PLASMA AS AN ENGINEERING TOOL

P I JOHN

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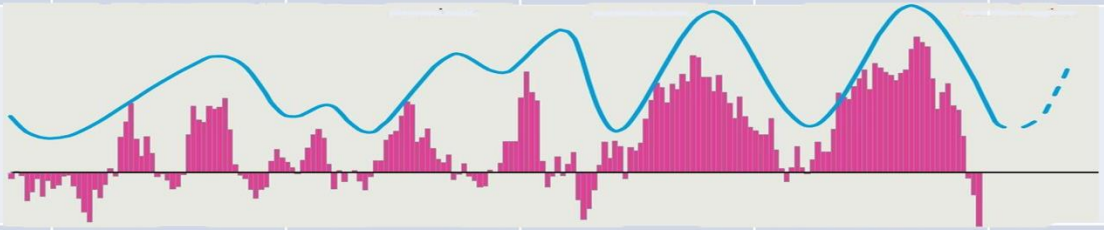
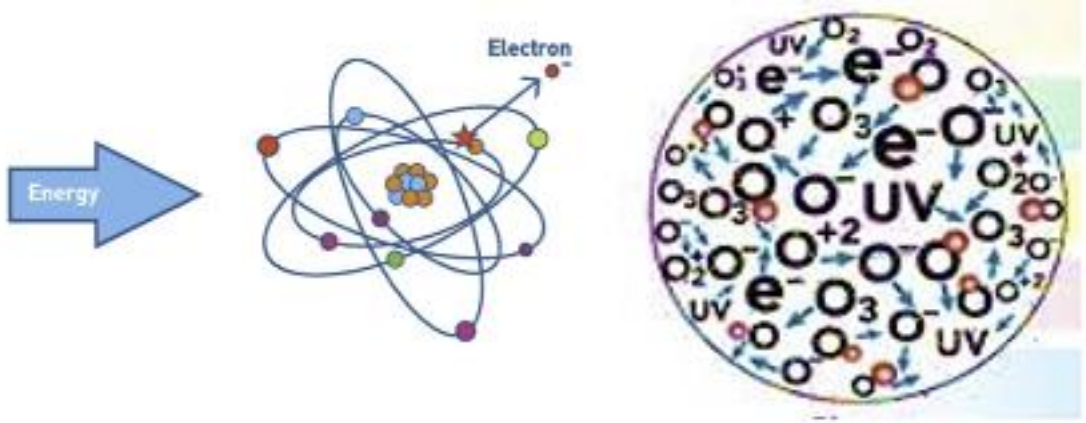
Economies grow cyclically with a periodicity of about 53 years. Technological developments drive each new cycle

Kondratieff Waves of Innovation

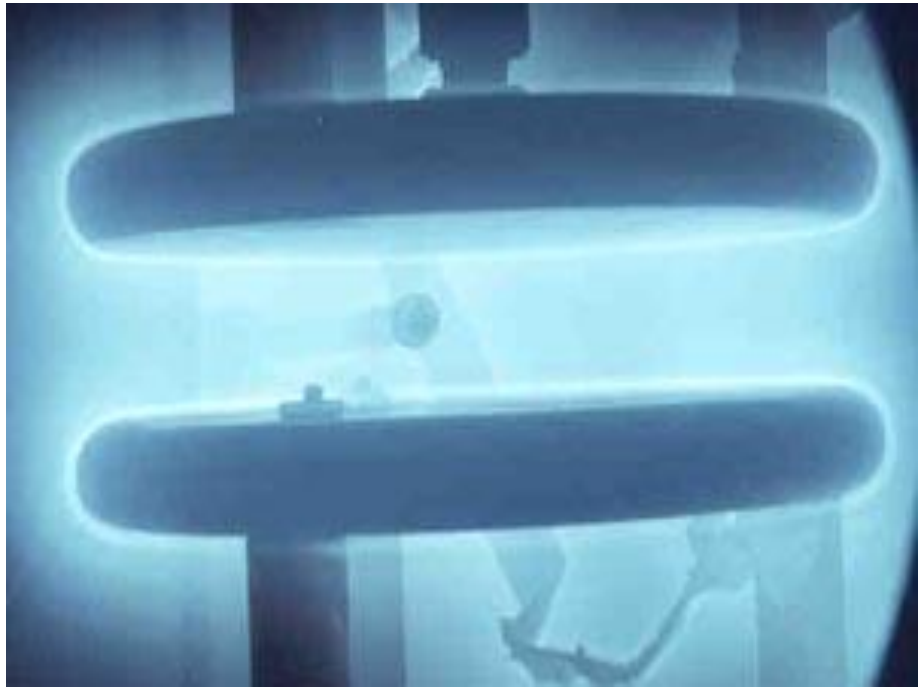
Waves:	1st Wave: Industrial Revolution	2nd Wave: Industrial Production	3rd Wave: Scientific Revolution	4th Wave: Scientific-Technical Revolution	5th Wave: Information and Telecom Revolution	6th Wave: …
Date range:	~1780 – 1830	~1830 – 1880	~1880 - 1930	~1930 – 1970	~1970 - 2010	~2010 – 2050
Economic trend (US S&P 500)						
Key developments	Steam engine, industrialization	Railways, steel, heavy engineering	Electricity, chemistry, chemical industry	Automobile, mass production, petrochemical industry	Microcomputers, information, telecom	

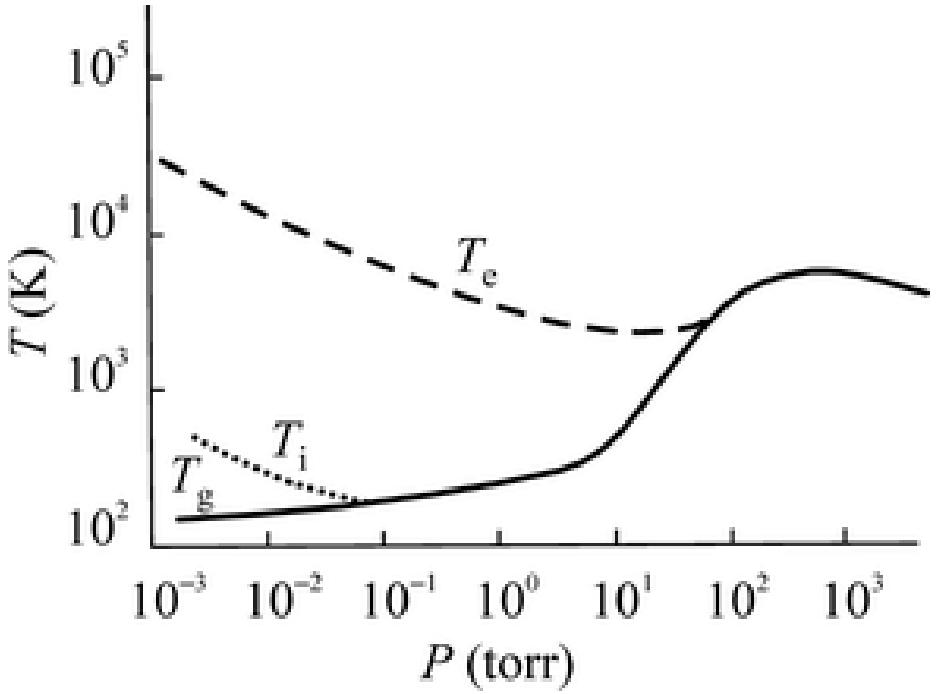
Physics and Engineering play a vital role in the development of new technologies

Plasma Physics has a very high potential to make contributions with a significant socio-economic impact

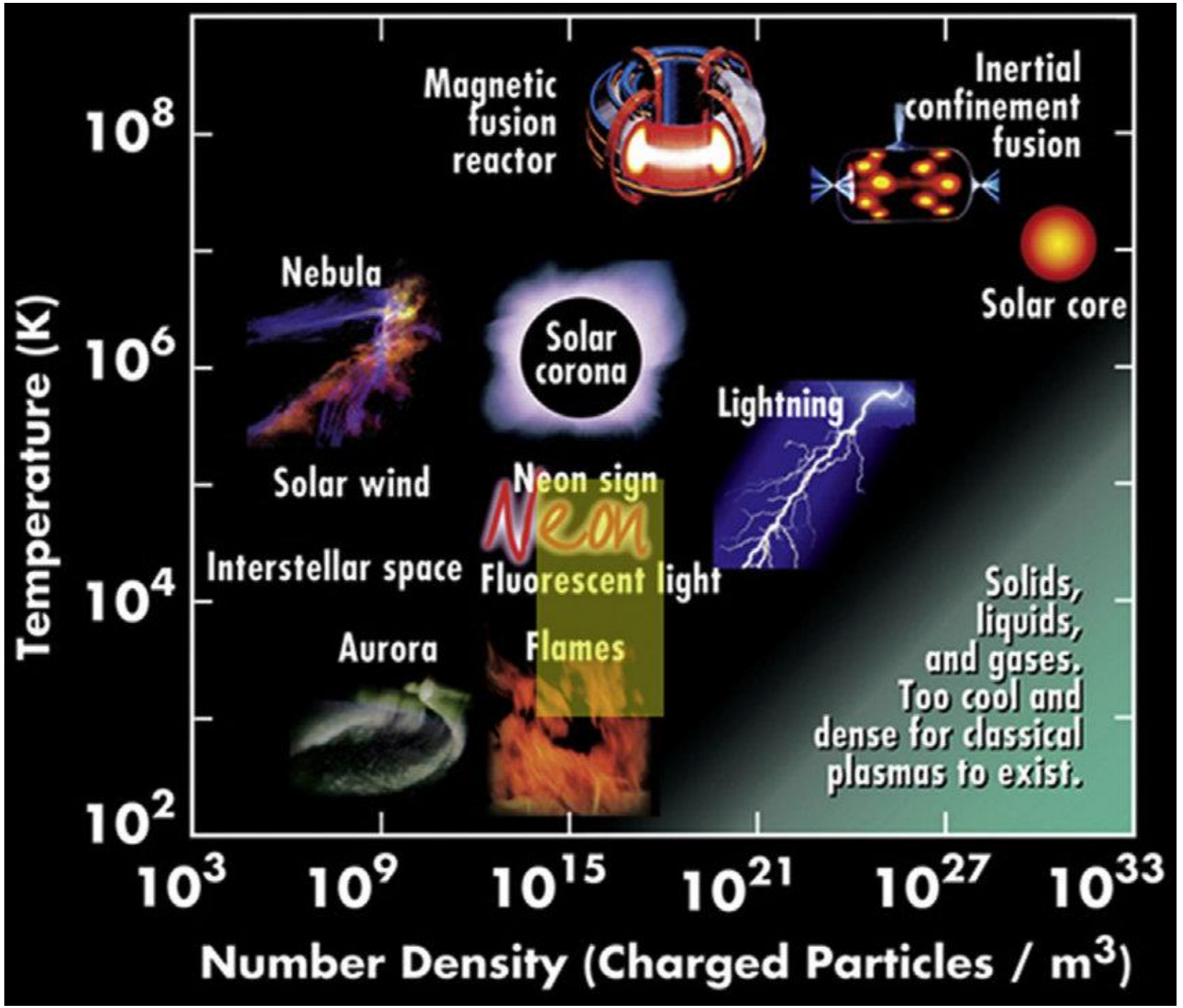


In an electric field, electrons get accelerated and gain energy; collide with atoms to knock off more electrons leading to an avalanche in ionization.





Electrons gain energy from the E-field and share it with ions and molecules through collisions



Plasmas exist in an extended parameter space.

Solar wind has a billion particles in a cubic meter and has a temperature of 100,000 degrees.

Fluorescent lamps contain plasmas at 10,000 degrees with a density of 10(15) particles per meter cubed.

The core of the sun has a plasma density of 10(32) particles per meter cubed, with a temperature of 10 million degrees.

