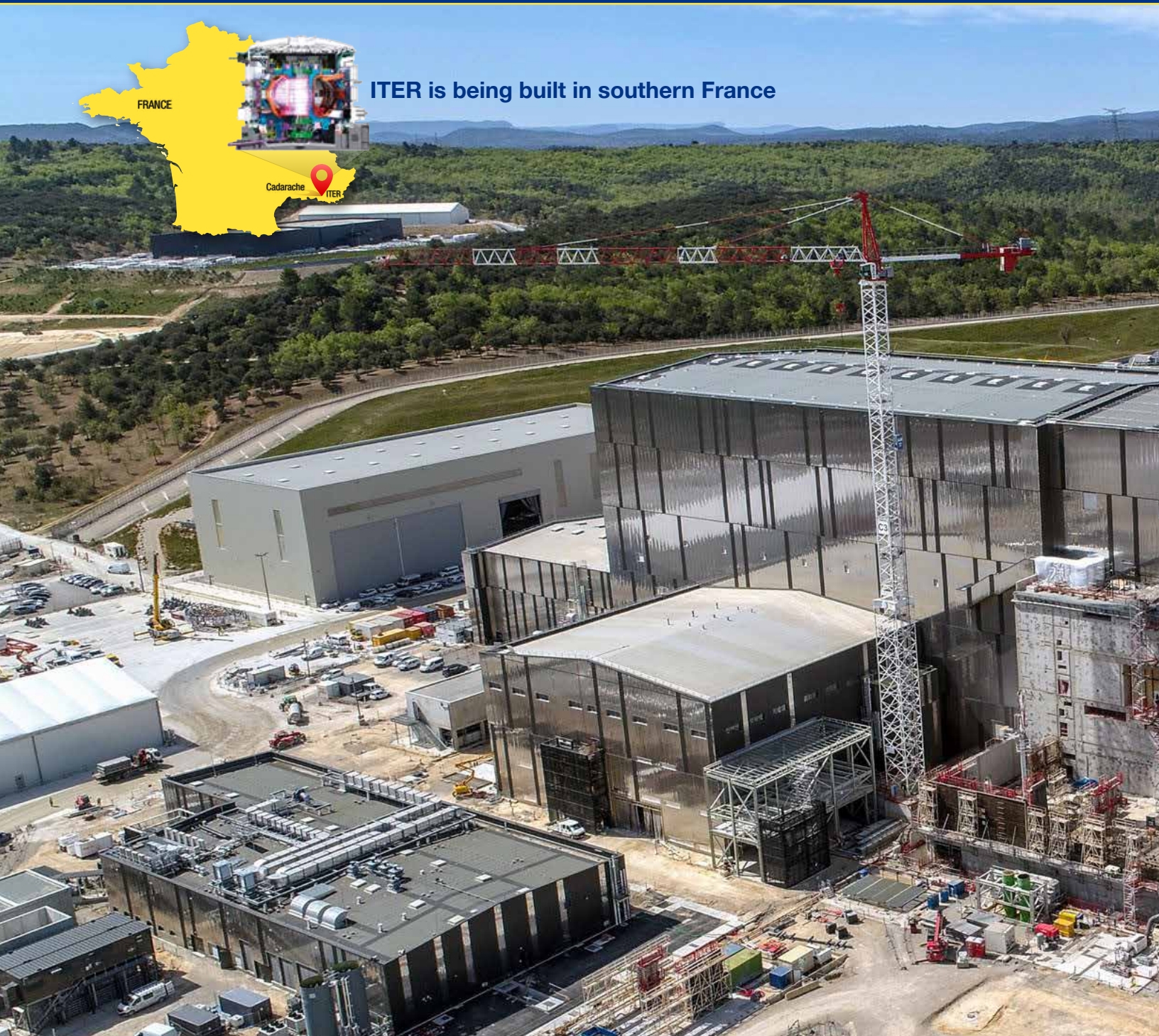


# ITER Central Solenoid

Building the World's Largest Pulsed  
Superconducting Magnet

# What is ITER?



ITER is being built in southern France

- World's largest scientific experiment being built by a partnership of 35 nations
- Plasma physics experiment to demonstrate the technological and scientific feasibility of magnetic fusion

