The Australian ITER Forum is a network of over 180 scientists, engineers, research administrators and policy specialists advocating sustainable Australian engagement in ITER, the experimental fusion reactor that is now being built in France. Fusion is the process that powers the Sun and the stars. If realised on earth, fusion energy offers millions of years of base-load energy generation, with almost no greenhouse gas emissions and insignificant amounts of radioactive waste compared to nuclear fission energy and fly-ash from coal.

The Forum is pleased to have this opportunity to provide this submission to the Inquiry. Our submission builds on submissions made to the 2006 Uranium, Mining, Processing and Nuclear Energy Review and the 2014 submission to the South Australian Nuclear Fuel Cycle Royal Commission. In 2014, the Forum, together with the Australian National University (ANU) and the Australian Nuclear Science and Technology Organisation (ANSTO) released a $16.3m strategic plan for fusion research in Australia: “Powering Ahead: A National Response to the Rise of the International Fusion Power Program”. The plan, focuses on international collaboration, and features dedicated programmatic support for Australians to take part in the International Tokamak Physics Activity, which operates under the auspices of ITER, the development of an Australian diagnostic on ITER, and a new capability for fusion materials studies involving the ANU, ANSTO and the University of Newcastle. Theoretical modelling of the fusion plasma interaction with first walls is being undertaken through a series of coordinated research projects at Curtin University of Technology, while the University of Western Australia has recently expanded into mathematical modelling of fusion plasmas.

Elements of this plan have now been realised. The 2016 signing of a collaboration agreement between ITER and the Australian Nuclear Science and Technology Organisation (ANSTO) enabled Australians to participate in the programmatic research framework for ITER science, the Integrated Tokamak Physics Activity (ITPA). Australia now has two prestigious ITER Science Fellows (A/Prof. Hole, Em. Prof. Howard). Five Australians are now expert members of the ITPA (Corr, Hole, Howard, Michael, Thompson) and three implementing agreements have been signed under the collaboration agreement. In March 2019 a team led by Em/ Prof. Howard completed a conceptual design review of a proposed Australian Coherence Imaging diagnostic for the ITER boundary, and in April the first ITPA meeting (in Diagnostics) was held outside of the ITER member states, at the ANU. In 2021 Australia will host the 17th International Atomic Energy Agency Technical Meeting on Energetic Particles in
Magnetic Confinement Systems and Theory of Plasma Instabilities, and the associated ITPA meeting in Energetic Particles.

Substantial long-term Australian participation in the ITER project and wider research activity requires a combination of targeted funding to support ITER collaboration and dedicated institutional support. This is best accomplished by supporting the funding components of the fusion science strategic plan. At a minimum to maintain competency in the field, programmatic support is required for Australian participation in the ITPA and employ Australian scientists in this field.

Beyond ITER the broader international fusion research program includes the W7-X €1bn stellarator (a German reunification project), the similarly-costed JT60-SA (a new Japan-EU experiment currently under construction as part of the ITER Broader Approach), the $USD350 million KSTAR experiment (South Korea), and ongoing and significant expansion of research investment in China (2 major new toroidal fusion devices within the last decade, at least three smaller machines, a theory and modelling centre, and several training programs, and the longer-term Chinese demonstration fusion reactor “DEMO” program.) These provide rich new collaboration opportunities to lever Australian science investment.

Our ability to access opportunity is however at risk. The widely supported International Science Linkage scheme for Australian participation in international science has not been renewed. Like other nations, Australia has decommissioned its plasma fusion experiment to better accommodate fusion-materials studies, which are much more internationally competitive at lower cost. National Collaborative Research Infrastructure funding that would otherwise support this transition has however not been renewed. The combination has left Australia at risk of losing our fusion research and technical capability during a global renaissance in the field of fusion research, and at a time when others are developing proof of principle power plant designs. Should these efforts prove the feasibility of fusion power, its adoption in Australia remains prohibited under the nuclear energy act.

Australia cannot afford to lose capability in this internationally strategic research field by neglect. We would be willing to provide more detail to the Inquiry and/or appear in person. Further detail on ITER and the international research program is furnished in the appendix.

Yours Sincerely,

[Signature]

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Disclaimer: The opinions expressed herein are the views of the Australian ITER Forum, but not necessarily those of the home institutions.
Appendix

Fusion and the international research program

Nuclear fusion is the process by which elements much lighter than iron bind together and release excess energy. This is what powers the Sun and the stars. If fusion power were harnessed directly on Earth, it could produce inexhaustible clean base-load power, with a component of sea-water as the primary source of fuel. The process is free of CO2 emissions and is intrinsically safe. Fusion has no proliferation concerns: toroidal magnetic confinement fusion cannot be weaponized, and research in this field was declassified more than 60 years ago in 1958. Radioactive waste from reaction is very-low level and indirect, arising from neutron activation of the first wall. With current technology, the materials of a fusion power plant could be completely recycled within about 100 years of shutdown.

