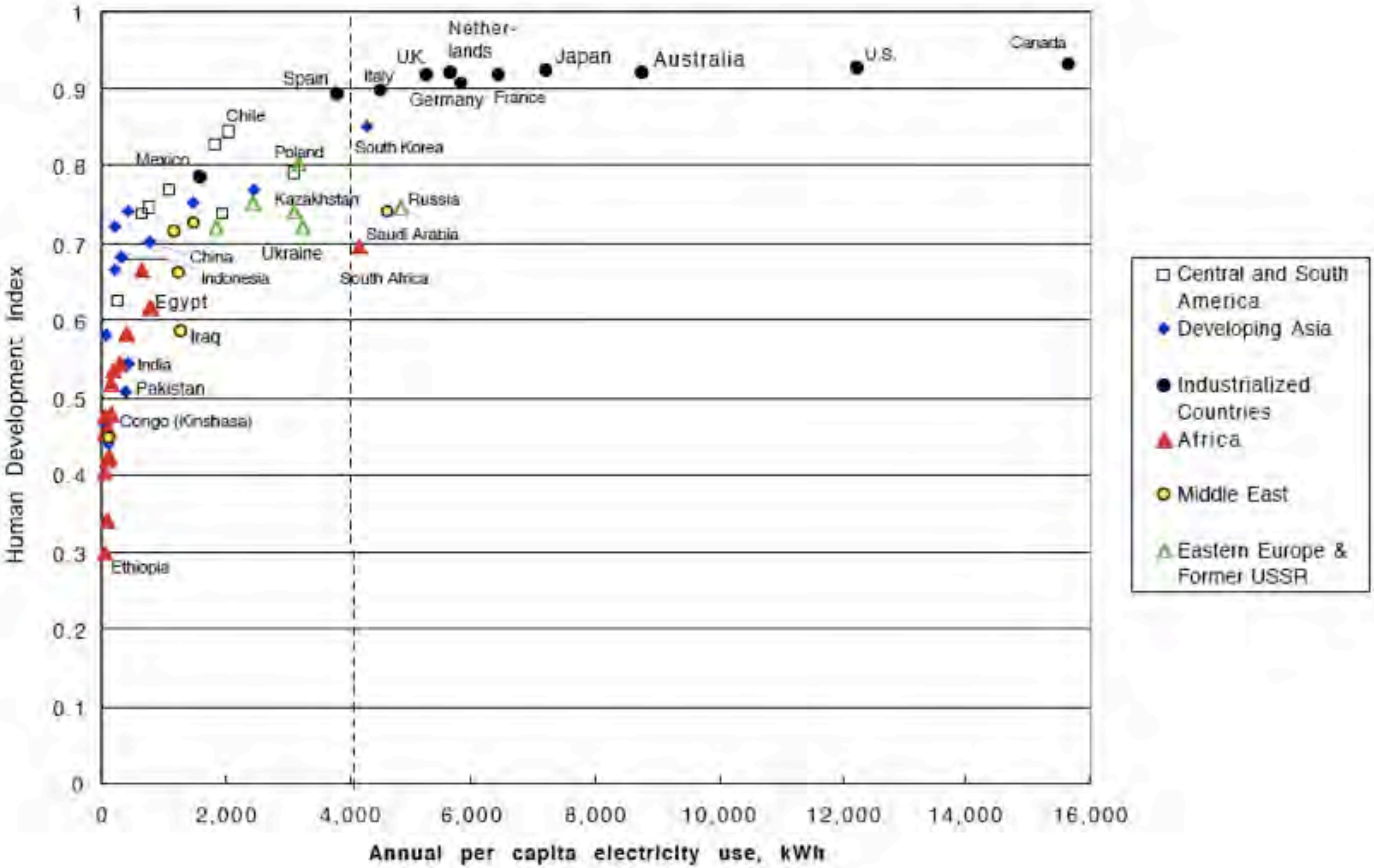
Consumo Energético

Consumo
Mundial
de Energía

90´s

x 3? =

Consumo
Energético
Mundial
Siglo XXI


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
Nether-lands
UK
Japan
Australia
U.S.
Canada
Spain
Italy
Germany
France
Chile
South Korea
Mexico
Poland
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

Consumo Energético

Consumo
Mundial
de Energía

90´s

x 3? =

Consumo
Energético
Mundial
Siglo XXI

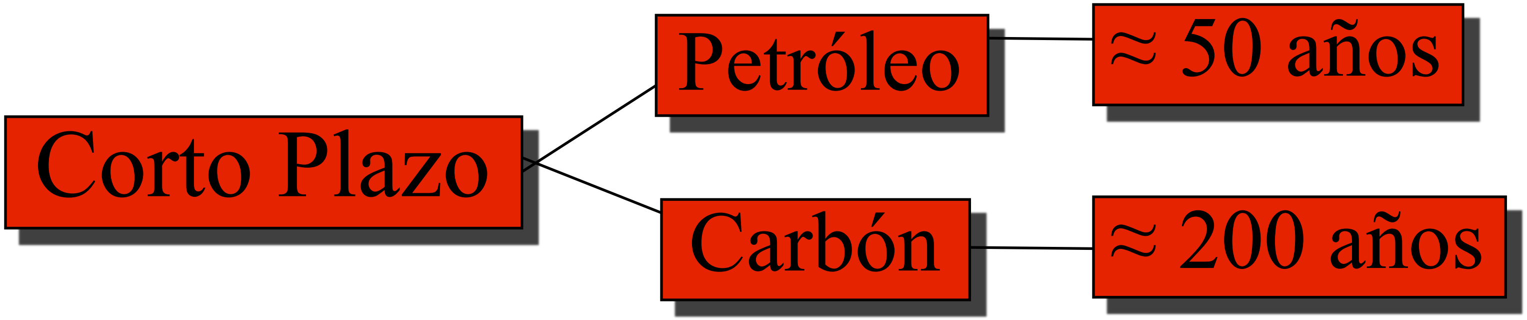
Petroleo	43 (32)%
Carbón	22 (30)%
Gas	20 (24)%
Nuclear	8 (4)%
Hydro	5 (7)%
Otro	2 (3)%

BP 2017 ENERGY OUTLOOK

Nuevo Cóctel Energético

- Disponibilidad de recursos
- Consecuencias medioambientales
- Seguridad de suministro

Opciones Energéticas



Corto Plazo

Petróleo

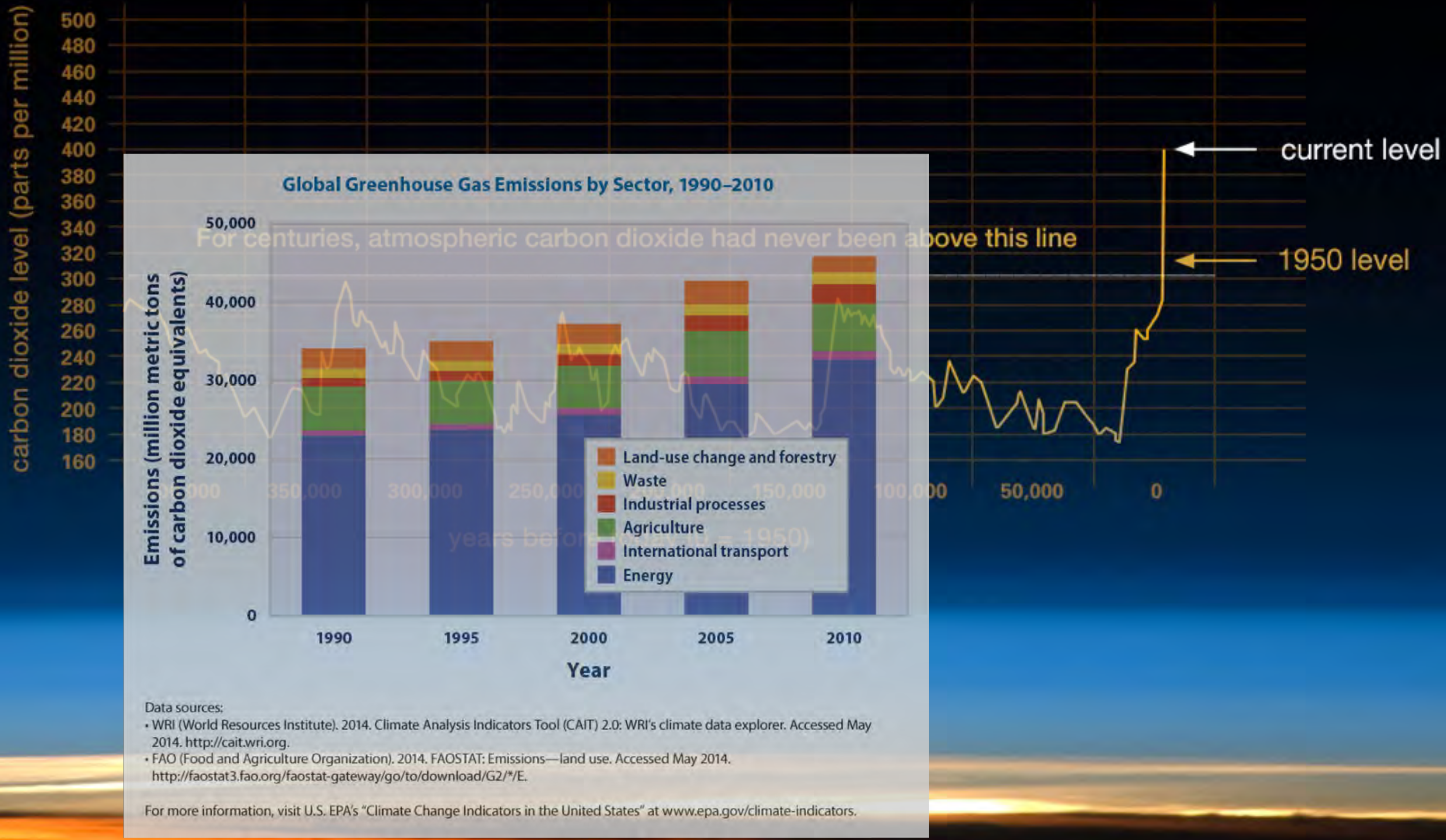
≈ 50 años

Carbón

≈ 200 años

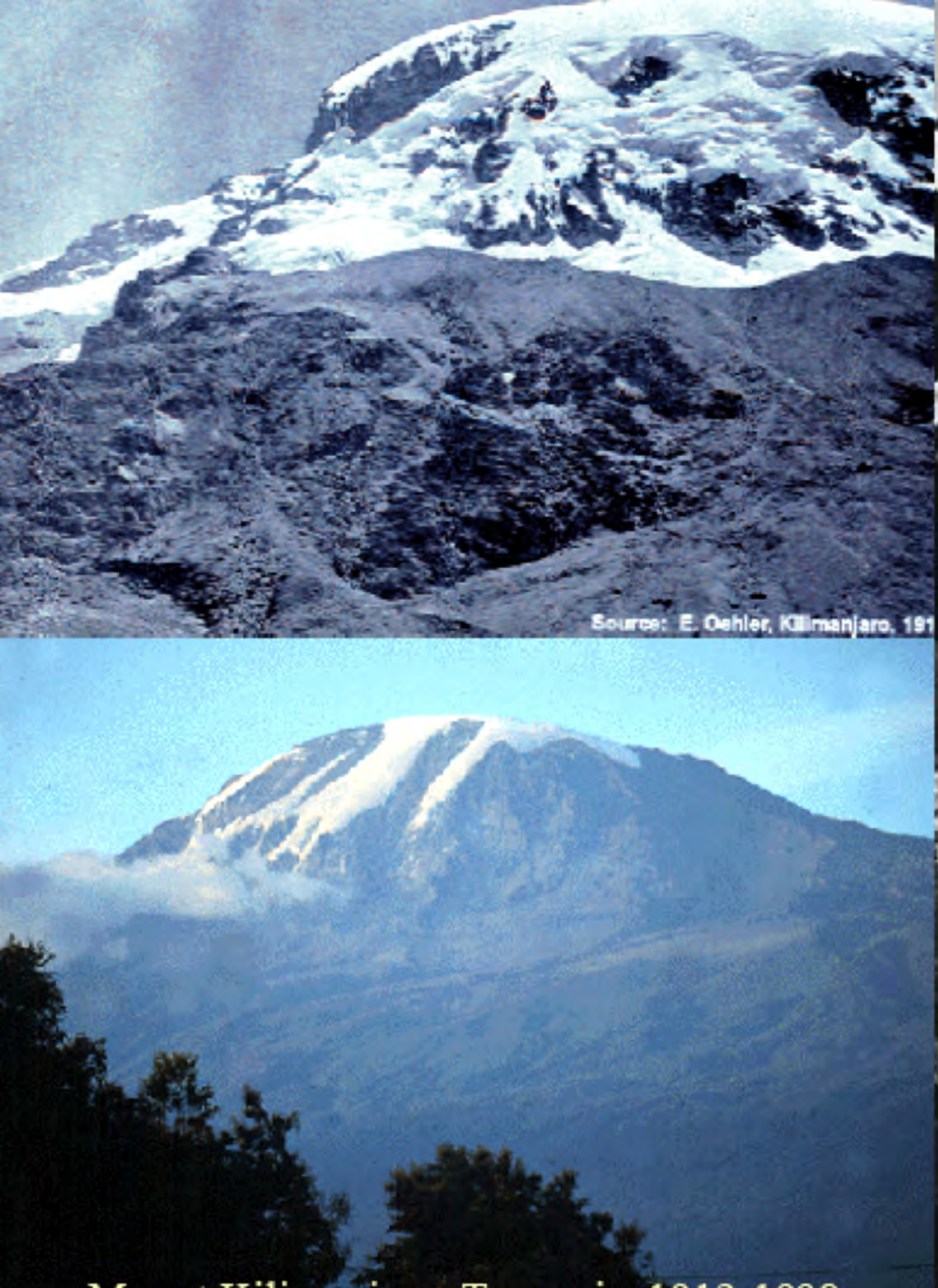
La producción de carbón se espera que llegue a 7.000 Mtons en 2030 – China será responsable de la mitad de ese aumento.