Plasma as an Engineering Tool Results from:

Extended parameter space in density, temperature, particle energy and chemical reactivity.

Extremely high temperatures or energy densities

Promotes nuclear interactions – Thermonuclear Fusion

Generates extremely high transient and non-equilibrium conditions.

Atomic-scale resolution in material processing

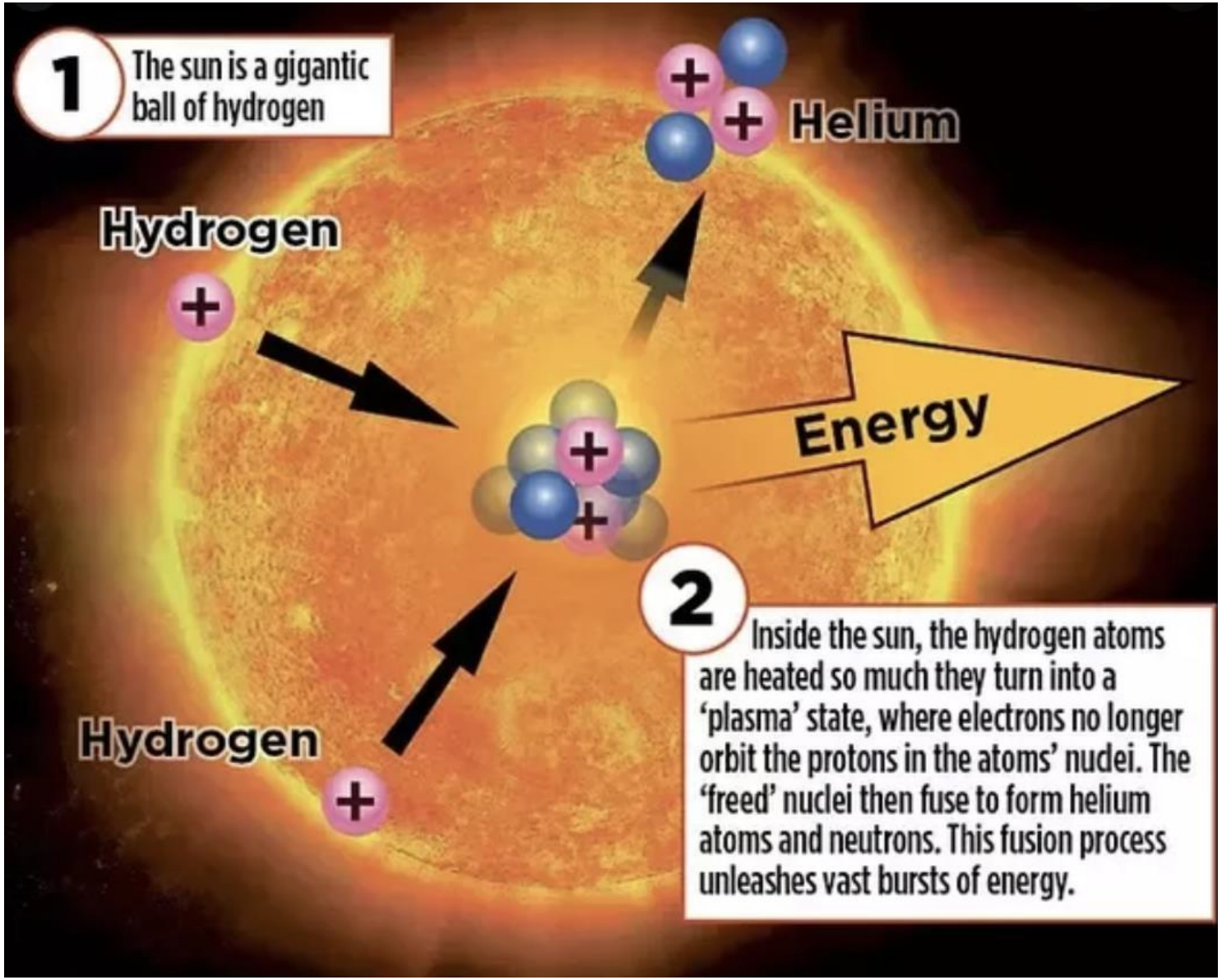
Plasma catalysis for mediating exotic chemical reactions

The Sun

Gigantic Sphere of Hydrogen Plasma

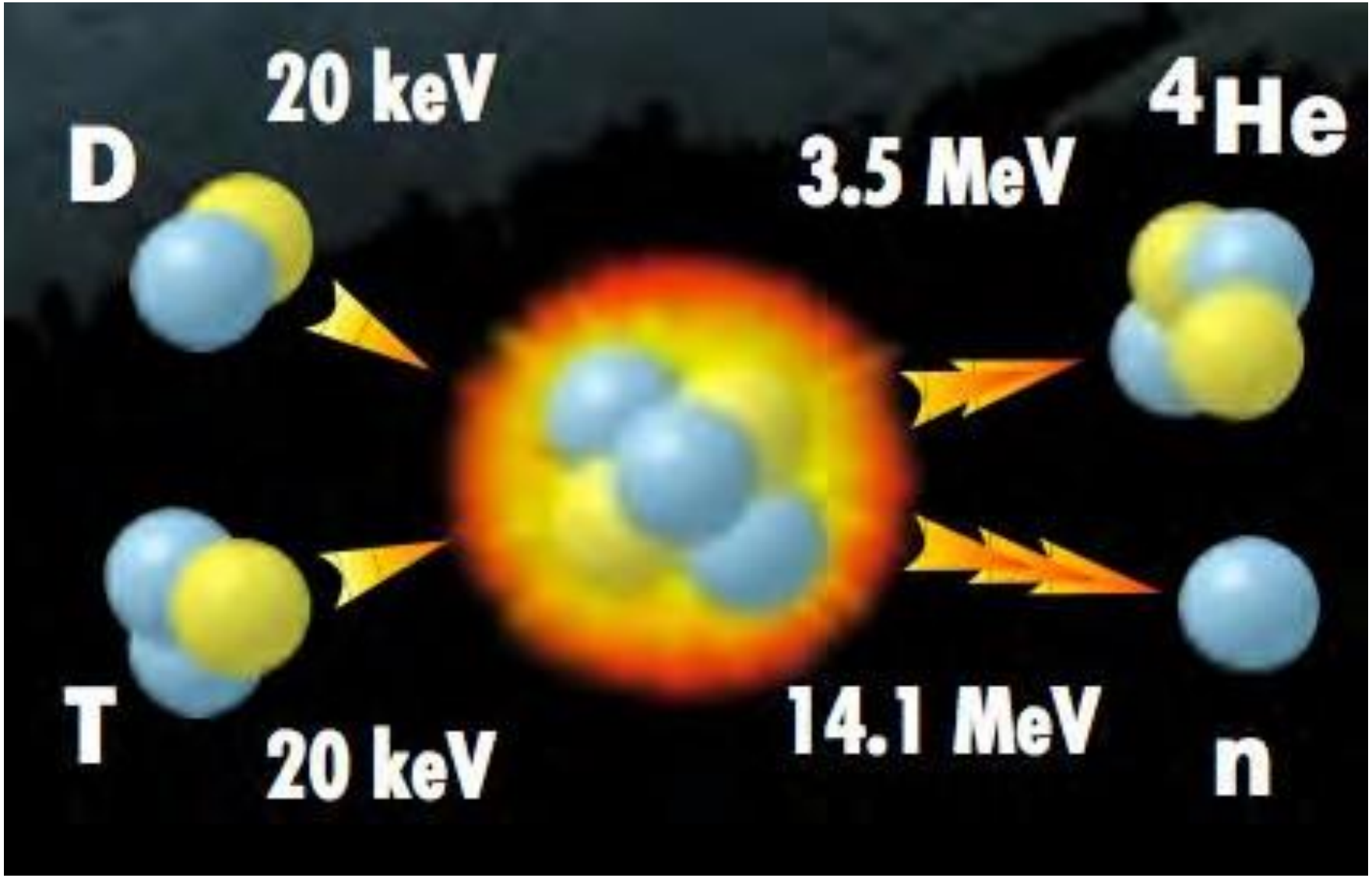
Fusion reactions convert Hydrogen into Helium

Every second, our Sun fuses about 600 million tons of hydrogen into helium, releasing a flood of light and heat that sustains life on Earth.

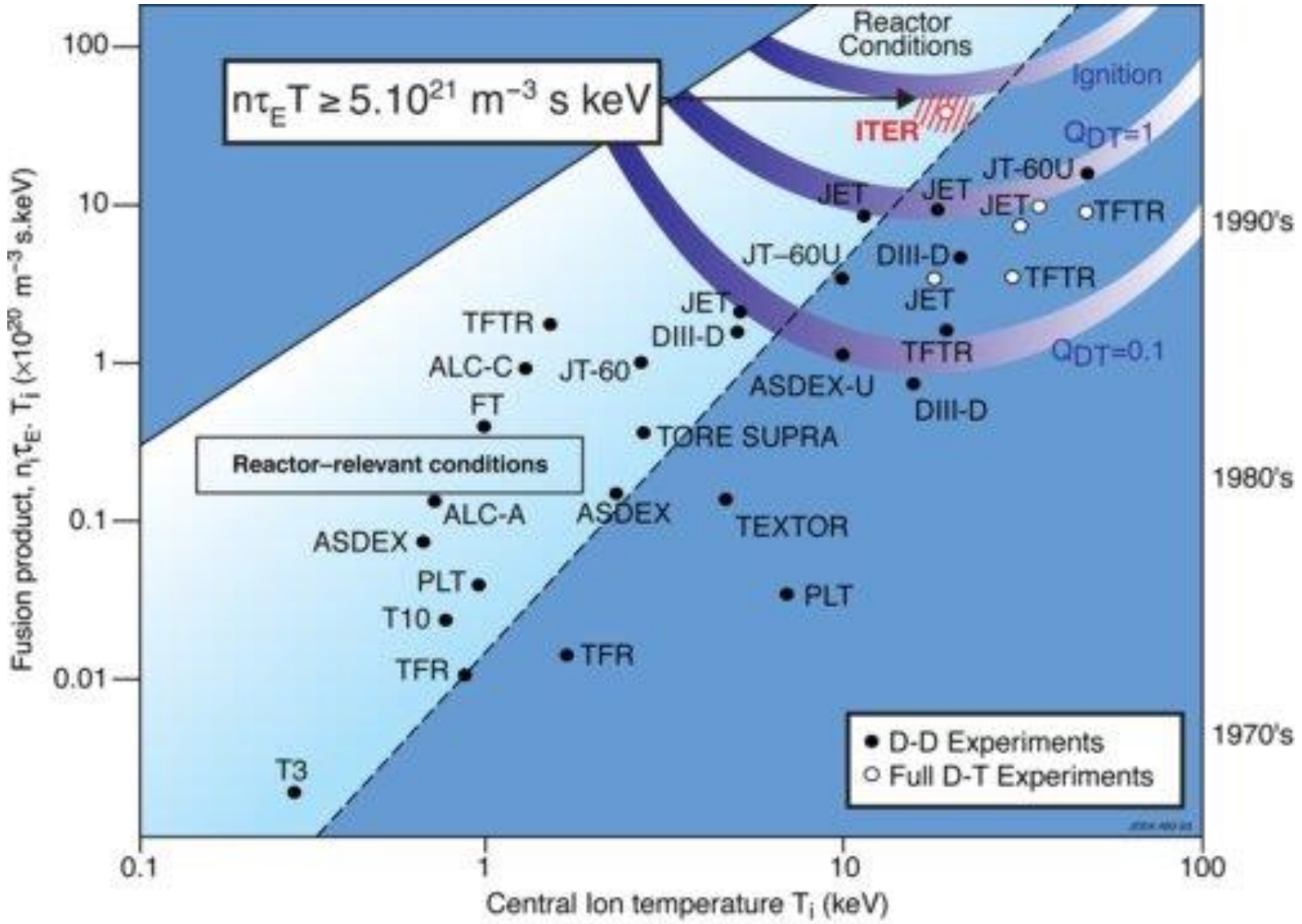


COULD WE REPLICATE THIS ON EARTH AND BUILD MINIATURE SUNS TO PRODUCE LIMITLESS ENERGY?