# What Will ITER Do?

Photo credit: ITER Organization, May 2021

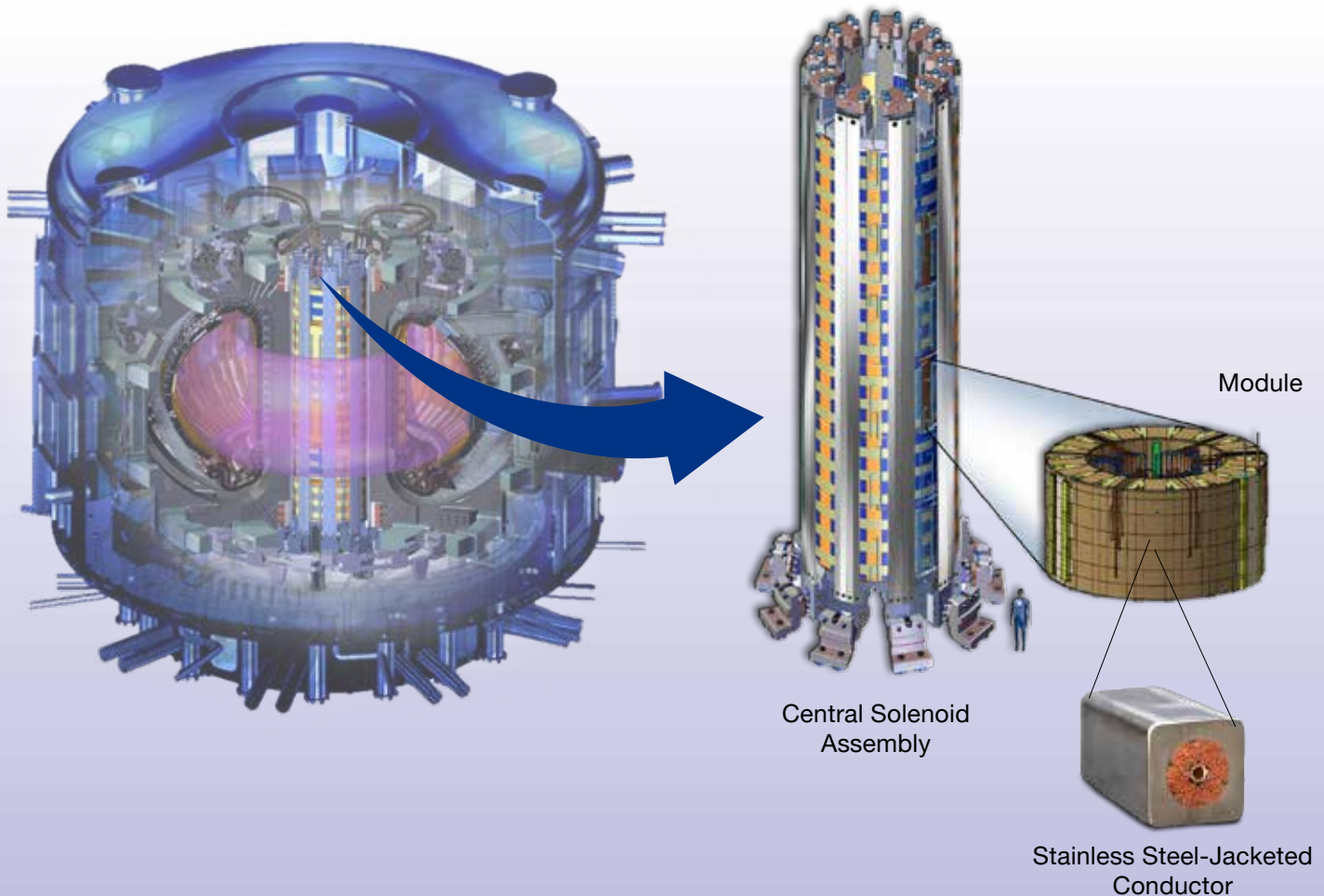


- Produce 500 MW of power, which is 10 times the input heating power
- Demonstrate the integrated operation of technologies for a fusion power plant
- Achieve a deuterium-tritium plasma in which the reaction is sustained through internal heating
- Test tritium breeding

# ITER Central Solenoid

The heart of the international fusion energy device

The Central Solenoid is the heart of ITER. The 5-story, 1,000-ton magnet will drive 15 million amperes of electrical current in ITER's fusion plasma for stabilization. General Atomics (GA) is fabricating the modules in a dedicated facility in San Diego, CA.