Niveles de CO_2 en los últimos 400.000 años

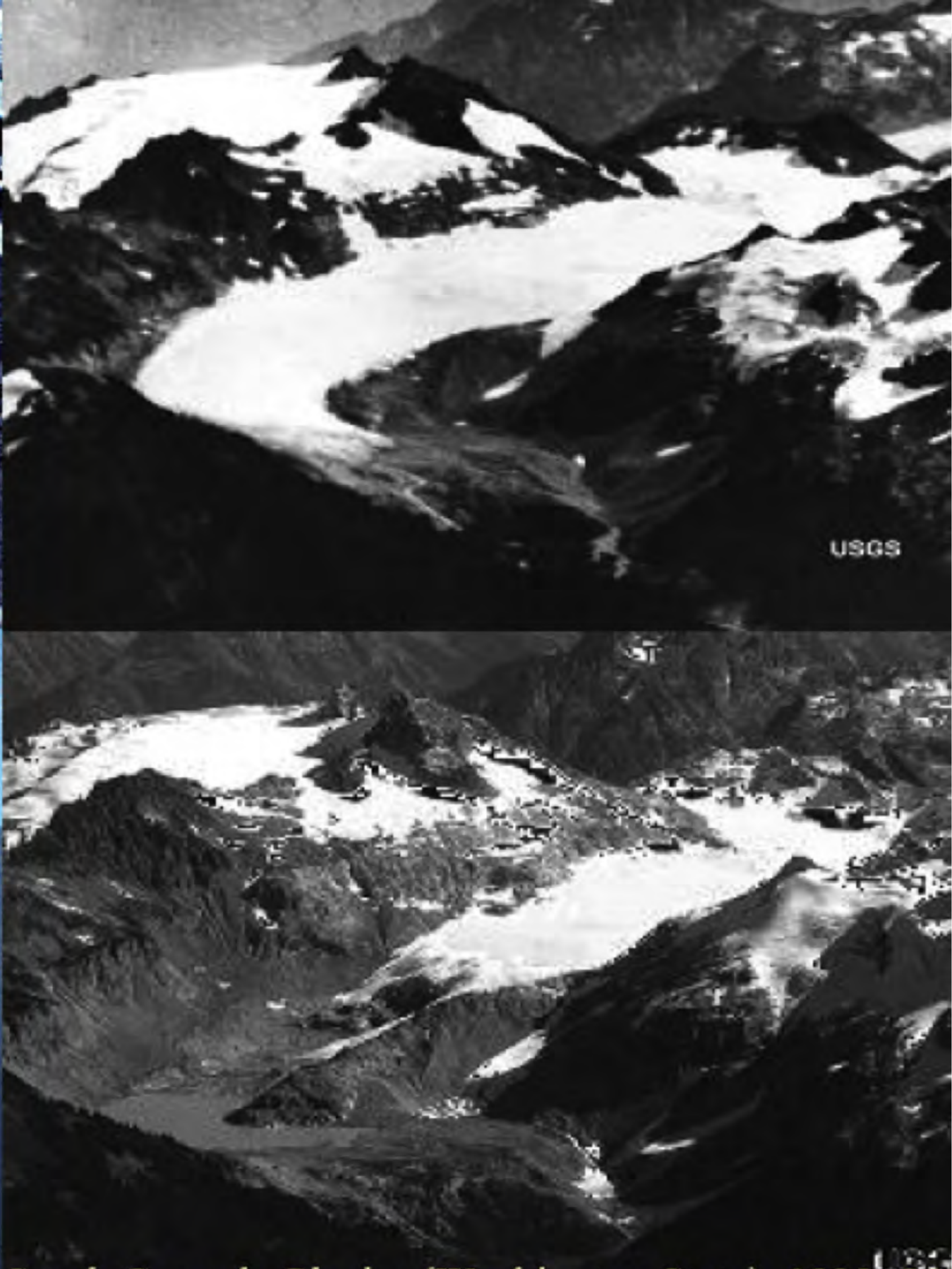


Data sources:
- WRI (World Resources Institute). 2014. Climate Analysis Indicators Tool (CAIT) 2.0: WRI's climate data explorer. Accessed May 2014. http://cait.wri.org.
- FAO (Food and Agriculture Organization). 2014. FAOSTAT: Emissions—land use. Accessed May 2014. http://faostat3.fao.org/faostat-gateway/go/to/download/G2/*/E.