Deuterium and Tritium nuclei fuse to form Helium and release energy in the form of 14 MeV Neutrons

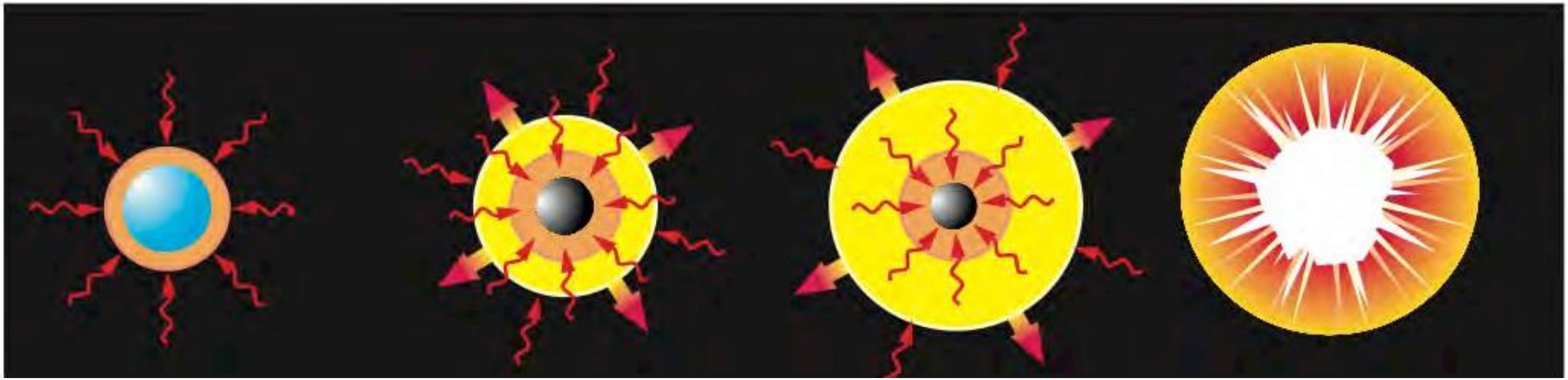


Progress in Fusion Research over the years



Too Expensive!
10 Bn Euro

Approach I : Inertial Fusion



Heating of the surface of mm sized pellets

Ablation of outer skin leads to compression

The core heats up by compression

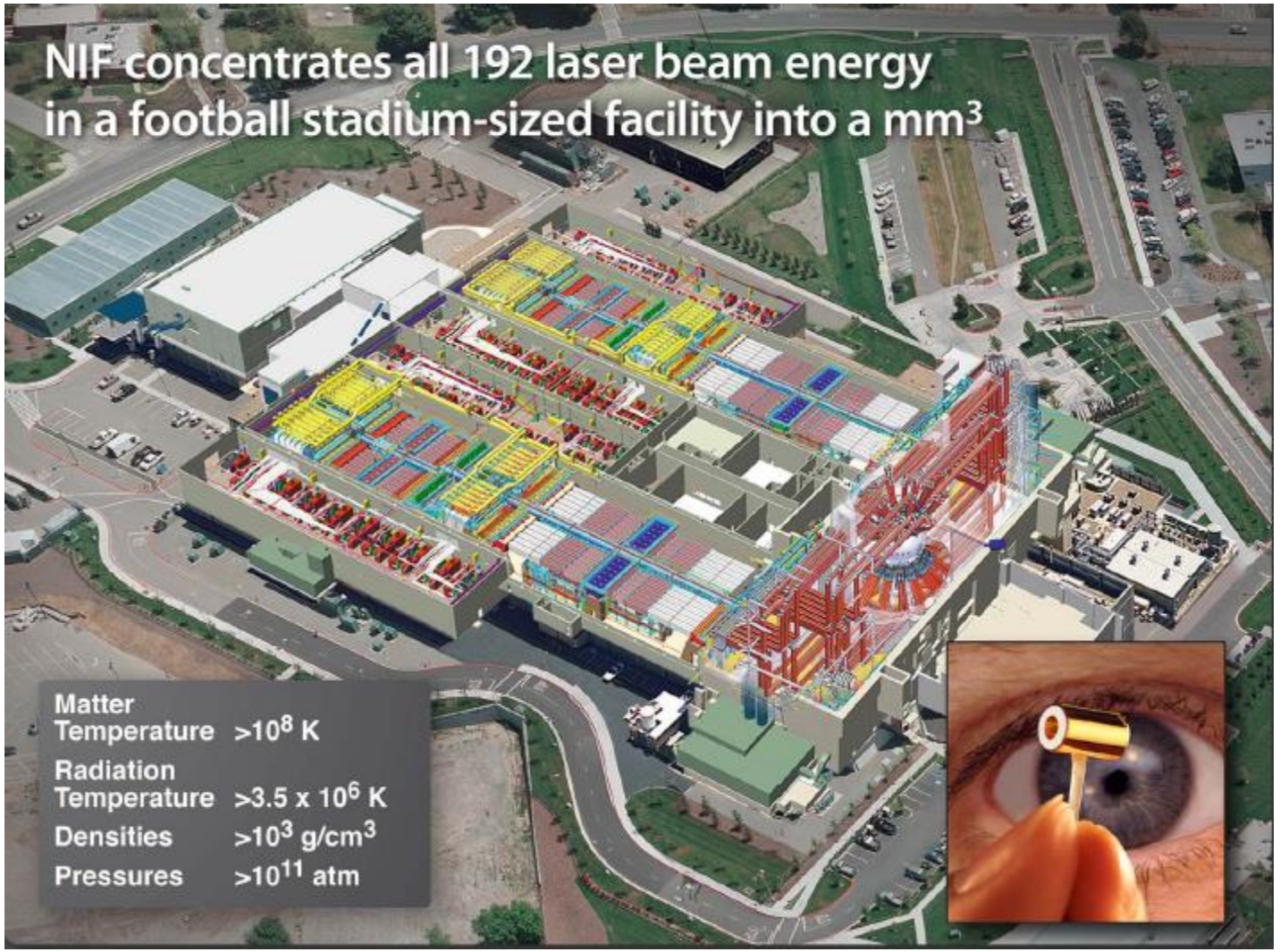
Fusion

National Ignition Facility

192 Beams

10^{15} WATTS

Lawrence Livermore National Laboratory

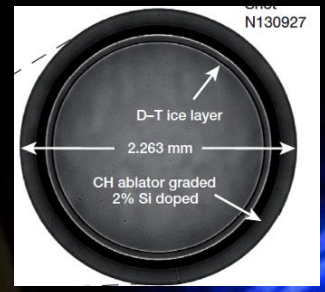


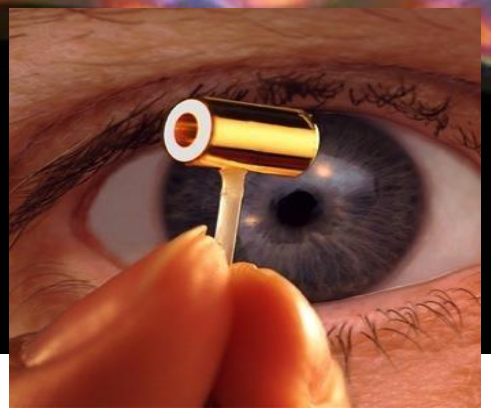
192 laser beams

Gold cavity (Hohlraum)

D-T Pellet

Matter Temperature	$>10^8$ K
Radiation Temperature	$>3.5 \times 10^6$ K
Densities	$>10^3$ g/cm^3
Pressures	$>10^{11}$ atm





The National Ignition Facility
Has Achieved Fusion Ignition

9 times

Setting a Record Fusion Yield of

8.6 MJ*

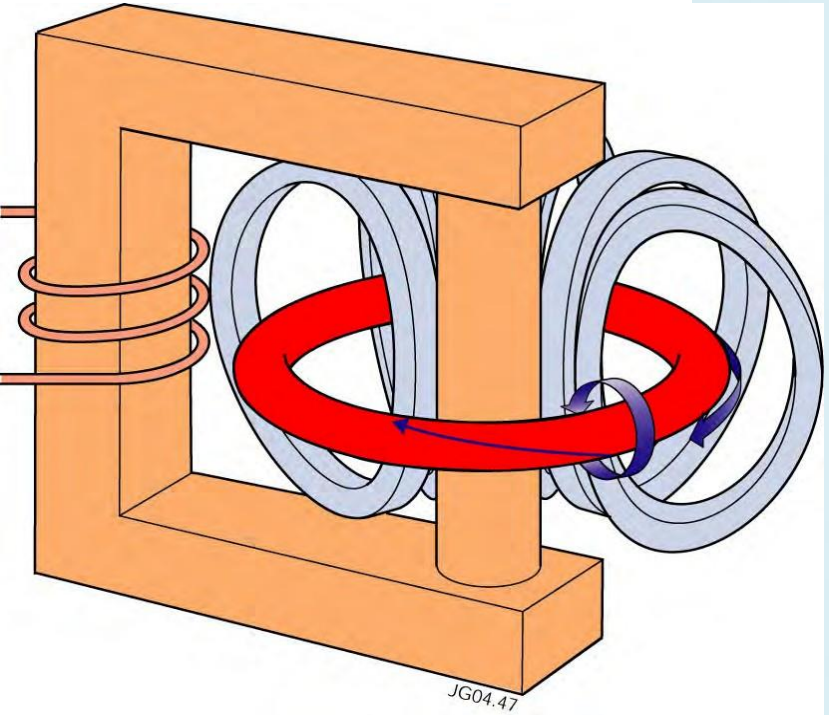
Approach 2

Magnetic Confinement Fusion (MCF)

Use Intense magnetic field to trap and confine a plasma heated to 100 Million deg