Today’s nuclear power plants exploit nuclear fission to produce electricity. In nuclear fission, elements much heavier than iron, such as uranium, thorium, and plutonium release energy by splitting into lighter daughter nuclei (or atoms). This process happens spontaneously in unstable elements, and can be amplified and controlled through a chain reaction involving neutrons.

In contrast, fusion power exploits the other side of the nuclear “valley” of binding energy per nucleon. Unlike fission, no nuclei spontaneously undergo fusion: nuclei are positively charged and must overcome, or quantum tunnel through, the electrostatic Coulomb barrier before the strong nuclear forces can bind nuclei together. In nature, the gravitational field of stars is strong enough that the stars core temperature, density and volume is sufficient to enable fusion through “quantum tunneling”. In the laboratory quantum tunneling rates are far too low, and so the Coulomb barrier must be overcome by making the fuel nuclei sufficiently hot.

The easiest fusion reaction to initiate, which was first co-discovered by Australian Sir Marc Oliphant, is the combination of deuterium and tritium, isotopes of hydrogen, to form helium and an energetic neutron. The necessary temperature is around 10 keV, or 120 million degrees Celsius. At these extreme temperatures, which are six to seven times hotter than the core of the Sun, the fusion fuel exists as ions in the state of plasma. That is, the fuel atoms are split into their component electrons and nuclei.

In the laboratory, confinement at such extremes can be accomplished through magnetic fields, where superconducting coils generate a powerful doughnut-shaped magnetic bottle. Today’s experiments can confine plasmas at the required temperatures for net power gain, but the plasma density and energy confinement time (a measure of the cooling time of the plasma) are too low to self-heat the plasma to foster plant operating conditions. Over a 50 year period of research, this fusion triple product of temperature, density and confinement time has increased by a factor of 1,000.

The next step fusion experiment, **ITER**, currently under construction in Cadarache in the south of France, will explore the “burning plasma regime”, where the plasma heating from the confined products of fusion reaction exceeds the external heating power. The total power gain for ITER will be more than 5 in near continuous operation, and approach 10-30 for a short duration.

At a cost exceeding USD$30 billion, and funded by a consortium of 7 nations and alliances, ITER is the largest science project ever undertaken. The purpose of ITER is to demonstrate the scientific and technological feasibility of generating fusion power for peaceful purposes (principally electricity generation).

The engineering, physics and materials challenges are significant. ITER will have a field strength of 5 Teslas on axis (1,000 times stronger than typical refrigerator magnets) and a device radius of 6 metres, confining 840 cubic metres of plasma (1/3 of an Olympic swimming pool). **ITER** will be a
23,000 ton device with 100,000 kilometres of niobium tin superconducting strands. Niobium tin is superconducting at 4.5 K=-268.5 Celsius, and so the entire machine will be immersed in a liquid helium cooled cryostat. The construction of ITER is now 63% complete.

ITER first plasmas are, at present, envisaged in Dec. 2025. Burning plasma experiments, planned from 2035, will be the first experiments to be dominantly heated by fusion-generated helium particles. Accessing, maintaining and controlling this state, while avoiding performance-limiting instabilities such as large Edge Localised Modes (ELMs) or Alfvénic eigenmodes that cause fast ion loss is a grand science challenge. So called “Type I” ELMs have the capacity to deposit up to 10% of the stored energy of the plasma on the divertor. Unmitigated, they could melt the divertor target in as little as a single pulse. The materials challenge for successor power plants is to develop materials that can withstand extreme heat fluxes of 10-100 MW per square metre (10,000-100,000 times solar irradiance) and maintain resilience to a high flux of 14 MeV neutrons.

Information obtained from building and operating ITER will inform the design of successor power plants. The commercialisation path of fusion power envisages multiple prototype demonstration power plants, constructed in the 2040’s. Concept designs are typically 1 GW electric, and 3 GW thermal. While first generation power plants will probably be the size and scale of ITER, it is hoped that improvement in magnetic confinement and turbulent control will lead to more compact later generation power plants. Likewise, power plants will be lower cost than ITER: long-term economic modelling forecasts the construction, fueling and operation costs of fusion power being similar to fission, and external costs to the environment comparable to wind.