## CENTRAL SOLENOID ASSEMBLY

- 6 modules
- Height: 59 feet (17.7 meters)
- Diameter: 14.1 feet (4.3 meters)
- Weight: 1,000 tons (900 tonnes)
- Peak field strength: 13.1 Tesla
- Stored energy capacity: 5.5 gigajoules

## EACH MODULE

- 250,000 lb. (110-tonne)
- Height: 7 feet (2.1 meters)
- Diameter 13.6 feet (4.1 meters)
- 3.6 miles (5.8 kilometers) of steel-jacketed conductor
- Conductor wound into 40 layers

# Central Solenoid Module Fabrication

Flows through 10 custom-built process stations

It takes 22-24 months to manufacture each coil and prepare it for full current testing at 4.7 K



**Station**  
**1**

Conductor Receiving Inspection



**Station**  
**2**

Winding



**Station**  
**3**

Joint & Terminal Preparation



**Station**  
**4**

Stack & Join/Helium Penetrations



**Station**  
**5**

Reaction Heat Treatment



**Station**  
**6**

Turn Insulation



**Station**  
**7**

Ground Insulation



**Station**  
**8**

Vacuum Pressure Impregnation



Turn Over Tool



**Station**  
**9**

Helium Piping



**Station**  
**10**

Final Test

# Central Solenoid Fabrication Facility



- 6,000 sq. meters of temperature-controlled production space
- 0.6 meters thick concrete floors
- 1MW diesel generator
- 1MW cooling tower
- Liquid argon, liquid nitrogen, & liquid helium systems
- Gantry & bridge cranes
- Two 100+ horsepower air compressors



Production Facility Under Construction



Completed High Bay



Final Test Facility

# Receiving the Conductor



One of 54 spools of conductor received at the Central Solenoid production facility



Unloading a conductor spool from the delivery



Conductor spools stored prior to winding



# Moving Module Between Stations



Moving 250,000 lb. (110-tonne) module in facility requires air transporter

## Station 2

# Winding the Module



Each Central Solenoid module is fabricated from approximately 6,000 meters of niobium-tin ( $\text{Nb}_3\text{Sn}$ ) conductor. The production module segment here is wound from 900 meters of conductor into 14-turn pancakes with six layers.



Bending to the required shape



Two spools loaded for winding

# Station 3

## Joint and Terminal Preparation



Wound six-layer submodules ready for terminal preparation



Terminal lead nearing completion



Conductor strands prior to chrome stripping



Conductor strands after chrome stripping

# Joining Coil Segments Together



Two hex submodules prepared prior to joining



Module with six completed splice joints



Splicing the conductor cable together similar to splicing a rope



Welding stainless steel cover over the splice joint



## Six ITER CS modules in different fabrication stages:

- 1 Post resin injection on VPI station
- 2 Piping complete and ready for final test
- 3 Ground insulation
- 4 Post heat treatment
- 5 Stack and Join
- 6 After thermal cycle and power testing



4

5

6

# Reaction Heat Treatment



Placing module in furnace for heat treatment at 650°C (1200°F)



Technician inspecting module after heat treatment



Furnace closed for module heat treatment



# Turn Insulation Station



Turn insulation station structure lifts and raises 110-tonne module and releases individual turns for insulation wrapping



Turn insulation of module nearing completion



Automated heads wrapping fiberglass tape around the conductor

# Ground Insulation Station



Helium inlet pipe with ground insulation



Module during ground insulation application

Technician inspects helium outlet pipe insulation on a completely insulated module