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

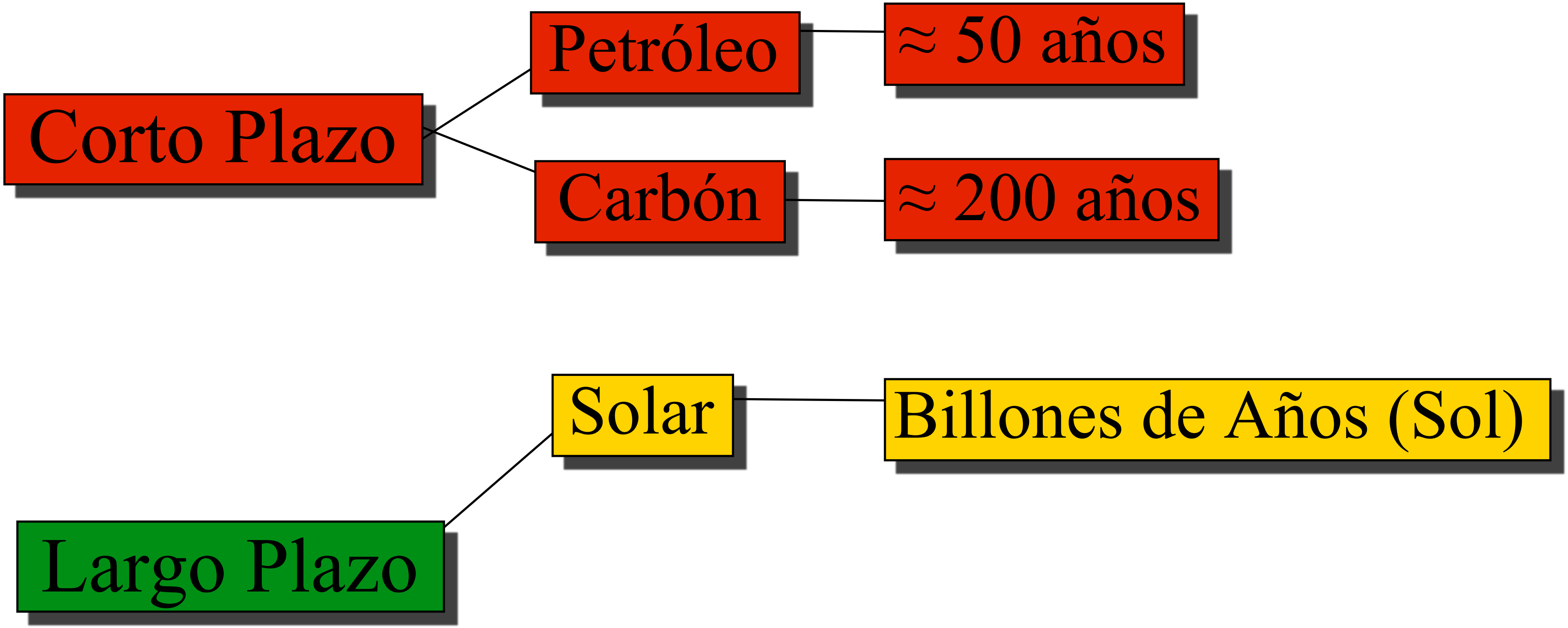

Source: E. Oehler, Kilimanjaro, 191

Mount Kilimanjaro, Tanzania, 1912-1998

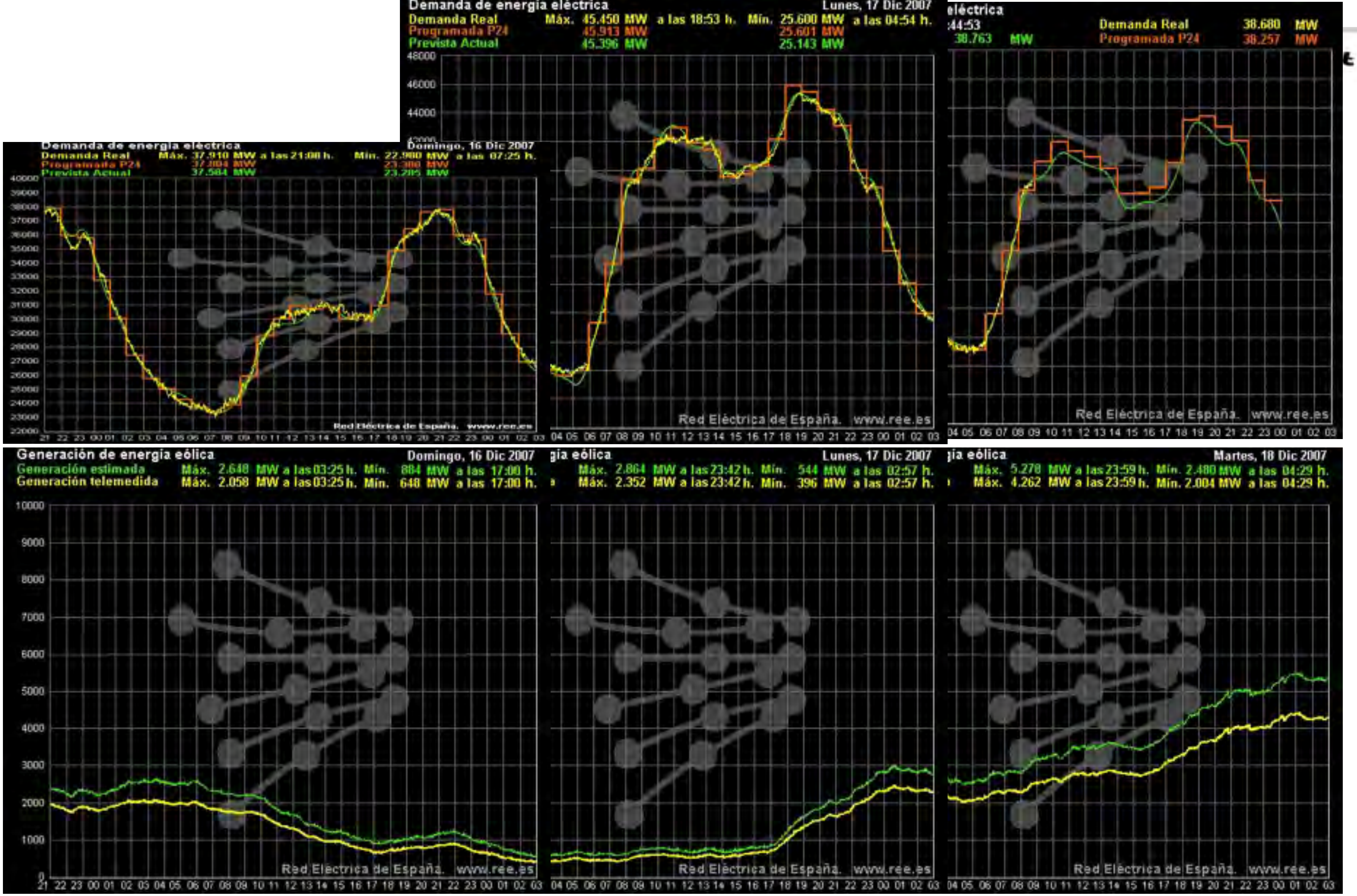


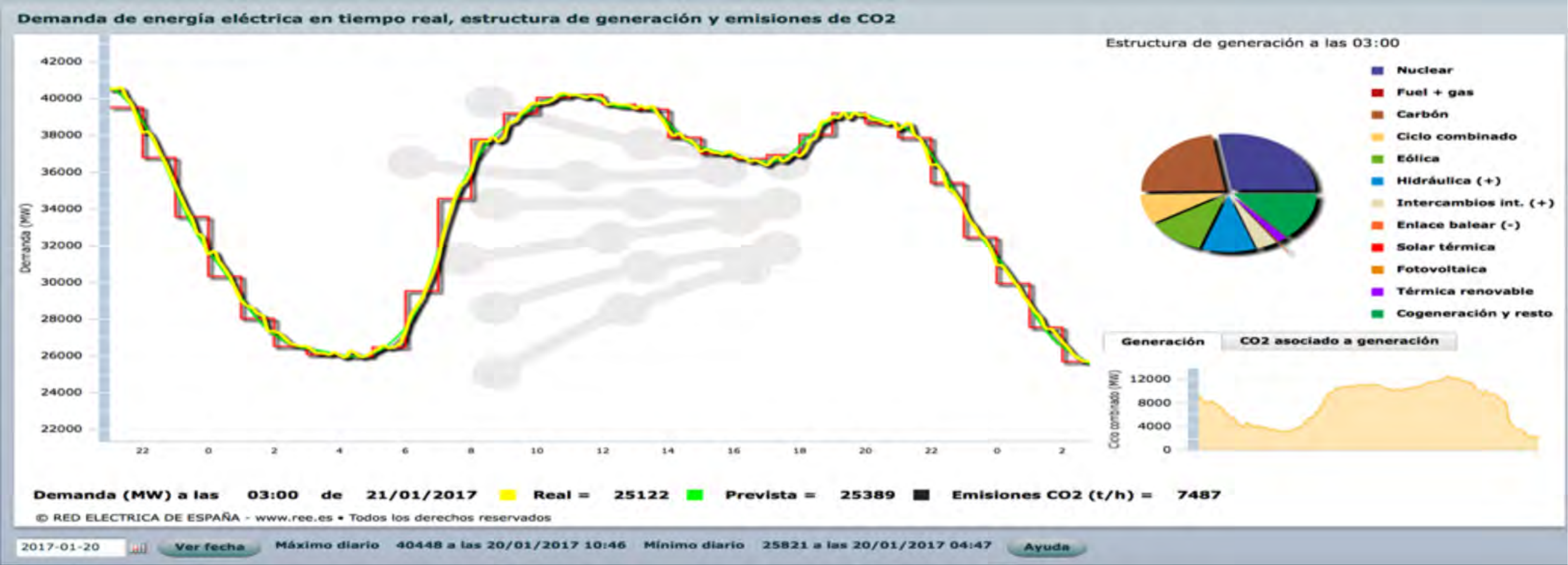
South Cascade Glacier (Washington State), 1928 -20

Opciones Energéticas



- Corto Plazo
  - Petróleo — ≈ 50 años
  - Carbón — ≈ 200 años
- Largo Plazo
  - Solar — Billones de Años (Sol)


Demanda de energía eléctrica
Domingo, 16 Dic 2007
Demanda Real Máx. 37.910 MW a las 21:00 h. Mín. 22.980 MW a las 07:25 h.
Programada P24 37.804 MW 23.300 MW
Prevista Actual 37.584 MW 23.285 MW
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
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.
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.
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
21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03


42000
40000
38000
36000
34000
32000
30000
28000
26000
24000
22000
Demanda (MW)
22
0
2
4
6
8
10
12
14
16
18
20
22
0
2
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
Ciclo combinado (MW)
12000
8000
4000
0
22
0
2
4
6
8
10
12
14
16
18
20
22
0
2
Ver fecha
Ayuda

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

Estructura de generación a las 03:00

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

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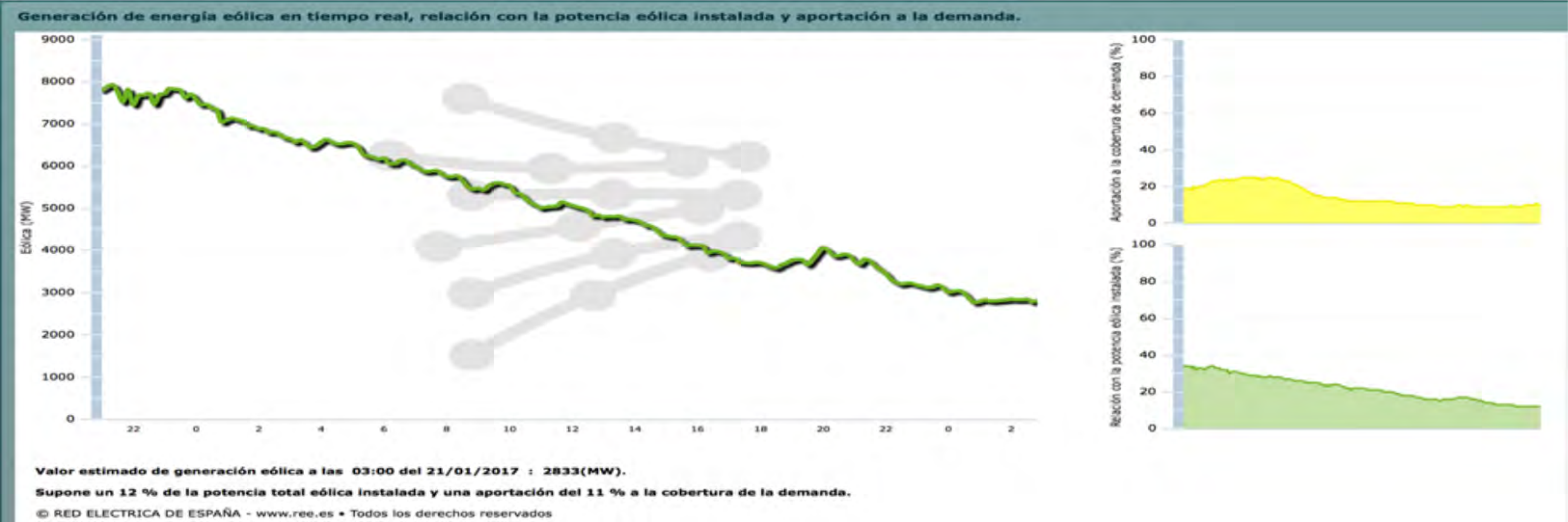
2017-01-20 **Máximo diario 40448 a las 20/01/2017 10:46 Mínimo diario 25821 a las 20/01/2017 04:47**


9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Eólica (MW)
22
0
2
4
6
8
10
12
14
16
18
20
22
0
2
Aportación a la cobertura de demanda (%)
100
80
60
40
20
0
Relación con la potencia eólica instalada (%)
100
80
60
40
20
0

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.

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Opciones Energéticas

- Corto Plazo
  - Petróleo — ≈ 50 años
  - Carbón — ≈ 200 años
- Largo Plazo
  - Solar — Billones de Años (Sol)
  - Fisión — Miles de Años
  - Fusión — Billones de Años

Combustible Fusion

La materia prima de una planta de fusion es agua y litio*

40 Toneladas de carbón

≈

45 litros de agua

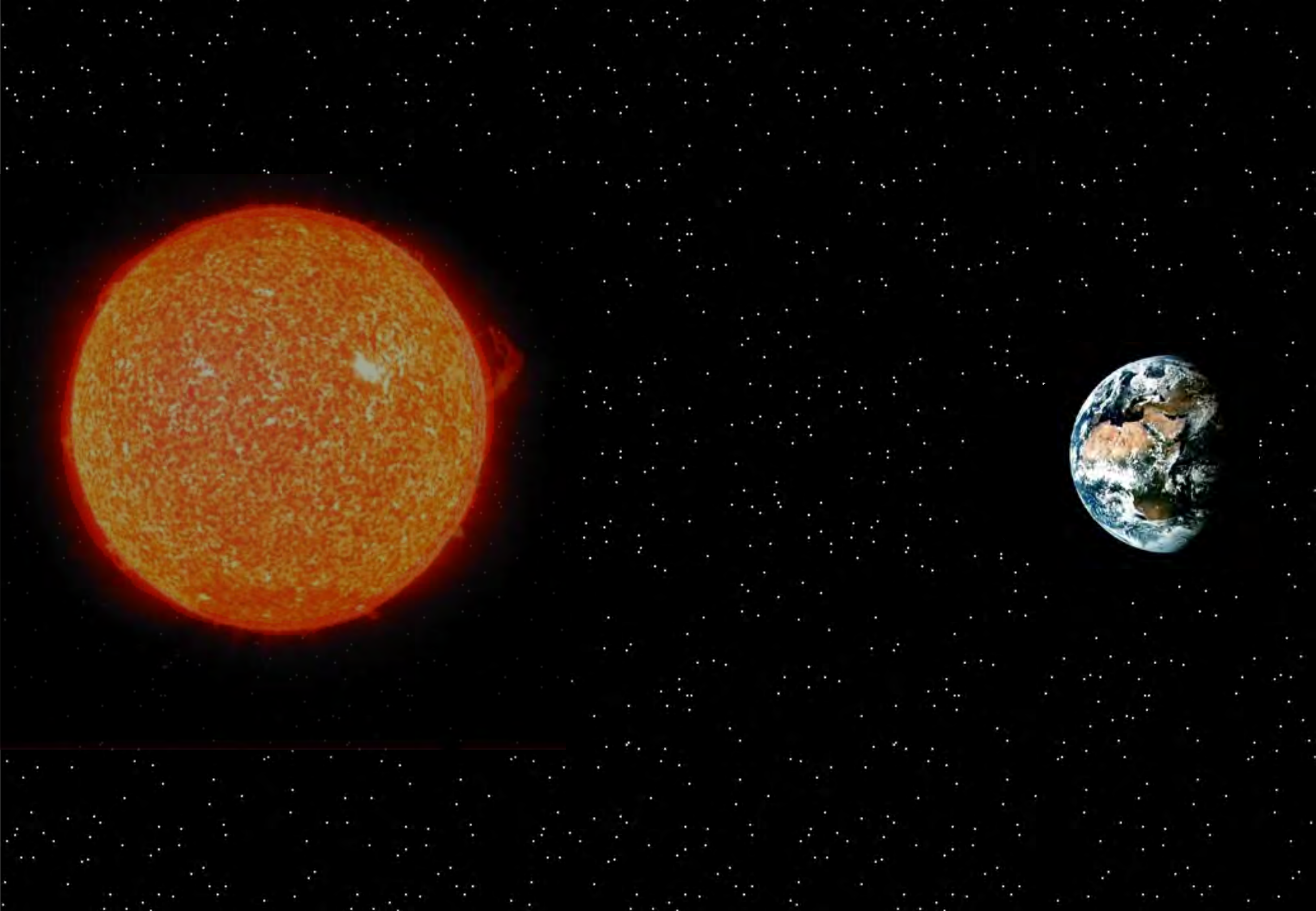
+

Batería ordenador

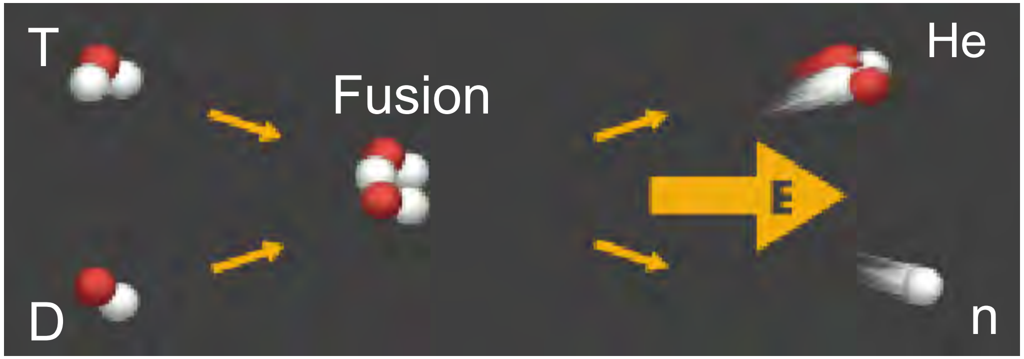
Litio en una bateria de un ordenador portàtil + media bañera de agua **(-> un dedal de agua pesada) puede producir** 200,000 kW-hora ≈ consumo promedio de un español durante 45 años