TOKAMAK IS THE MOST SUCCESSFUL TRAP

TOKAMAK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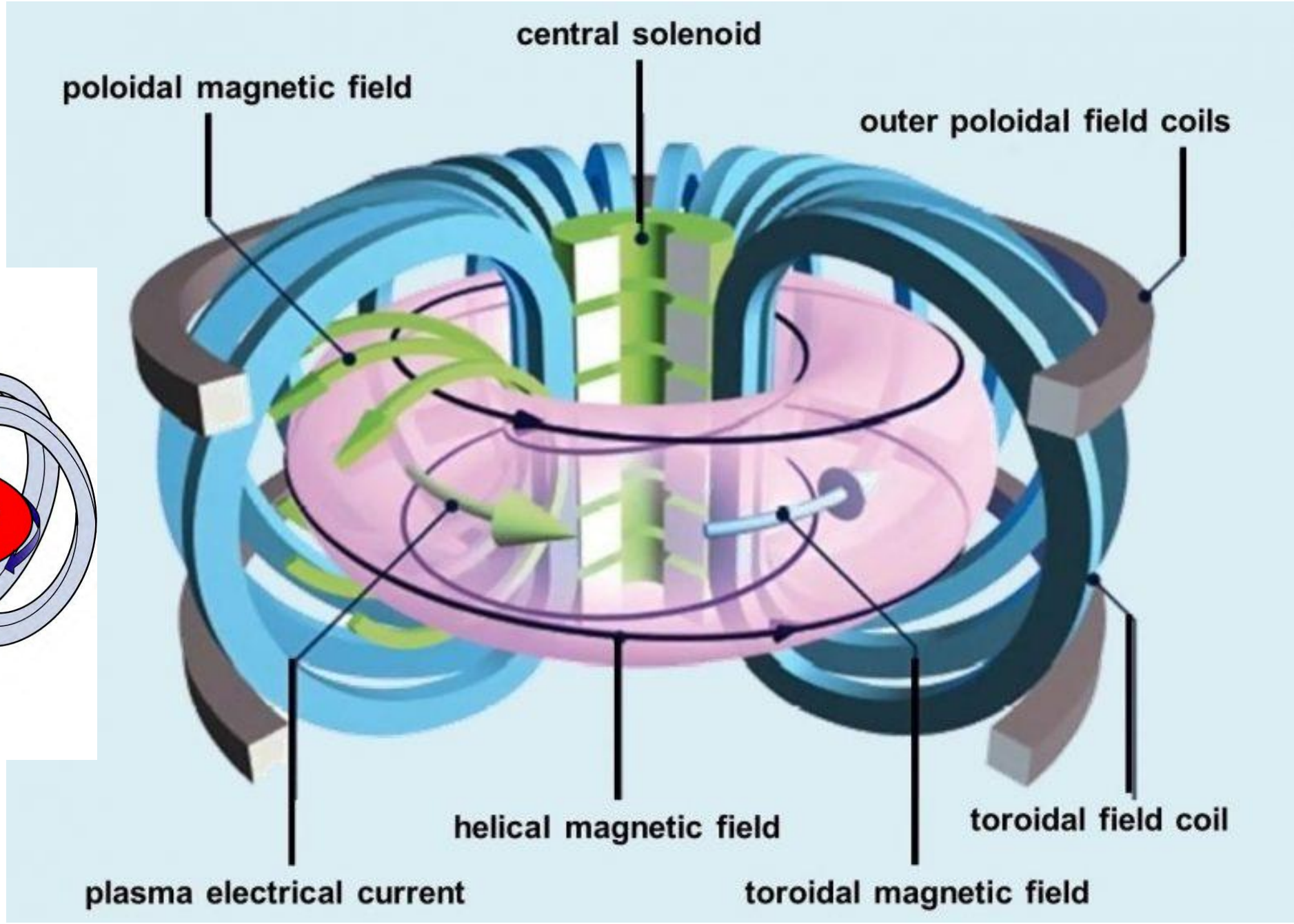
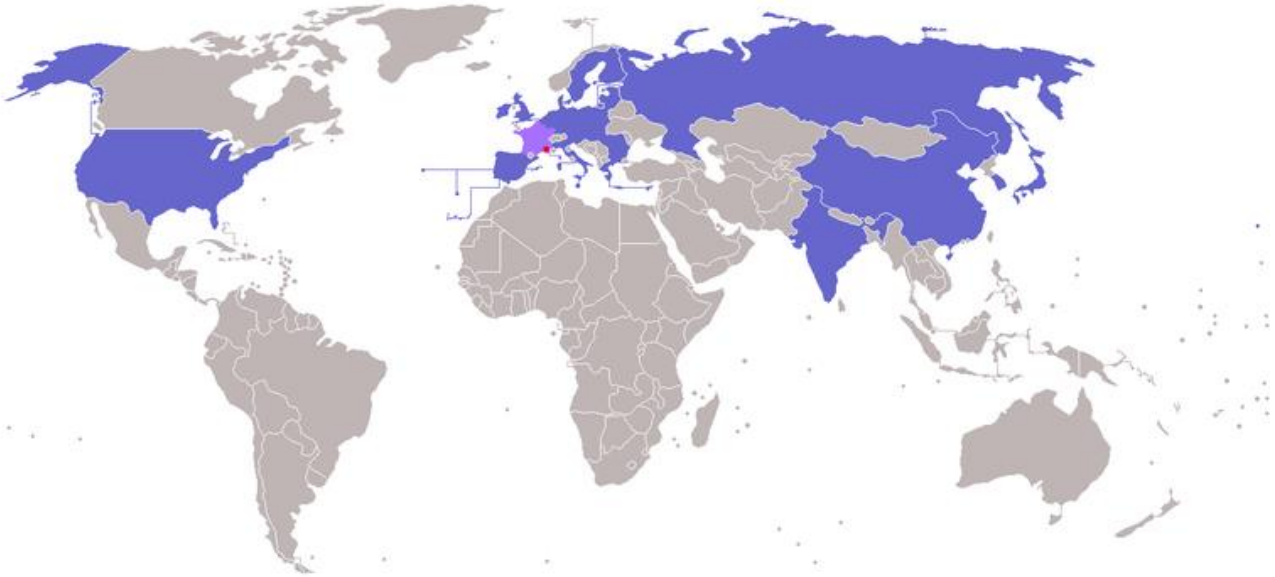

central solenoid
poloidal magnetic field
outer poloidal field coils
helical magnetic field
toroidal field coil
plasma electrical current
toroidal magnetic field

ITER: International Thermonuclear Experimental Reactor



7-NATION COLLABORATION

Miniature Sun on Earth

The ITER Tokamak

Toroidal Field Coil

Nb_3Sn, 18, wedged

Vacuum Vessel 9 sectors

Poloidal Field Coil Nb-Ti, 6

Port Plug

heating/current drive,

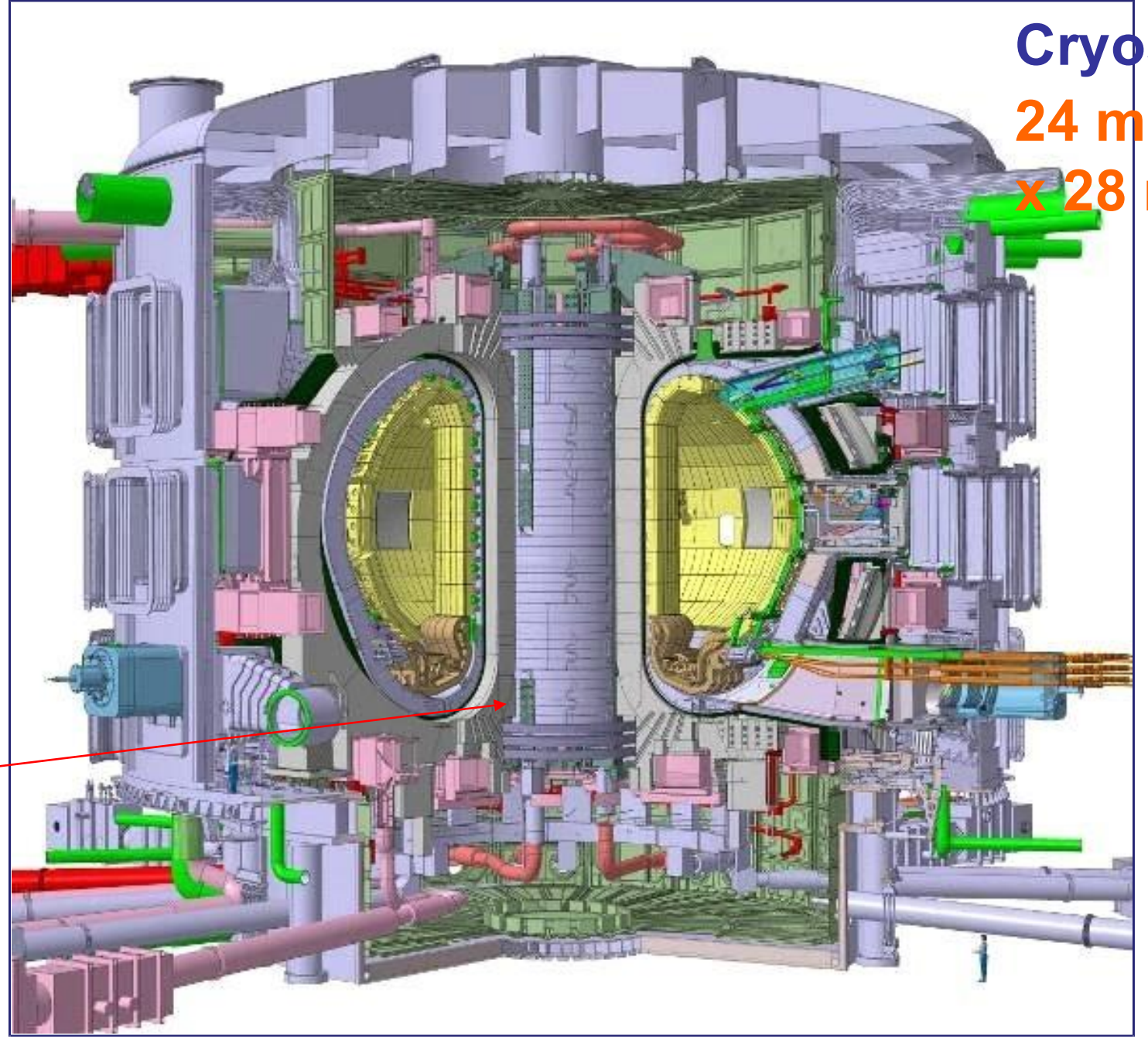
test blankets

limiters/RH

diagnostics

Central Sole noid

Nb_3Sn, 6 modules



Cryostat

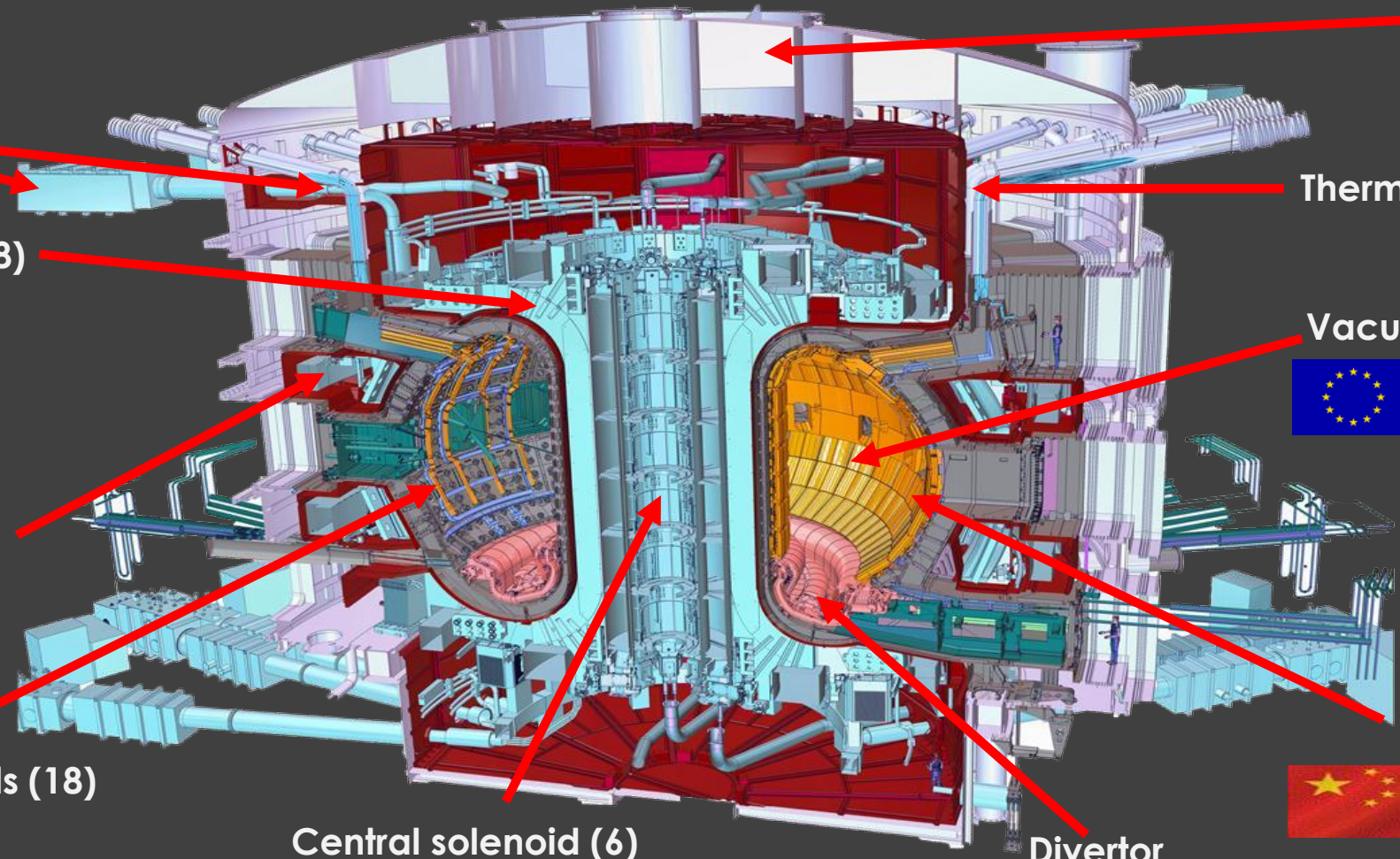
24 m high

x 28 m dia

Man standing

Who manufactures what?