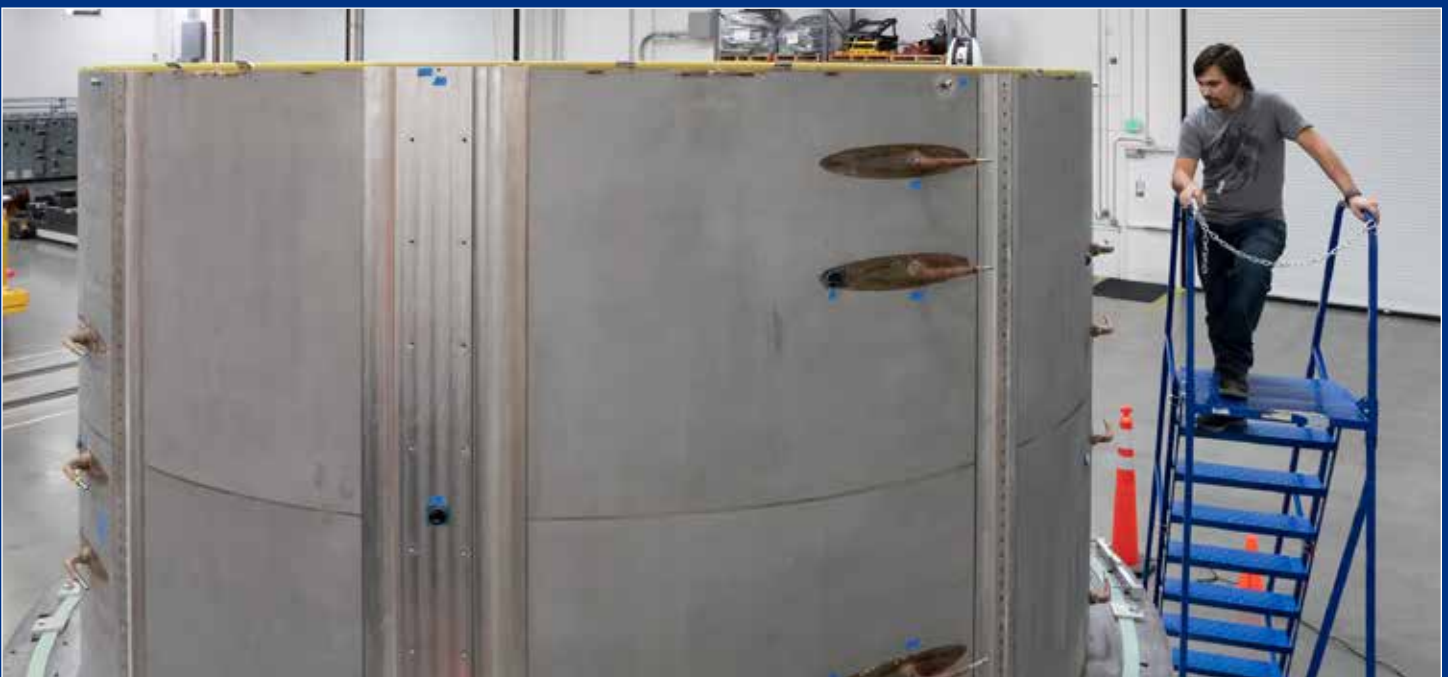
# Vacuum Pressure Impregnation



VPI mold being placed over the module in preparation for resin injection



Module mold alongside resin tanks and mixing pump system for injecting 3,500 liters of resin to encapsulate the module



Completed module after resin injection

# Turnover Tool



Modules require rotation to exchange bases under coil and allow access for piping installation



Turnover of module in process

# Helium Piping



Technician applying insulation to piping on inner bore



Thirty-nine helium pipes welded and insulated to provide the supply and return for supercritical helium at 4.7 K



Module after piping installed

# Final Testing



Module in final test chamber with camera system installed ready to begin high voltage testing



1 kW supercritical helium supply system used for cooling the CS modules to 4.7 K



Module in final test chamber



50kA magnet charging power supply with 1GJ fast discharge system including 7kV DC switch and dump resistor for full-current testing of CS modules

# Preparing module for shipment



Preparation for Shipment





# Loading module for transport



Lowering module into the 24-axle super-heavy trailer



Setting the module inside the cradle



Locked down and ready to go



# Transporting module to port in Houston, TX

Houston





**If you have unique, precise superconducting magnet fabrication needs, contact us:**

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