* *Deuterio/hydrogeno = 1/6700*

+ tritio de: neutron (de fusion) + litio → tritio + helio



La Fusión en nuestro Planeta *"... no es la misma que en el Sol"*



+ 20% de Energía (3.5 MeV)

+ 80% de Energía (14.1 MeV)

- **La reacción de fusión más sencilla de conseguir en condiciones terrestres:**

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

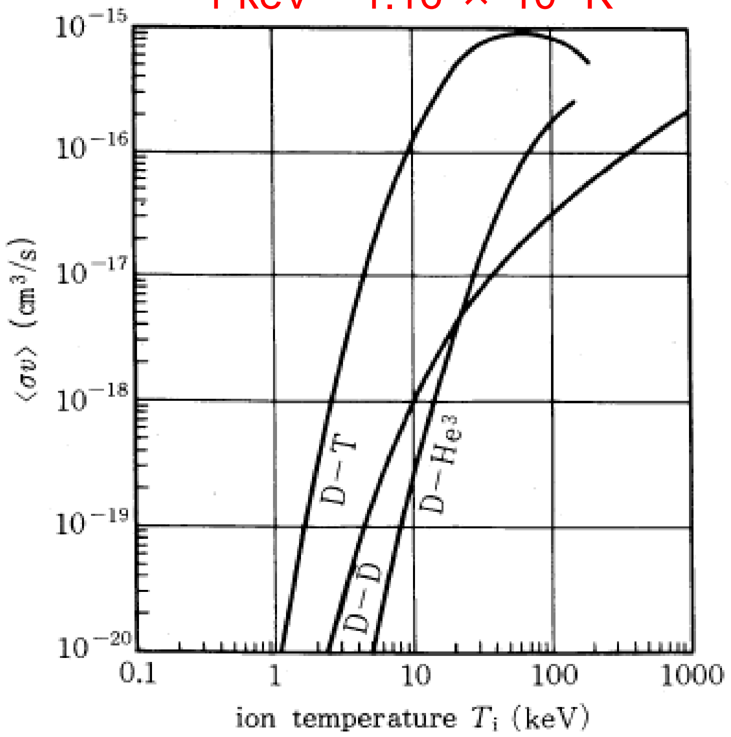
- **Otras dos reacciones importantes para la fusión DT son:**

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

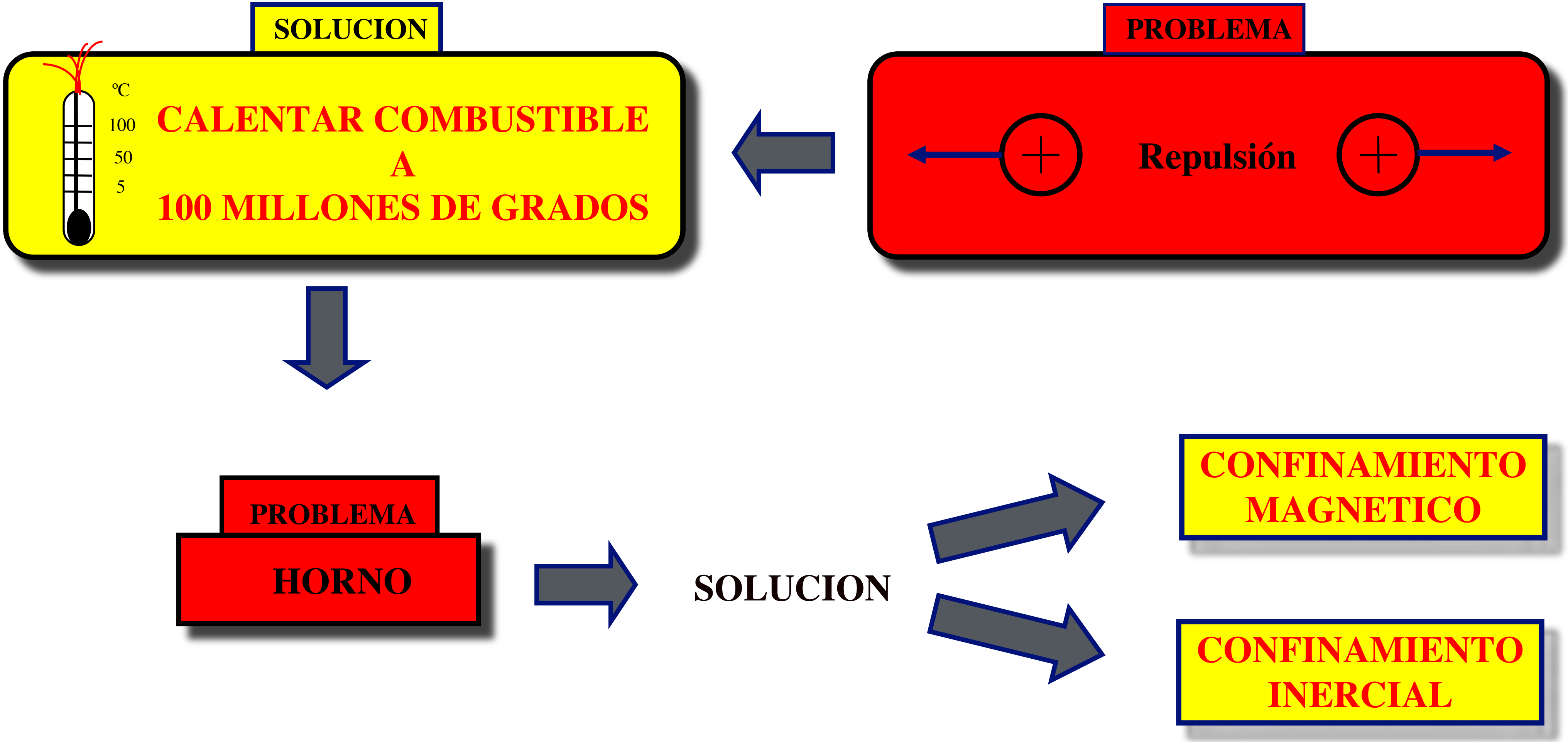
$${}^{1}n + {}^{7}Li \Rightarrow {}^{3}He + {}^{3}T + {}^{1}n - 2.5\ MeV$$