The ITER Members share all intellectual property



Feeders (31)

Toroidal Field coils (18)

Poloidal field coils (6)

Correction coils (18)

Central solenoid (6)

Cryostat

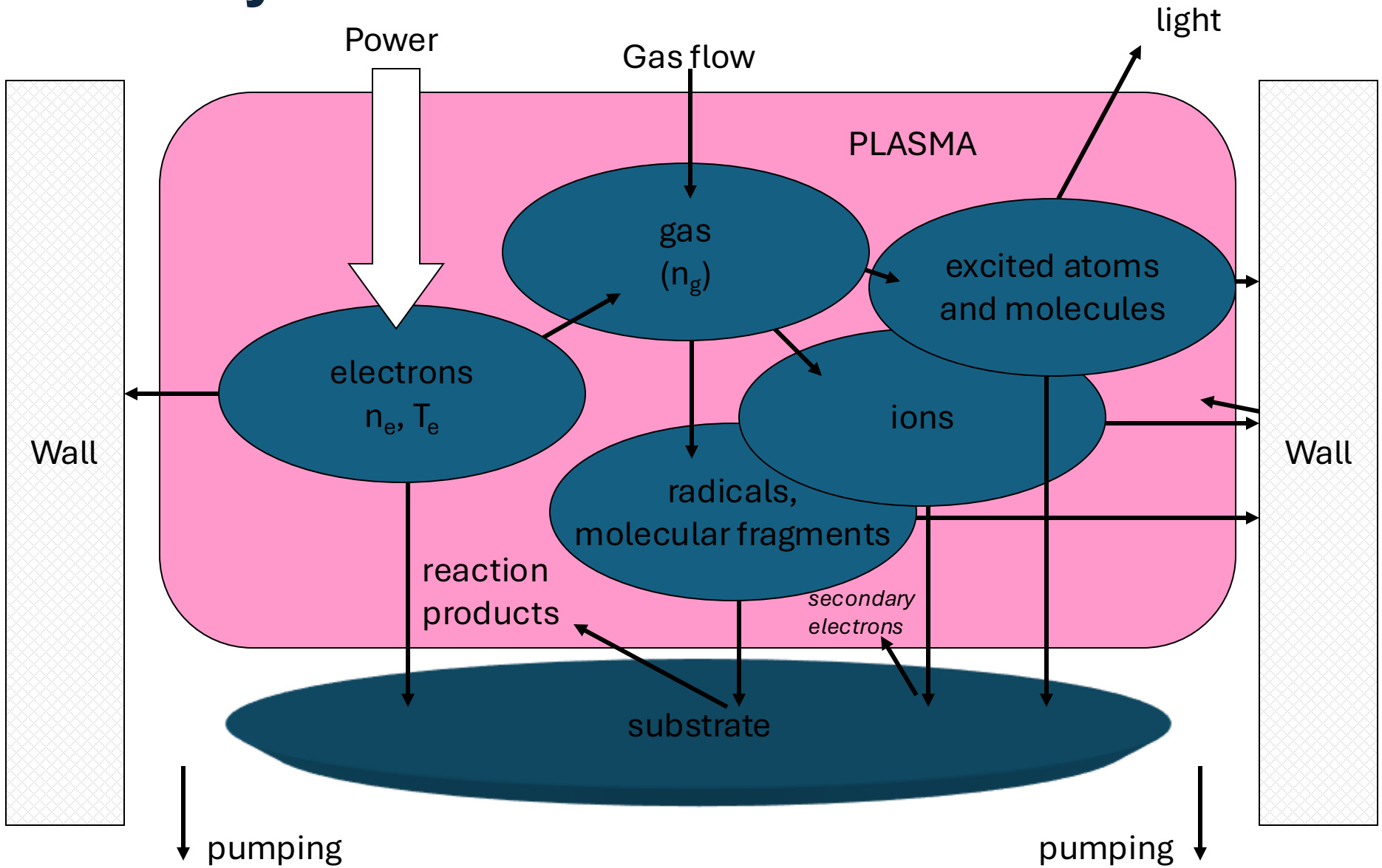
Thermal shield

Vacuum vessel

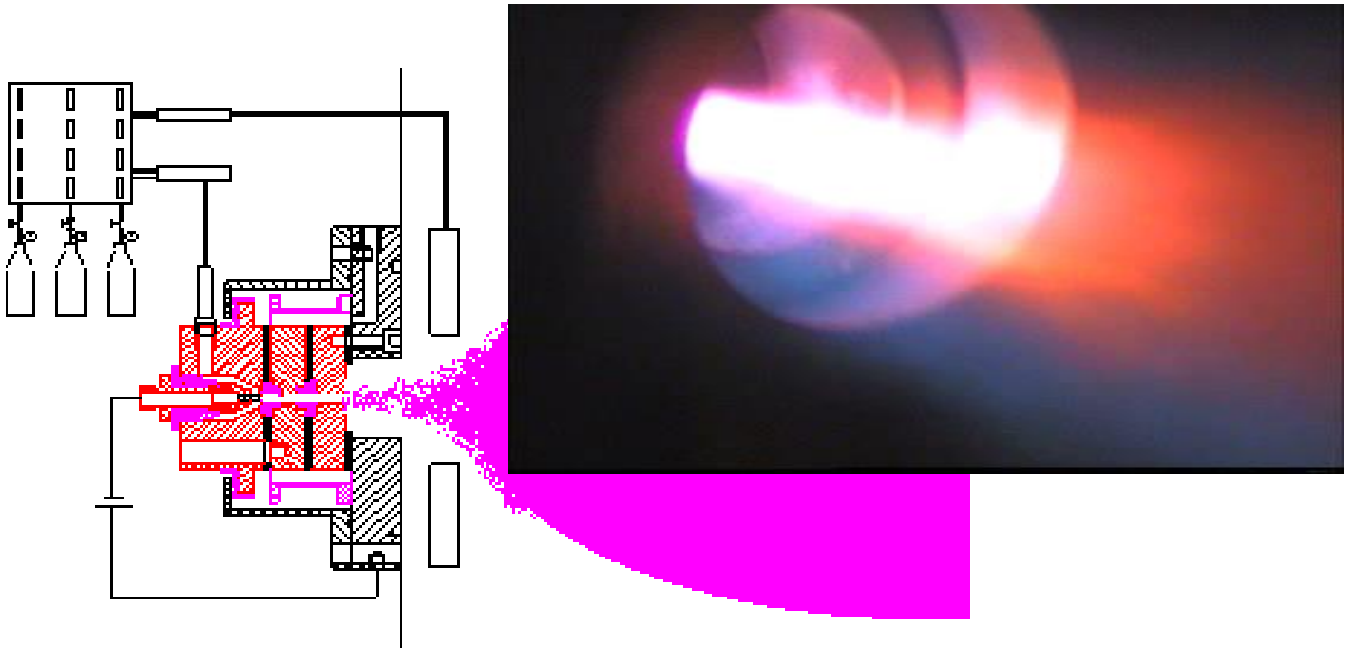
Blanket modules

Divertor

Enhanced Chemical Reactivity of Plasma Synthesis of Advanced Materials



Nanostructured Superhydrophobic Silicon carbide and Teflon like Coatings Coatings



Electron temperature

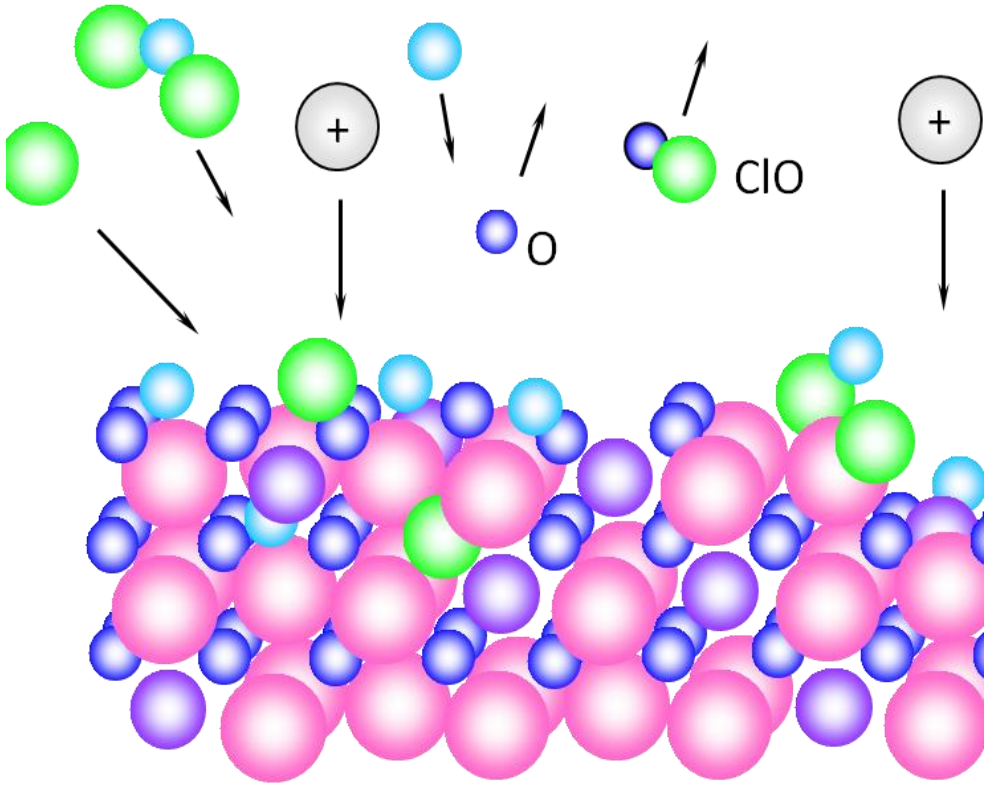
~ 1 eV

5-10 % ionization

1 scc/sec ~ 10^{20} ions/sec

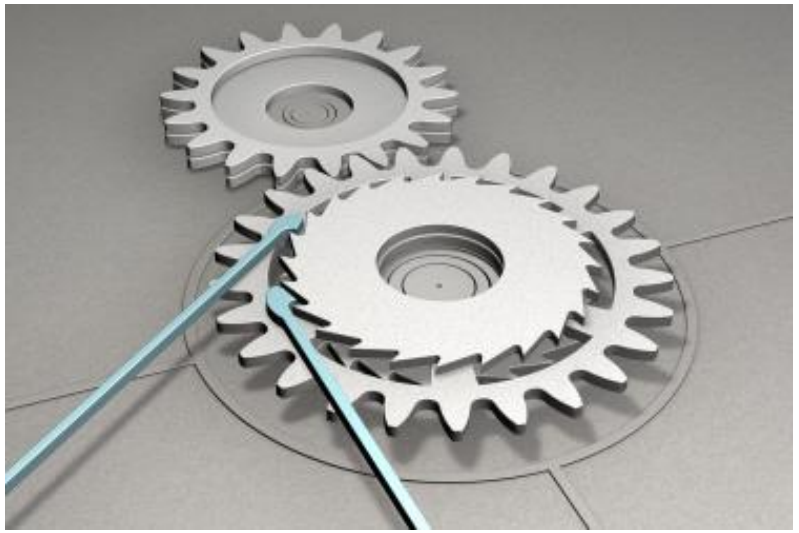
High-rate PECVD coating by a high speed non-equilibrium plasma jet produced in Segmented Electrode Expanding Thermal Plasma Source