  - Estas reacciones permitirán a un reactor de fusión generar tritio

1 keV = 1.16×10^{7} K



Problema-Solución



PROBLEMA

Repulsión

SOLUCION

CALENTAR COMBUSTIBLE
A
100 MILLONES DE GRADOS

PROBLEMA

HORNO

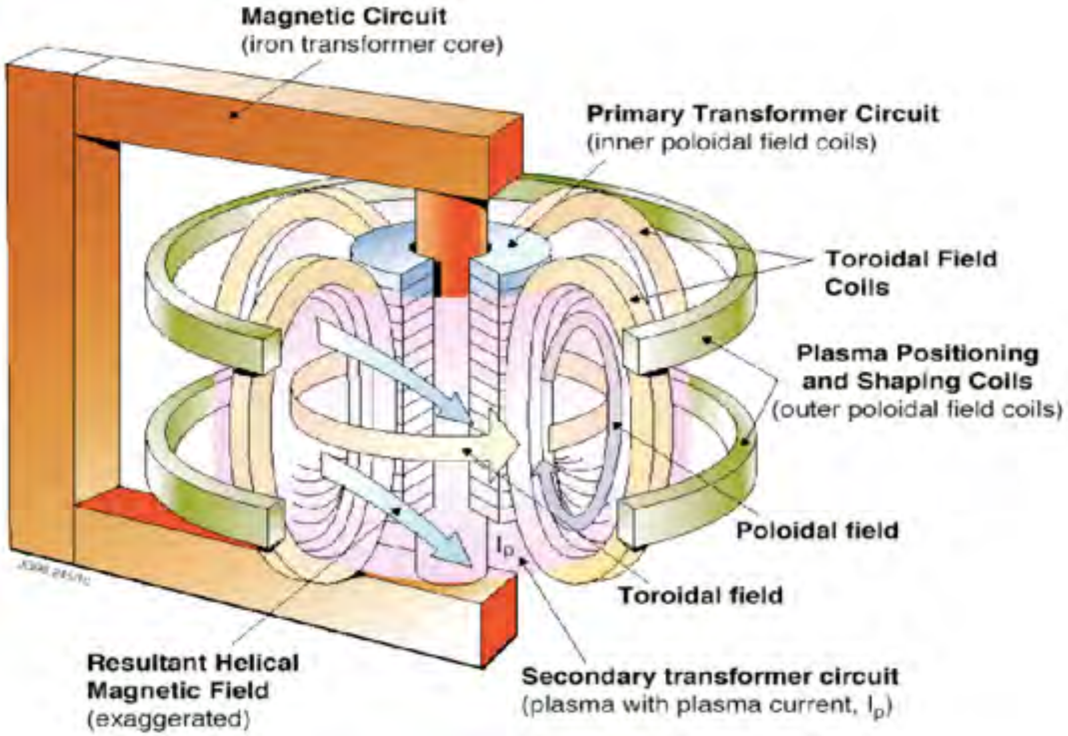
SOLUCION

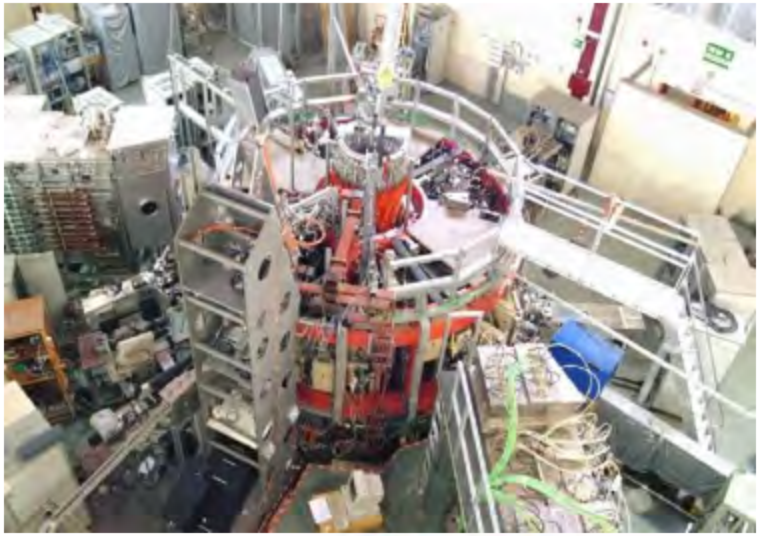
CONFINAMIENTO MAGNETICO

CONFINAMIENTO INERCIAL

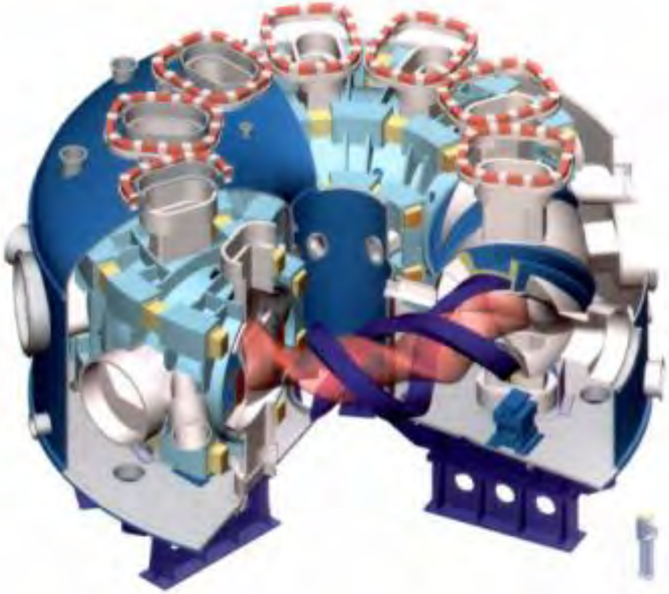
Las Botellas: Tokamak y Stellarator

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

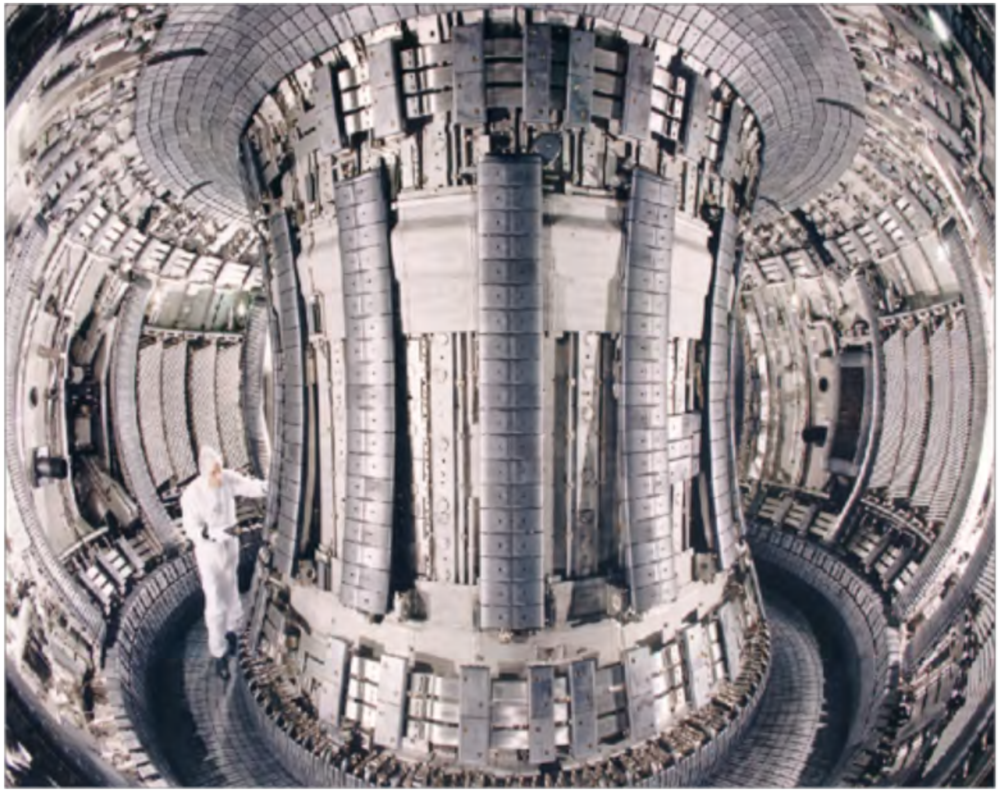

Magnetic Circuit
(iron transformer core)
Primary Transformer Circuit
(inner poloidal field coils)
Toroidal Field
Coils
Plasma Positioning
and Shaping Coils
(outer poloidal field coils)
Poloidal field
Toroidal field
I_p
Resultant Helical
Magnetic Field
(exaggerated)
Secondary transformer circuit
(plasma with plasma current, I_p)



TJ-II
CIEMAT

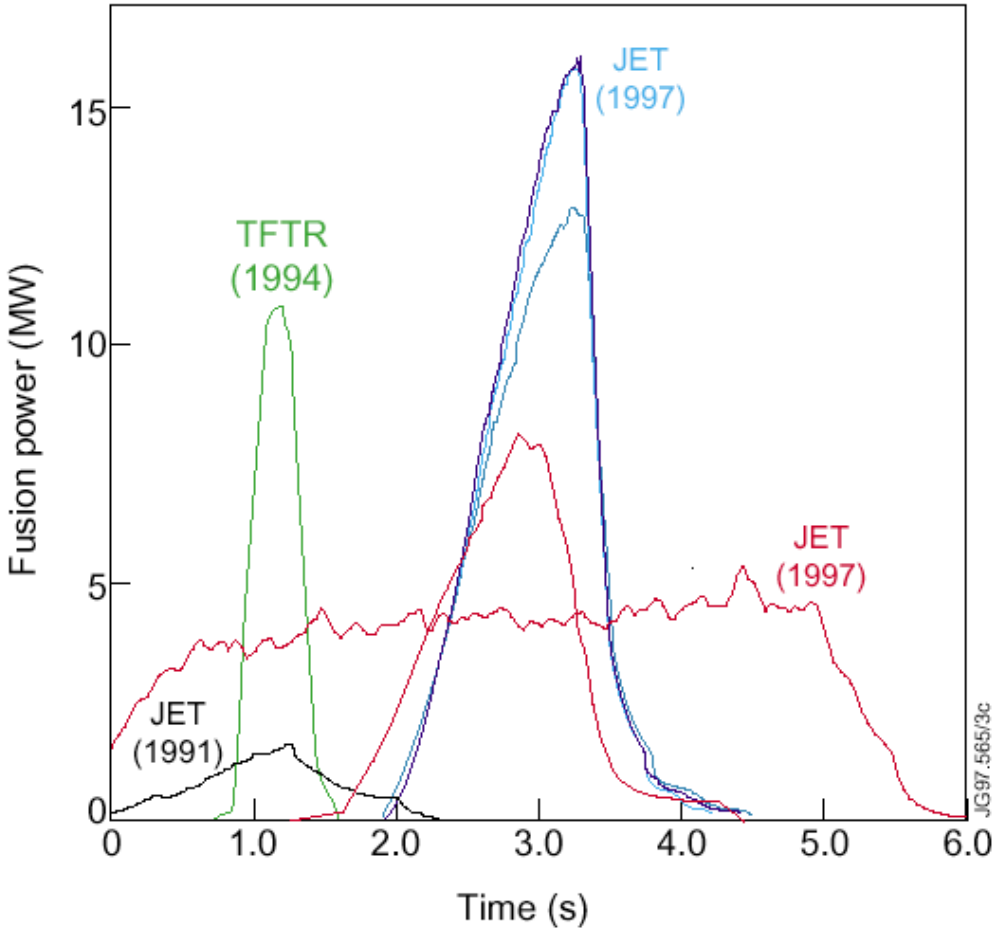


LHD
Japón



La "botella" de Fusión Nuclear mayor del mundo: JET

Records Obtenidos



64159 46.449 9:09

Plasma fusion performance

Temperatura - T_i: $1\text{-}2 \times 10^8$ K (10-20 keV)

(~10 × temperatura del centro del Sol)

Densidad - n_i: $1 \times 10^{20}\ m^{-3}$

(~10^{-6} densidad atmosférica)

Tiempo confinamento energía- τ_E: unos segundos ($\propto$ corriente × radio^2)

(duración pulso plasma ~1000s)

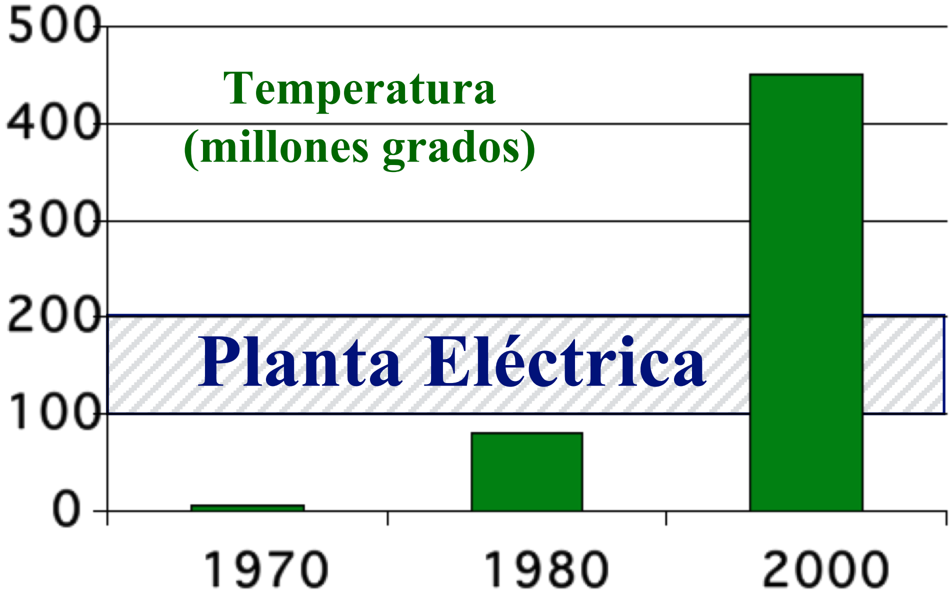
Fusion power amplificación: $$Q = \frac{\text{Fusion Power}}{\text{Input Power}} \sim n_i T_i \tau_E$$