In Plasma Etching, energetic ions remove material from a surface through Physical and Chemical Sputtering



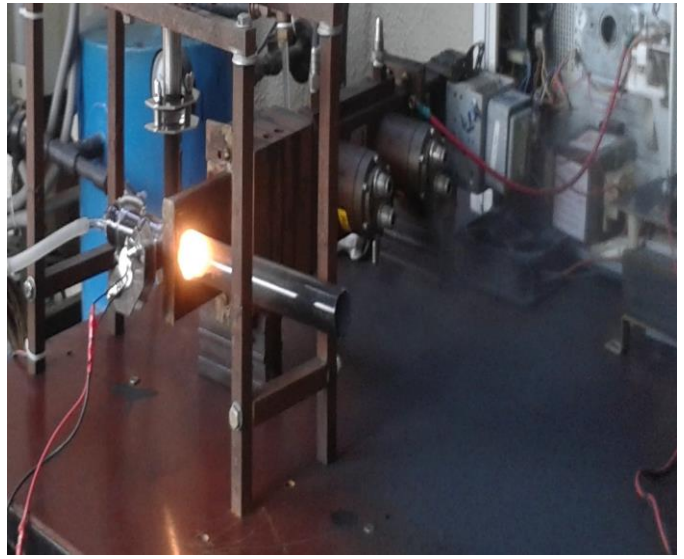
Atom by Atom Process

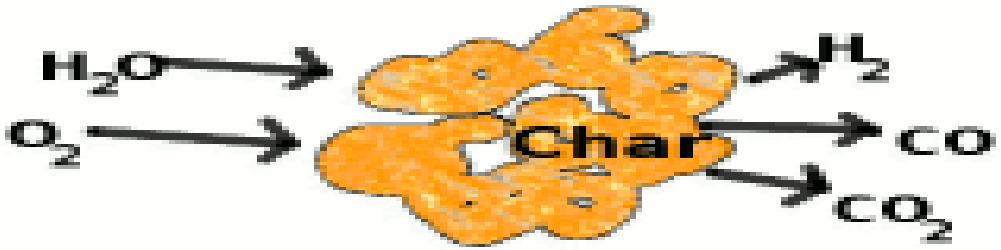
Micro-electromechanical systems (MEMS) combine computers with tiny mechanical devices such as sensors, valves, gears, and actuators on semiconductor chips.



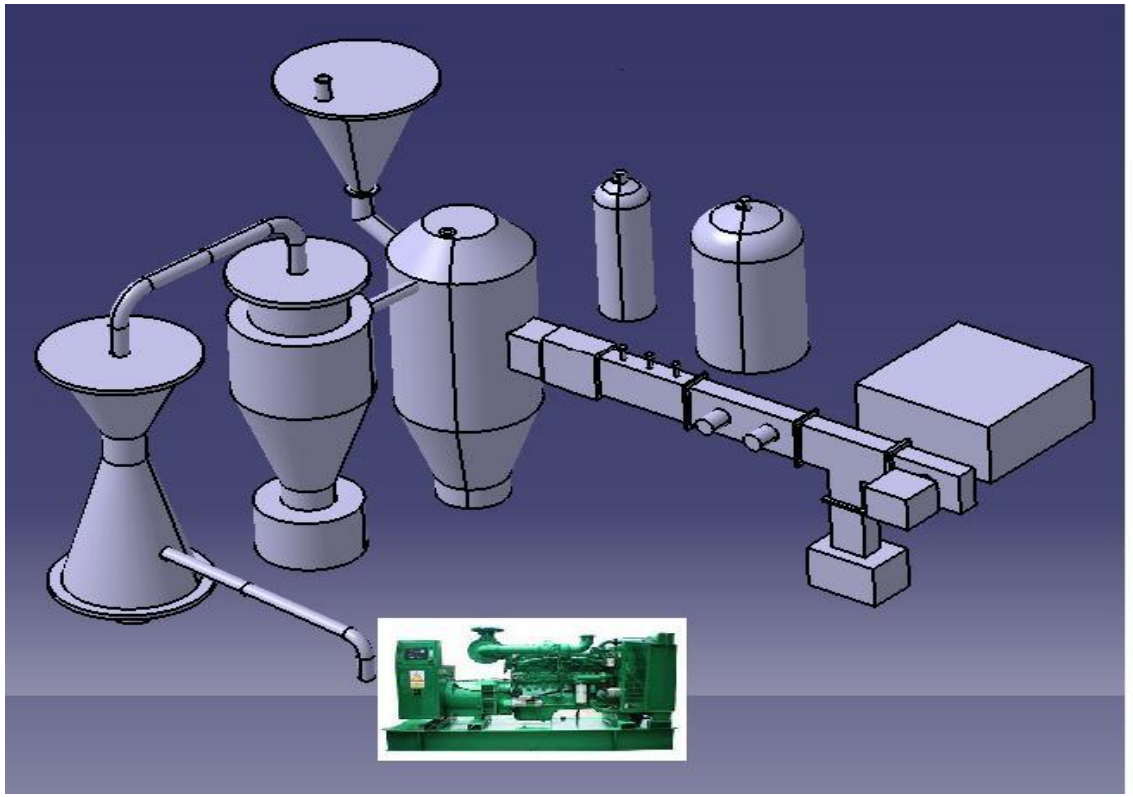
Gasification is a process that converts carbonaceous materials, such as coal, petroleum coke or biomass, into carbon monoxide and hydrogen.

Plasma Gasification of Coal At FCIPT

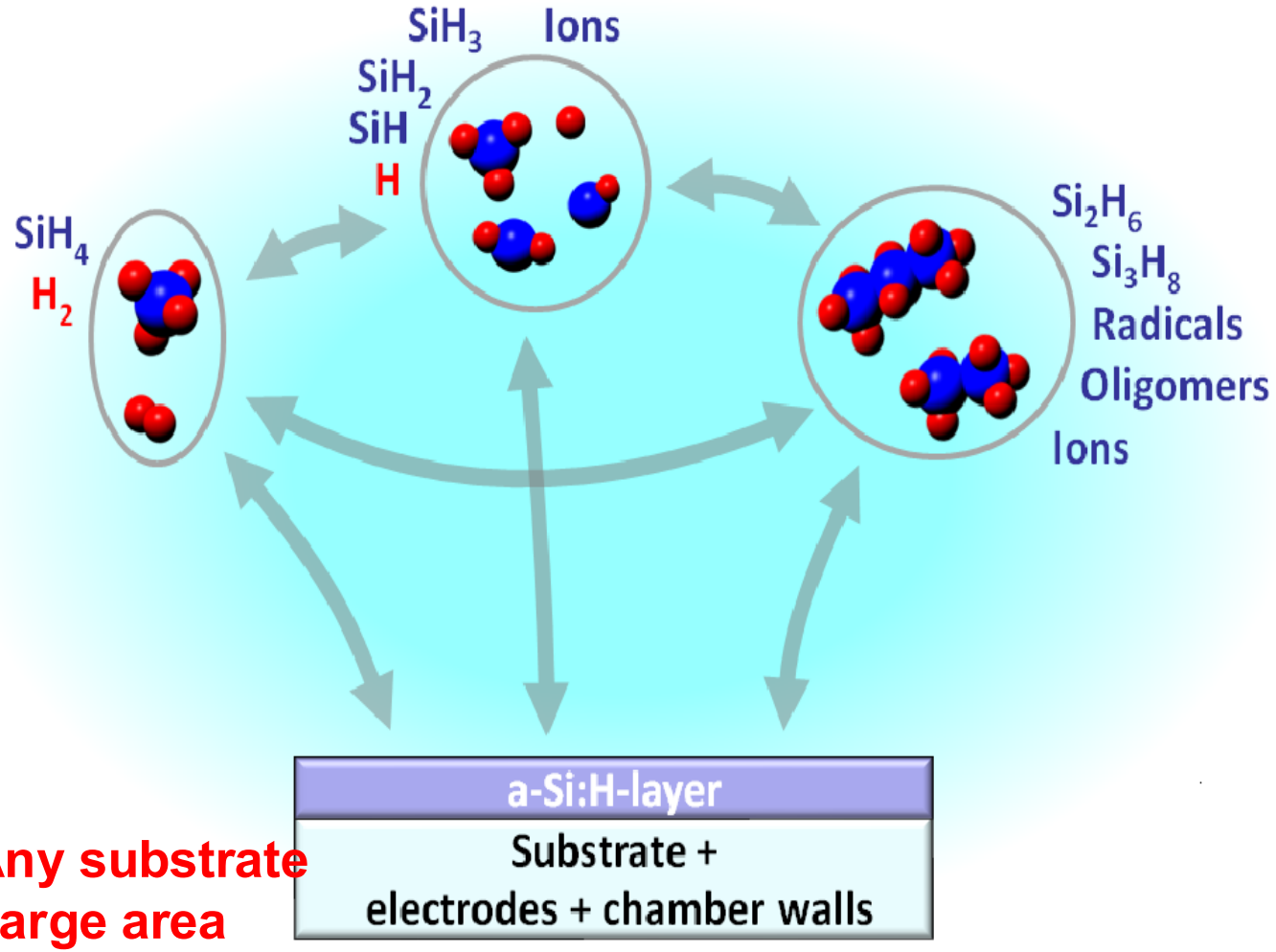




The carbonaceous material undergoes three processes: pyrolysis, combustion, and gasification

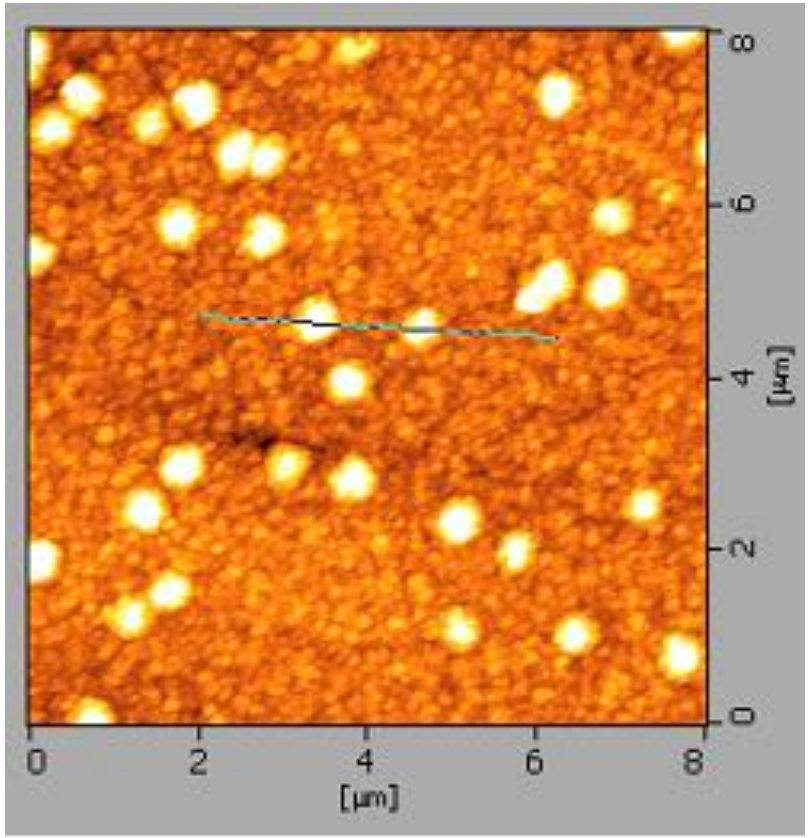


Plasma Enhanced Chemical Vapor Deposition



Any substrate
Large area
Low temperature

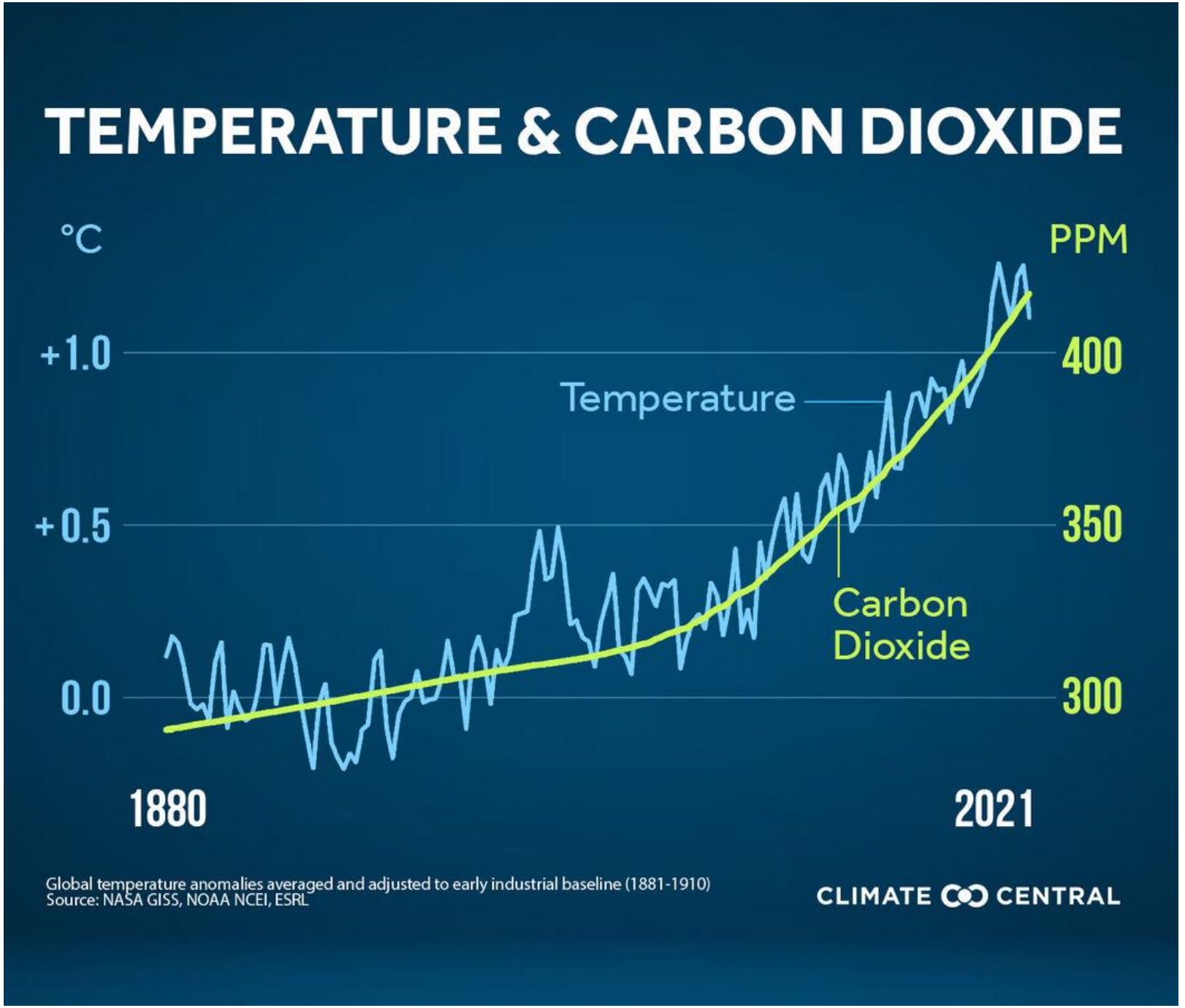
VHF PECVD enables high rate, large area deposition of device grade microcrystalline Si:H Films



C. Jariwala et.al. Applied Physics Letters 93, 191502 (2008)

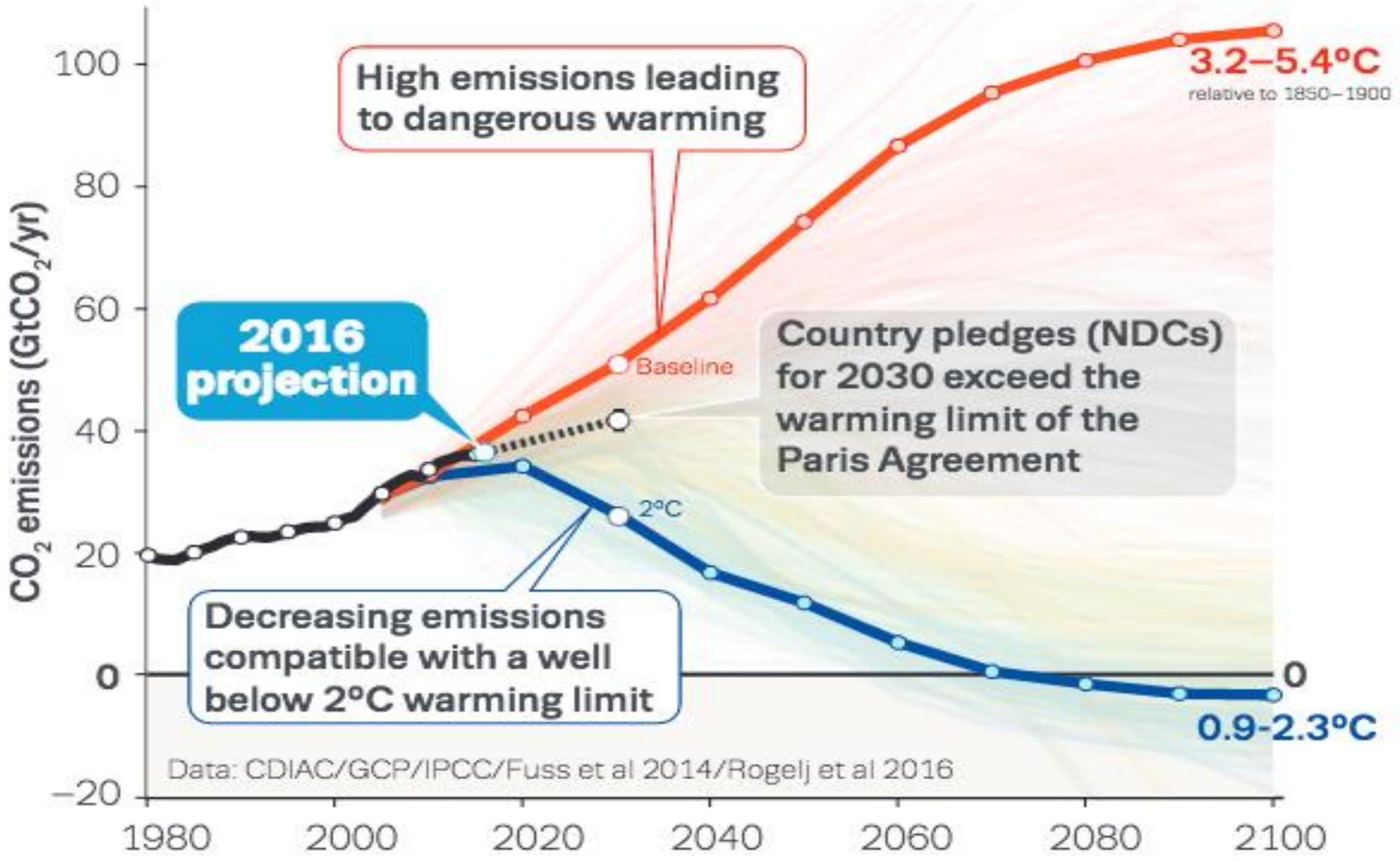
GLOBAL WARMING

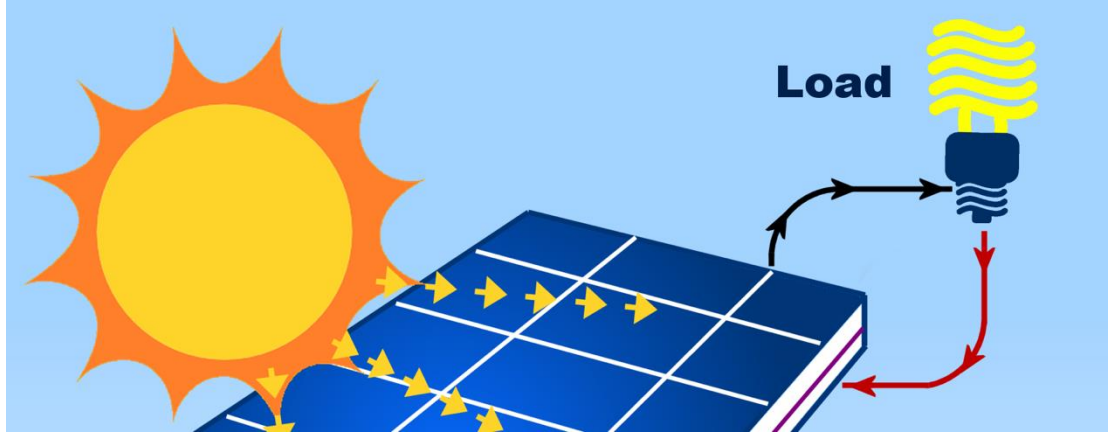
CAN PLASMA PHYSICS HELP IN ITS MITIGATION?

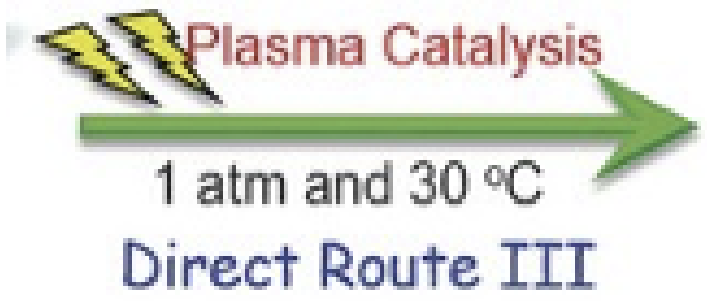


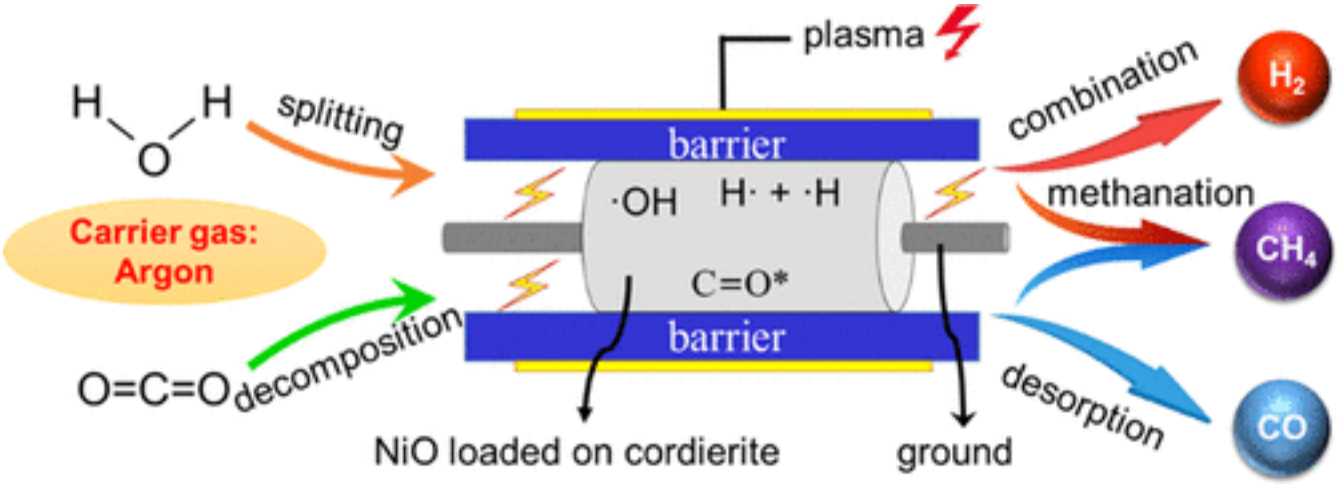
Source: Earth Syst. Sci. Data, 8, 1–45, 2016 Global Carbon Budget 2016 Corinne Le Quéré et. al.