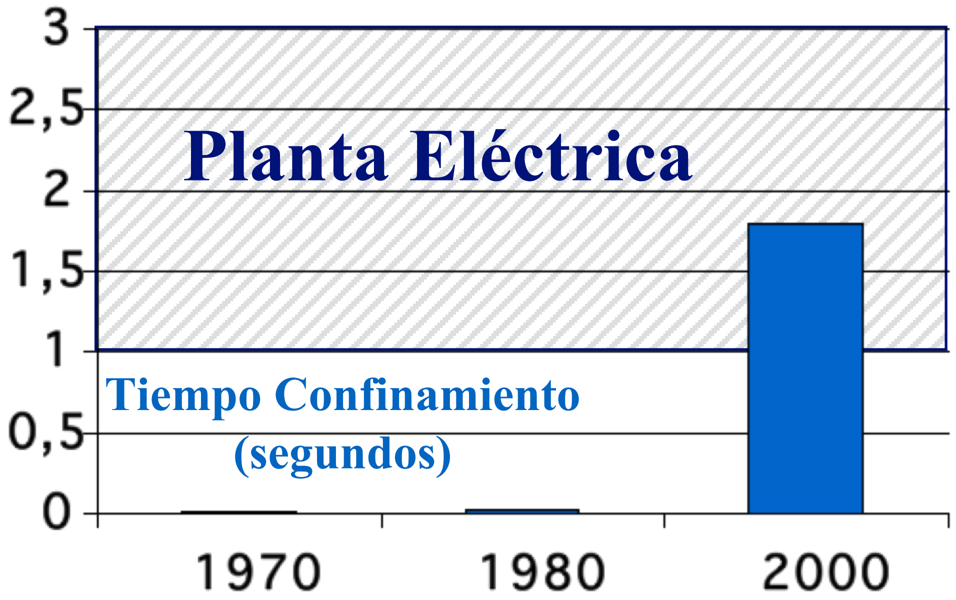
⇒ Dispositivos actuales : Q ≤ 1

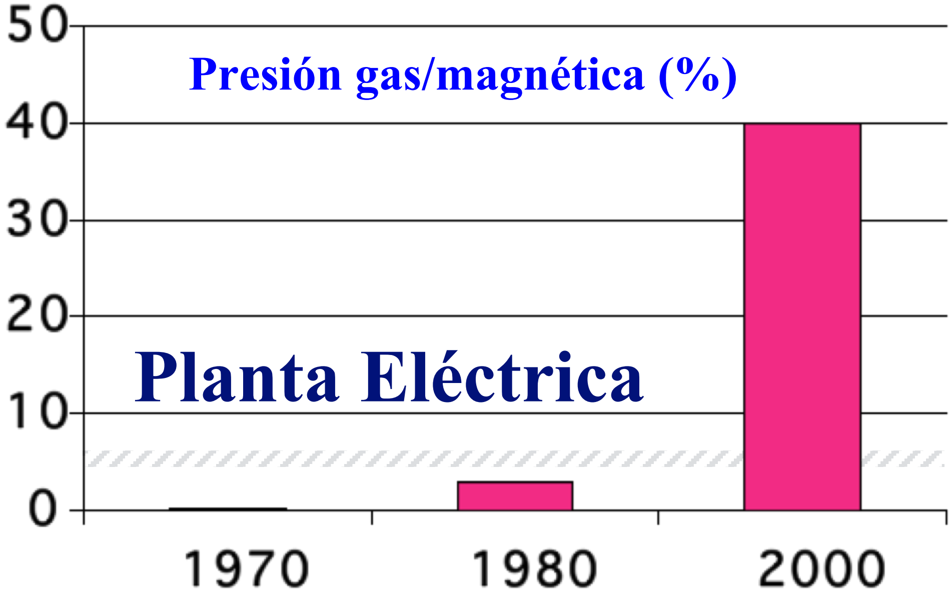
⇒ ITER: Q ≥ 10

⇒ ’ Ignición controlada’: Q ≥ 30

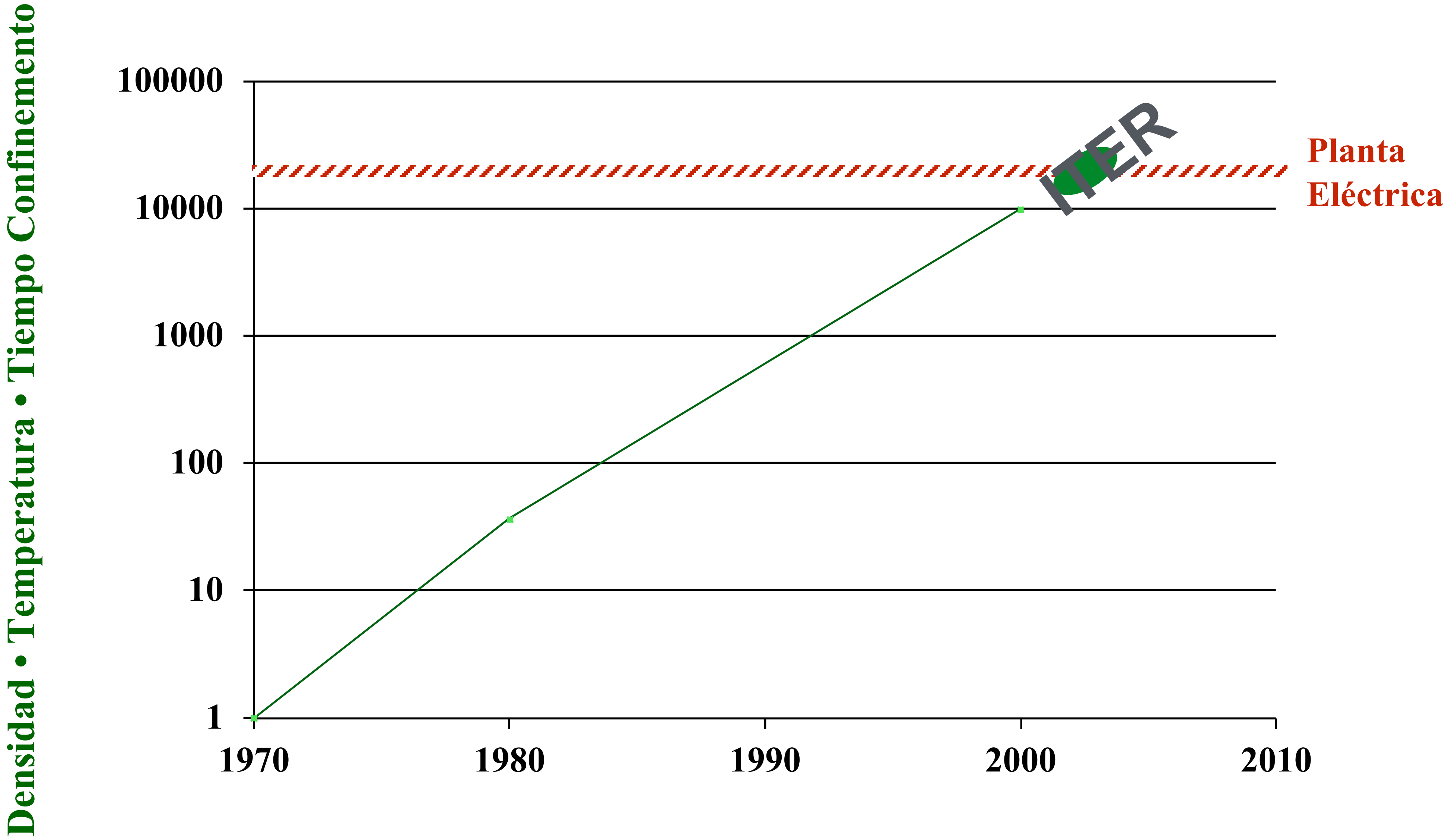
Resultados en la Tierra







Globalmente



"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.

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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
g today, as made public by the
House:*

nutual agreement, the Presi-
f 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-
Regan; Assistant to the Presi-
obert C. McFarlane; Ambas-
the U.S.S.R., Arthur A. Hart-
pecial adviser to the President
Secretary of State for Arms
, Paul H. Nitze; Assistant Sec-
of State of European Affairs,
e L. Ridgway; Special Assist-
he President for National Se-
Affairs, Jack F. Matlock.
ding on the Soviet side were
r of the Politburo of the Cen-
ommittee of the C.P.S.U.,
r of Foreign Affairs Eduard
ardnadze; First Deputy For-
nister Georgi M. Korniyenko;
ndor 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-
n their systems and ap-
s 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 th
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 weap
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 re
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.

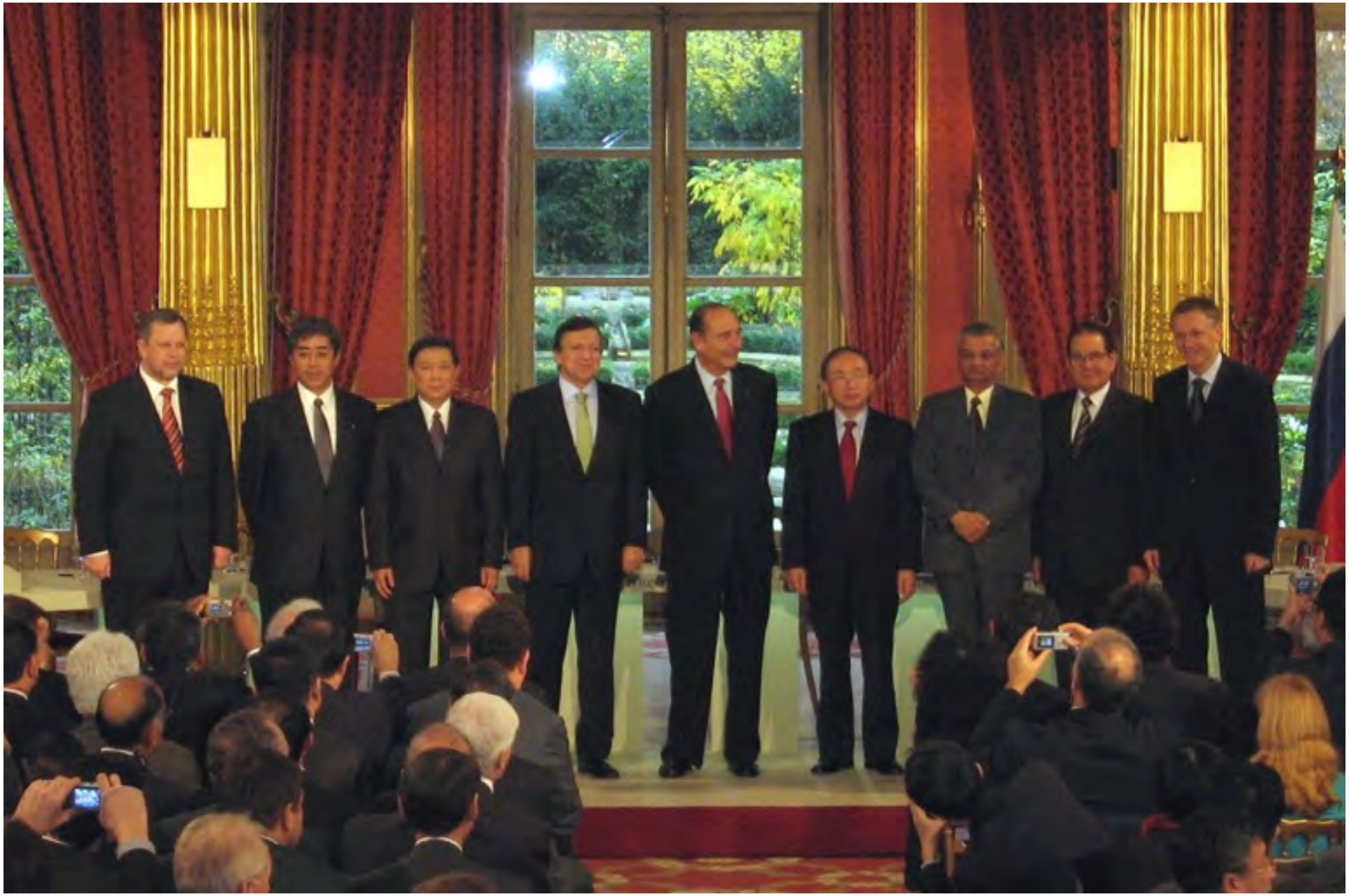
Exchange Initiatives

The two leaders agreed on the utility of broadening exchanges and contacts including some of their new

Fusion Research

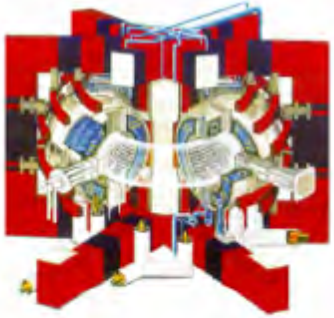
The two leaders emphasized the potential importance of the work aimed at utilizing controlled thermonuclear fusion for peaceful purposes and, in this connection, advocated the widest practicable development of international cooperation in obtaining this source of energy, which is essentialy inexhaustible,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

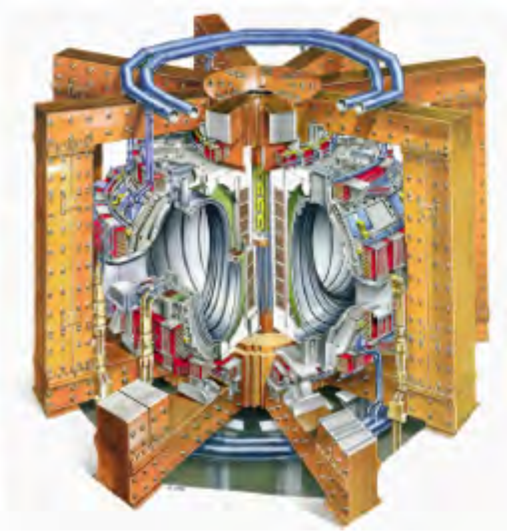
Collaboration is our greatest asset

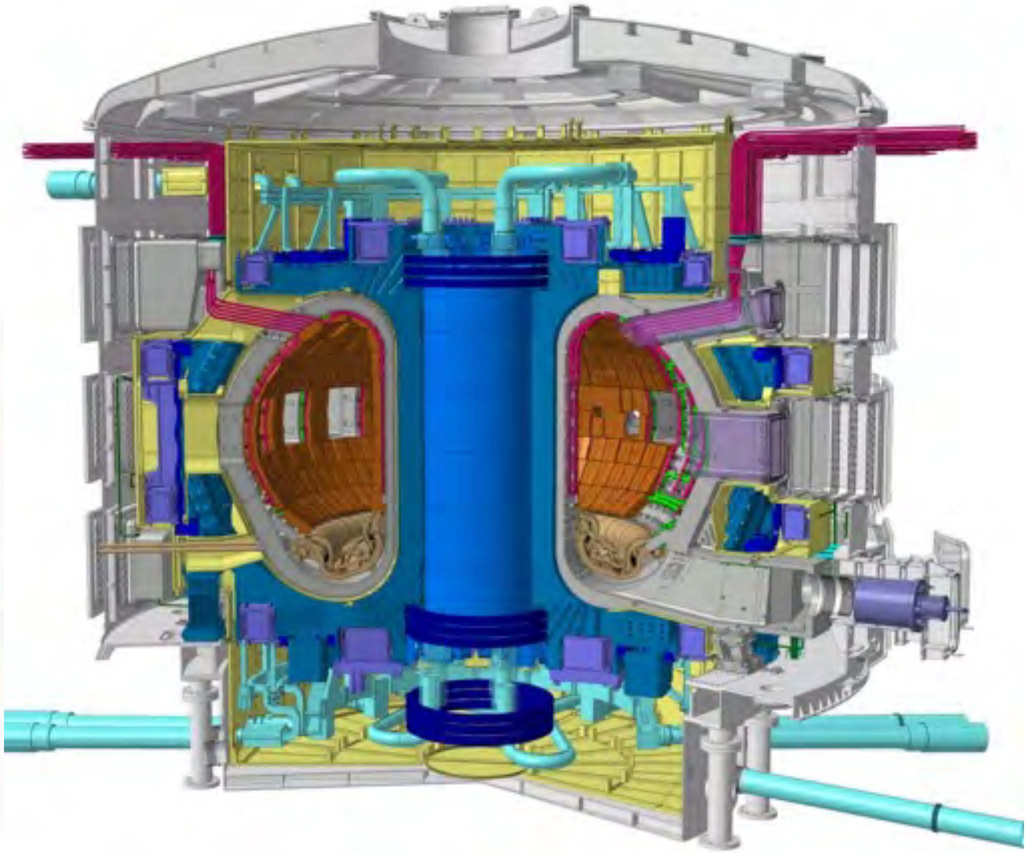


Ceremony ITER Agreement Signature, Elysee Palace, 21 November 2006

El tamaño de ITER es el doble del mayor experimento existente





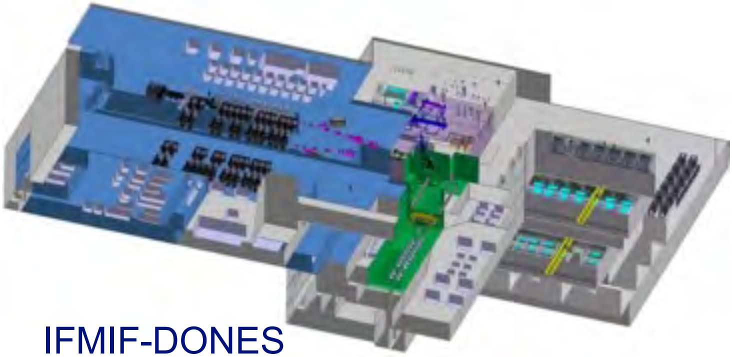


	Tore Supra	*JET*	*ITER*
V_{plasma}	*25* m^3	*80* m^3	*830* m^3
P_{fusion}	*~0*	*~16 MW, 2 s*	*~500 MW, ~400 s*
T_{plasma}	*~400 s*	*~30 s*	*~700 s*

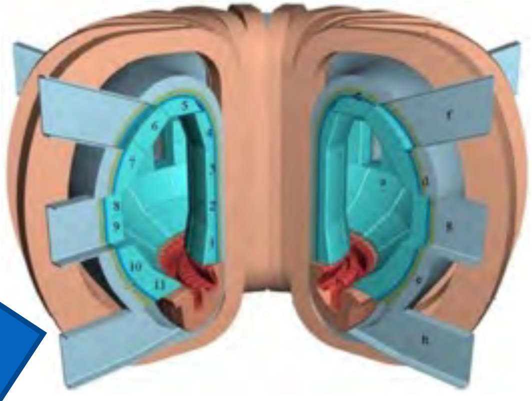
Tokamak Complex

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

ROADMAP TO NUCLEAR FUSION ENERGY

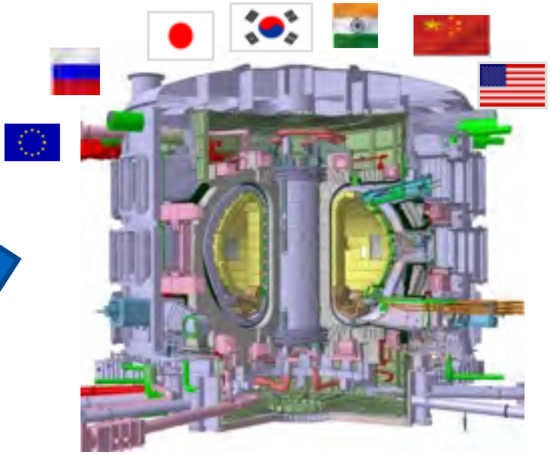


IFMIF-DONES
2 D+ beams, 40 MeV, 125 mA on a Li target



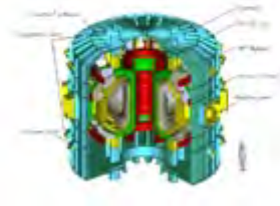
DEMO ≥ 500 MW_{el}

1 – 2 Horas



ITER – 500 MW_{th}

300– 500 segs



K-STAR

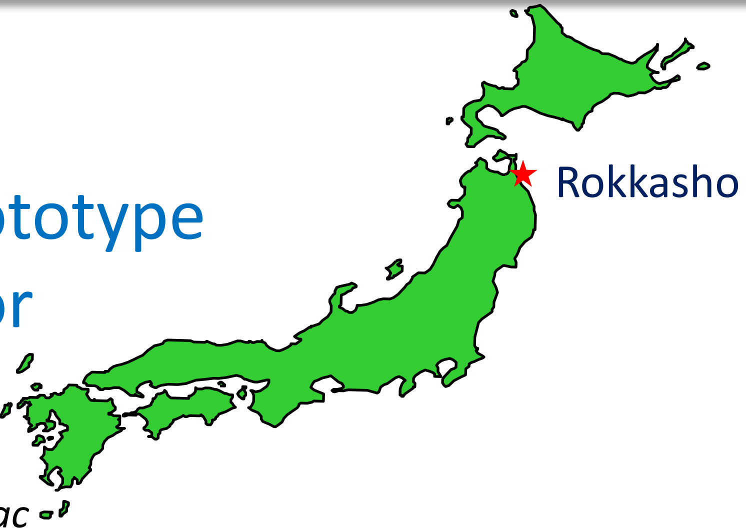
JET

JT-SU

IFMIF DONES GRANADA

Current accelerator design validation (ongoing part of IFMIF/EVEDA Project)

LIPAc
Linear IFMIF Prototype Accelerator

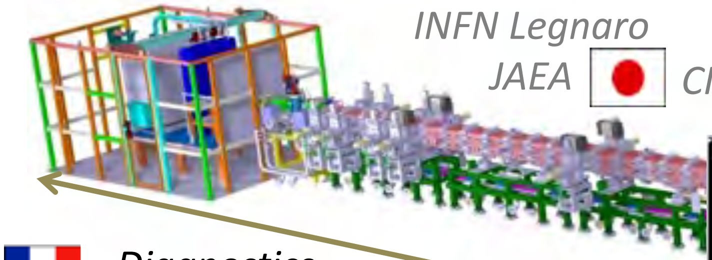


Injector + LEBT
CEA Saclay

RFQ
INFN Legnaro
JAEA

MEBT
CIEMAT Madrid

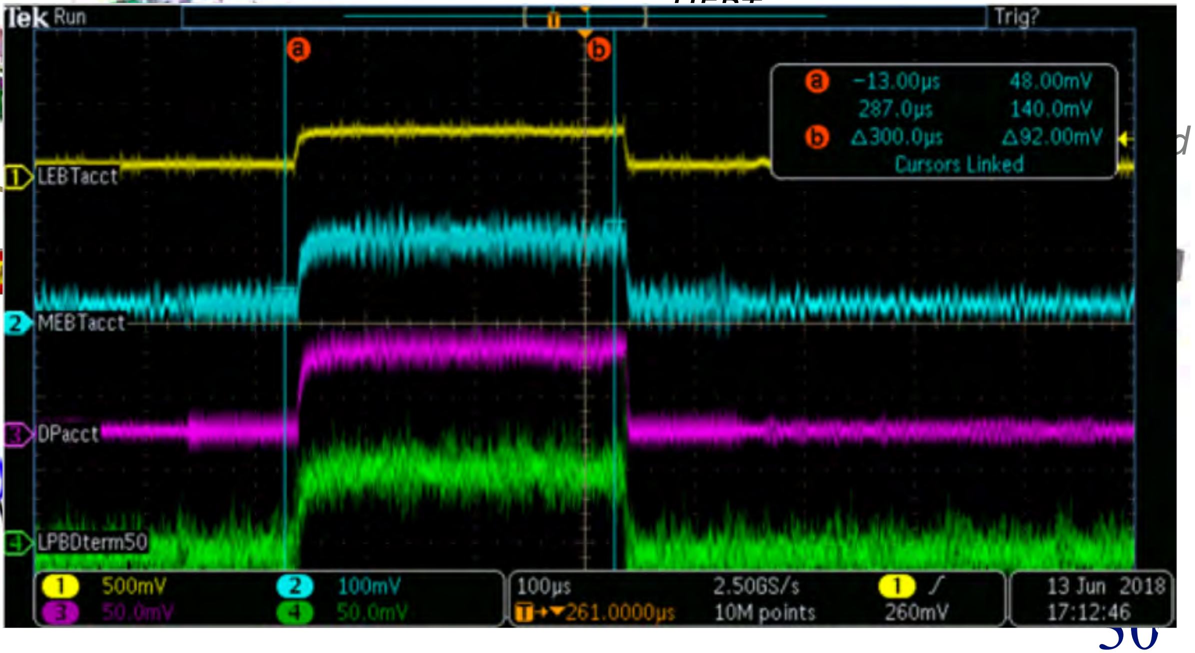
SRF Linac
CEA Saclay
CIEMAT Madrid



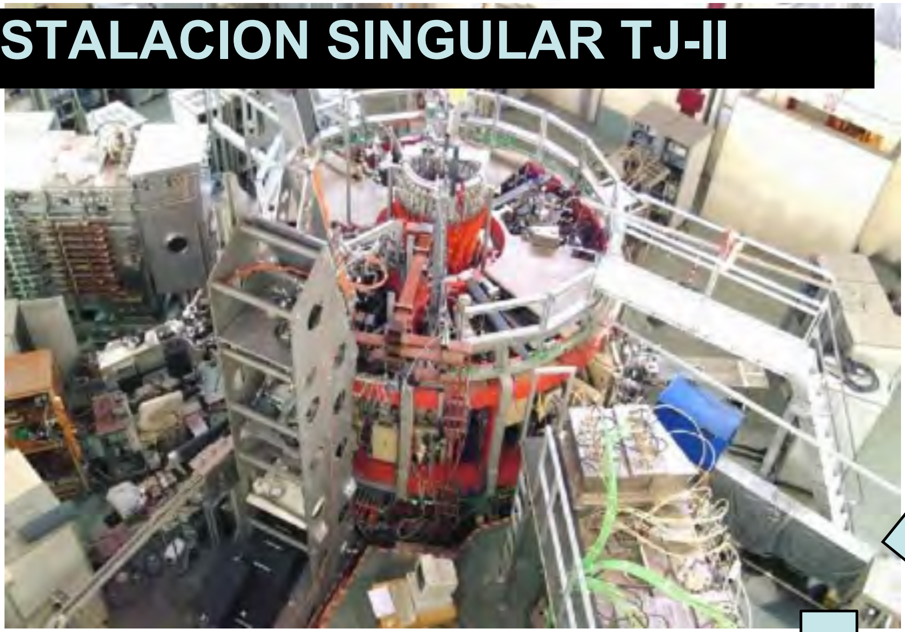
Diagnostics
CEA Saclay
CIEMAT Madrid

Cryoplant
CEA Saclay

FUSION FOR ENERGY
JAEA
cea
Ciemat
INFN
SCK•CEN

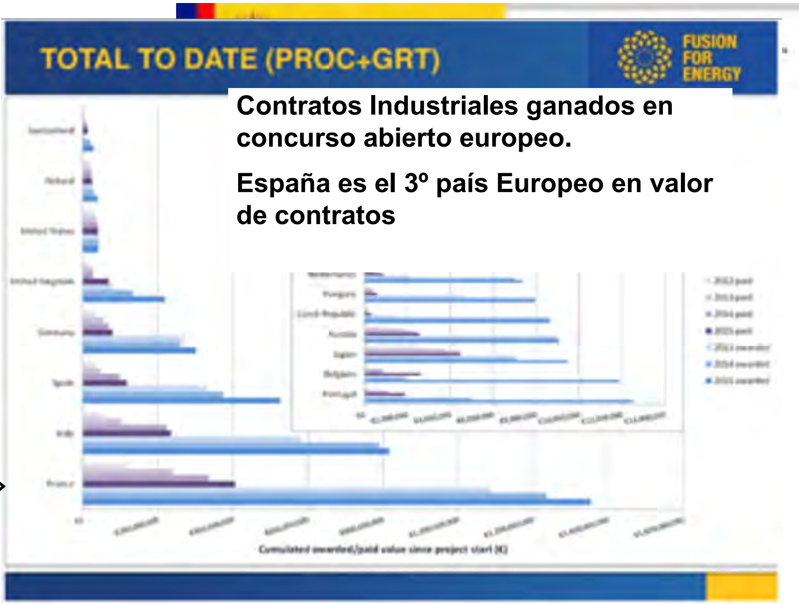

Tek Run
Trig?
a
b
a −13.00μs 48.00mV
287.0μs 140.0mV
b Δ300.0μs Δ92.00mV
Cursors Linked
1 LEBTacct
2 MEBTacct
3 DPacct
4 LPBDterm50
1 500mV
3 50.0mV
2 100mV
4 50.0mV
100μs
T→▼261.0000μs
2.50GS/s
10M points
1 ∫ 260mV
13 Jun 2018
17:12:46

Fusión en España: impacto



INSTALACION SINGULAR TJ-II

Implicar a la Industria



TOTAL TO DATE (PROC+GRT)

FUSION FOR ENERGY
Cumulated awarded/paid value since project start (€)

Contratos Industriales ganados en concurso abierto europeo.