YEARLY CO2 EMISSIONS IN GIGATONNES PER YEAR









Plasma processes driven by Solar Energy can to convert CO2 into fuels, enabling a sustainable fuel cycle.

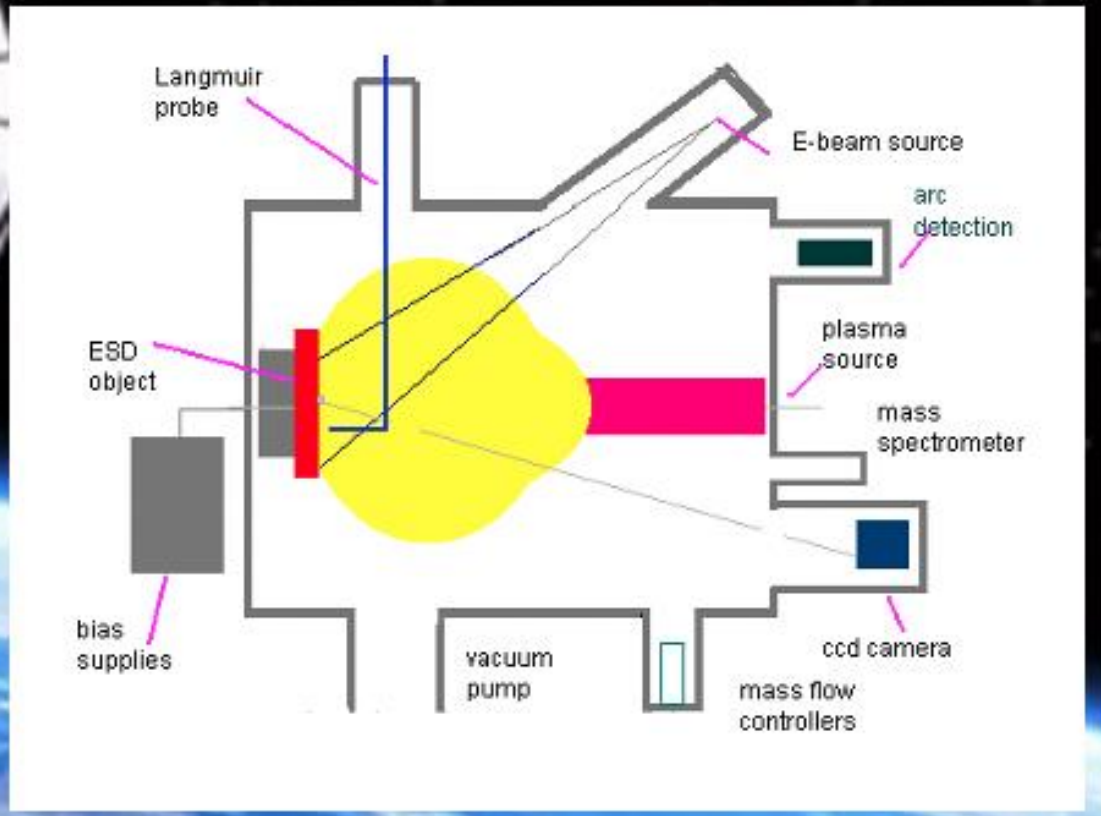
It will also allow us to continue using the abundant Hydrocarbon resources.

There are unexplored possibilities like Plasma Catalysis, which may further increase the energy efficiency and through put of the Plasma Process..

Space-Quality Plasma Nitriding System Installed at IISU Thiruvananthapuram

Satellites in orbit are embedded in a plasma environment and the charging due to energetic electrons raise their potential over the plasma potential. The prolonged high potential state leads to arcing damaging the solar panel.

SPIX Facility

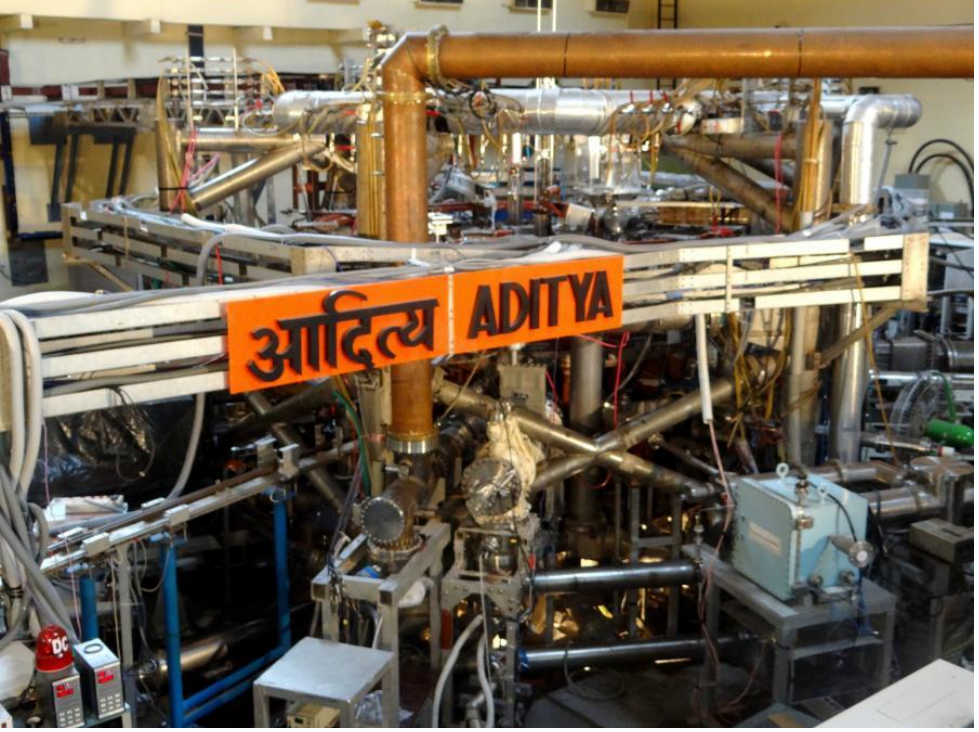


Institute for Plasma Research is an autonomous Institute under the Department of Atomic Energy, Govt of India: National Centre for Plasma Physics, Fusion Research and Plasma Applications

Facilitation Centre for Industrial Plasma Technologies links IPR with Industry

ITER India coordinates India's commitment to ITER

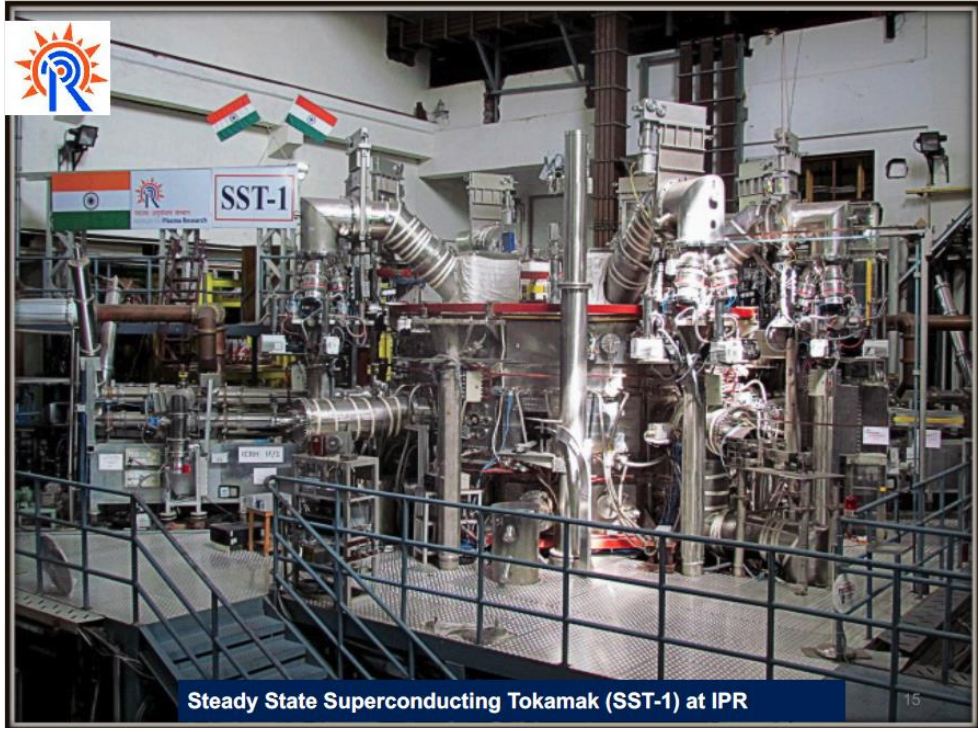
Plasmatech Innovation Foundation

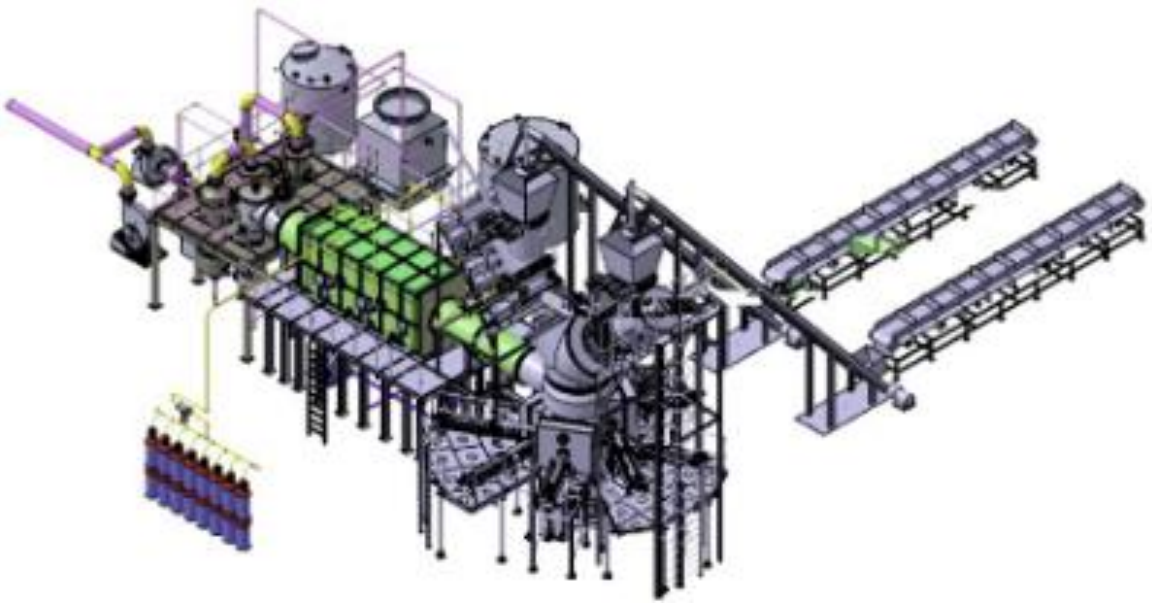


ADITYA Tokamak
1990

SST-1 Tokamak
2002

Plasma Pyrolysis
System for
Medical Waste
Destruction





I invite all of you to visit the Plasma Exhibition being set up here
And share with us the excitement of witnessing futuristic technologies.

Thank you!