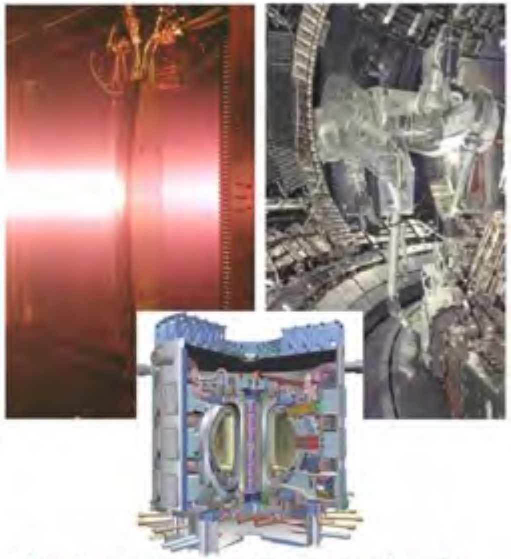
España es el 3º país Europeo en valor de contratos

Implicar al sistema nacional de I+D

Barcelona
Fusion for Energy
≈ 7.000 M€

INDUSTRIA

Plataforma Tecnológica de Fusión



Centro para las Tecnologías de Fusión (TECNOFUSION)

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

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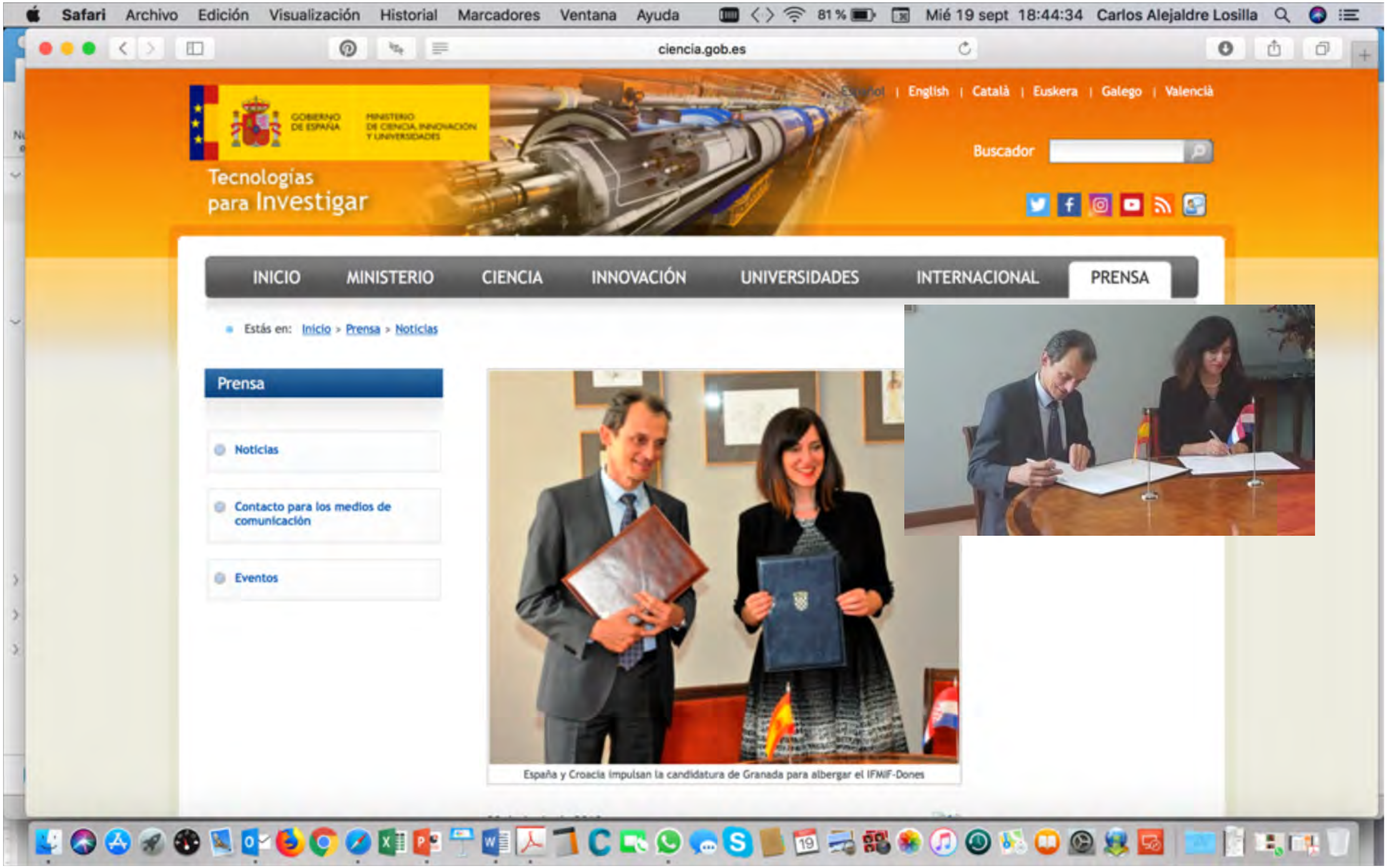
  - Diputacion de Granada
  - Ayuntamiento de Granada
- CIEMAT
  - Laboratorio Nacional de Fusión
- CDTI
- Universidad de Granada
- INEUSTAR Asociación Española de Industria de la Ciencia
- INDUCIENCIA Plataforma Tecnológica
- Ongranada Tech City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Eventos

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

ersidad de Gra

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.

Genyo
CEAMA
cmcyc
IMUDS

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

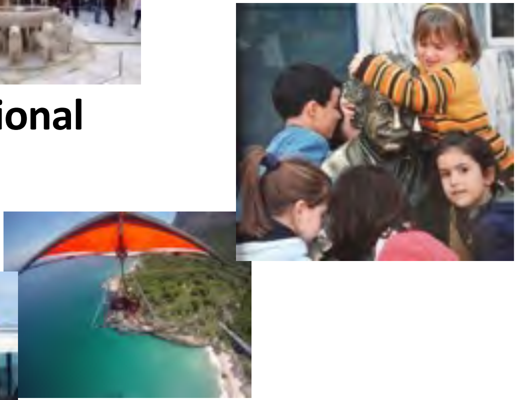
- **High Reputation with high quality research**:
  - **TOP 300 Shangai Ranking**
  - **2nd university in Spain**
  - 1st University **in TIC in Spain**
  - **TOP 50 in TIC Shangai Ranking**

Granada: Living Conditions

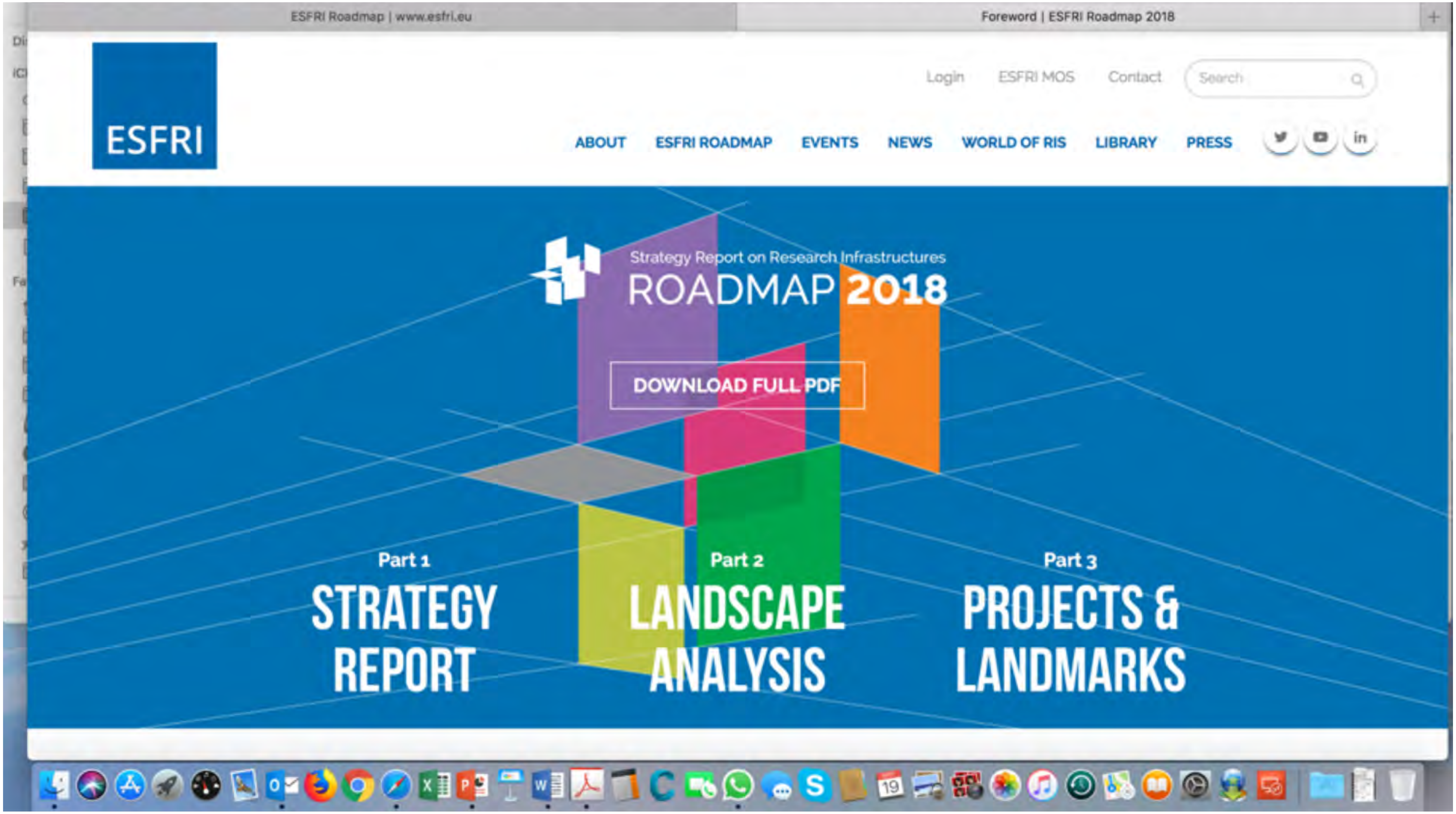
-one of the most **historic** and **culturally rich** urban centers in the world

-**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



ESFRI


ESFRI Roadmap | www.esfri.eu
Foreword | ESFRI Roadmap 2018
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Strategy Report on Research Infrastructures

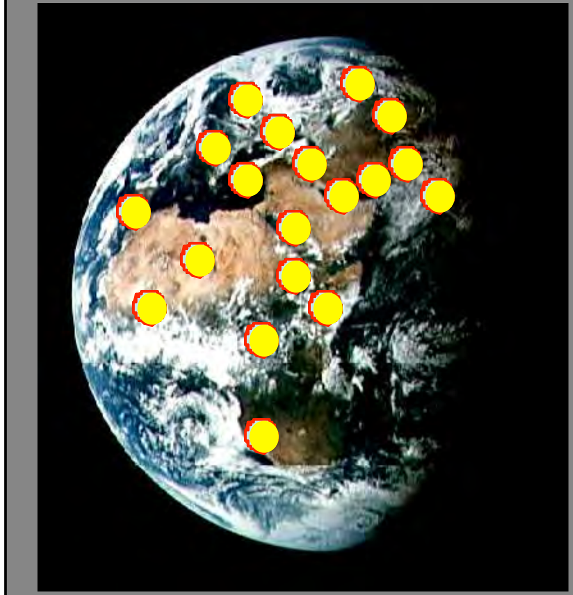
ROADMAP 2018

Part 1
STRATEGY REPORT

Part 2
LANDSCAPE ANALYSIS

Part 3
PROJECTS & LANDMARKS

Ultimos comentarios



- No hay una solución sencilla, ni probablemente única al problema energético de la Humanidad. Intensificar la investigación en Energía es una necesidad.
- Viabilidad científica de la fusión ha sido demostrada (16 MW en JET).
- El Laboratorio mundial ITER, la demostración científica y tecnológica, se está instalando en Europa (Cadarache). Barcelona acoge la Agencia Europea del proyecto.
- IFMIF-DONES es imprescindible para conseguir construir las futuras plantas de fusión.
- España es parte importante de la estrategia Europea en Fusión y el Programa de Fusión buen ejemplo que un cambio en el modelo productivo es posible.

Fusión nuclear es una realidad y puede ser la fuente de energía inagotable, barata y medioambientalmente aceptable del Futuro

Bienvenidos a la nueva era de la Fusión

Continuará… (Próximo capítulo en Granada)

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

¿Preguntas?
¿Comentarios?

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