
Fusion Energy

The key to the future energy
architecture

September 2023



Key takeaways



Global problem and radical solution

The current rate of global renewable energies development makes emission-free energy supply by 2050 unlikely. Without radical new approaches, the Paris climate targets will be missed. Fusion energy may be the missing key to achieving a sustainable energy architecture in time. The combination of rapid commercialization of fusion energy and the fastest possible renewables build-out might make the Paris goal of Net Zero by 2050 finally achievable



Decisive advantage

As the first climate-neutral energy source, fusion is also base-load capable and readily scalable. The raw materials required for operation are available worldwide and are sufficient for secure and affordable electricity oversupply. In the long term, the energy costs from fusion are expected to be below those of today's renewables



Why only now

New breakthroughs in materials, computing and laser research are making the remaining challenges increasingly manageable and bringing the "Holy Grail" of energy generation within reach. Progress is reflected in rapidly increasing private investment in commercial fusion startups. With modern approaches and faster innovation and decision cycles, they are aiming for a much earlier breakthrough than government research: Their ambition is to realize fusion energy in the 2030s



Strategy

Countries are now positioning themselves for the race to the first commercial use of fusion. In Germany, the Federal Ministry of Education and Research (BMBF) published a strategy paper on fusion energy in June 2023. Germany's position in this regard is (time-)critical right now. In academic research, the country holds a leading position - but in entrepreneurial terms, it is about to be left behind. Therefore, bold action is needed now. A national fusion energy strategy can turn this position into an agenda for success and could develop fusion into an engine for the German economy

Forecasts show: The global expansion in renewable energy is not sufficient for emission-free power generation by 2050

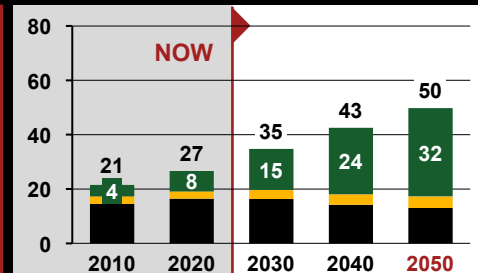
The renewables expansion only covers additional demand – society remains dependent on fossil power sources

Global demand for electric energy in PWh and the expected coverage by source:

STEPS: Stated Policies Scenario¹

Conservative scenario
("Realistic path")

of the International Energy Agency

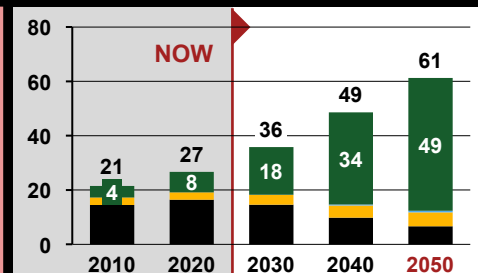


- **2050:** Electricity demand increase by **+85%** over today
- Renewables expansion of **+300%** required
- Fossil power sources remain **at current levels**

APS: Announced Pledges Scenario¹

Moderate scenario
("Statement of intent")

of the International Energy Agency

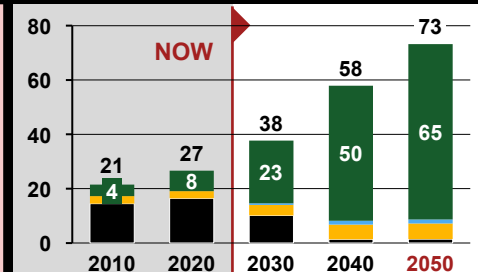


- **2050:** Electricity demand increase by **+130%** over today
- Renewables expansion of **+550%** required
- Fossil power sources **at 50% of today's levels**

NZE: Net Zero Emissions by 2050¹

Ambitious scenario
("Desired target")

of the International Energy Agency



- **2050:** Electricity demand increase by **+190%** over today
- Renewables expansion of **+750%** required
- Almost no more **fossil fuel power sources**

Electricity from renewables From hydrogen etc. From nuclear energy From fossil fuels

An inconvenient truth:

Today's global renewable energy expansion rate of ~3.3 PWh of energy per decade² makes a net-zero-emission energy supply by 2050 (net zero scenario) unlikely

Without radically new approaches to the transformation of the global energy architecture, the Paris climate targets will be missed by a significant margin

Fusion energy may be the missing key to a sustainable, sufficient and affordable energy supply

Potential solution:

Fusion energy may be the missing key to timely realization of a sustainable energy architecture

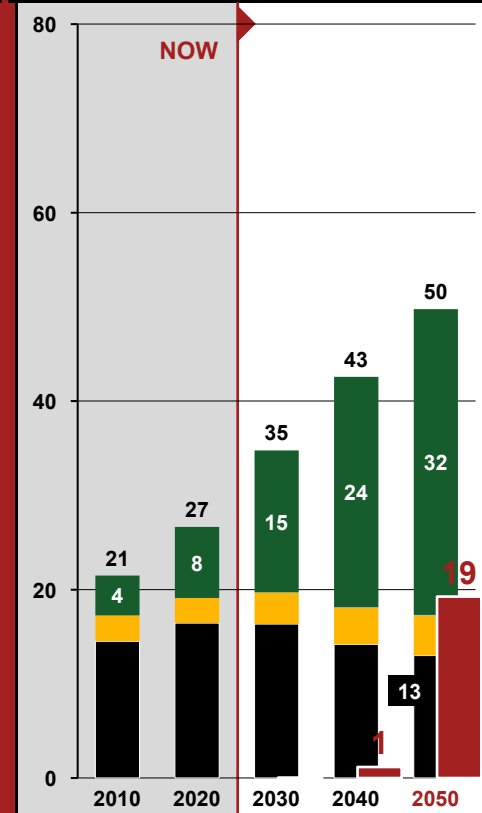
The combination of rapid commercialization of fusion energy and the fastest possible expansion in renewables makes the Net Zero by 2050 goal of the Paris Climate Agreement finally achievable

Global demand for electric energy in PWh and the expected coverage by source:

STEPS: Stated Policies Scenario¹

Conservative scenario
("Realistic path")

of the International Energy Agency



- **Conservative STEPS scenario:** "realistic renewables expansion rate" and "therefore high dependency on electricity from fossil sources".
- Ramp-up of **fusion at equivalent rate as nuclear energy** in the 20th century, from commissioning of first power plant in 2030s

• **2050:**

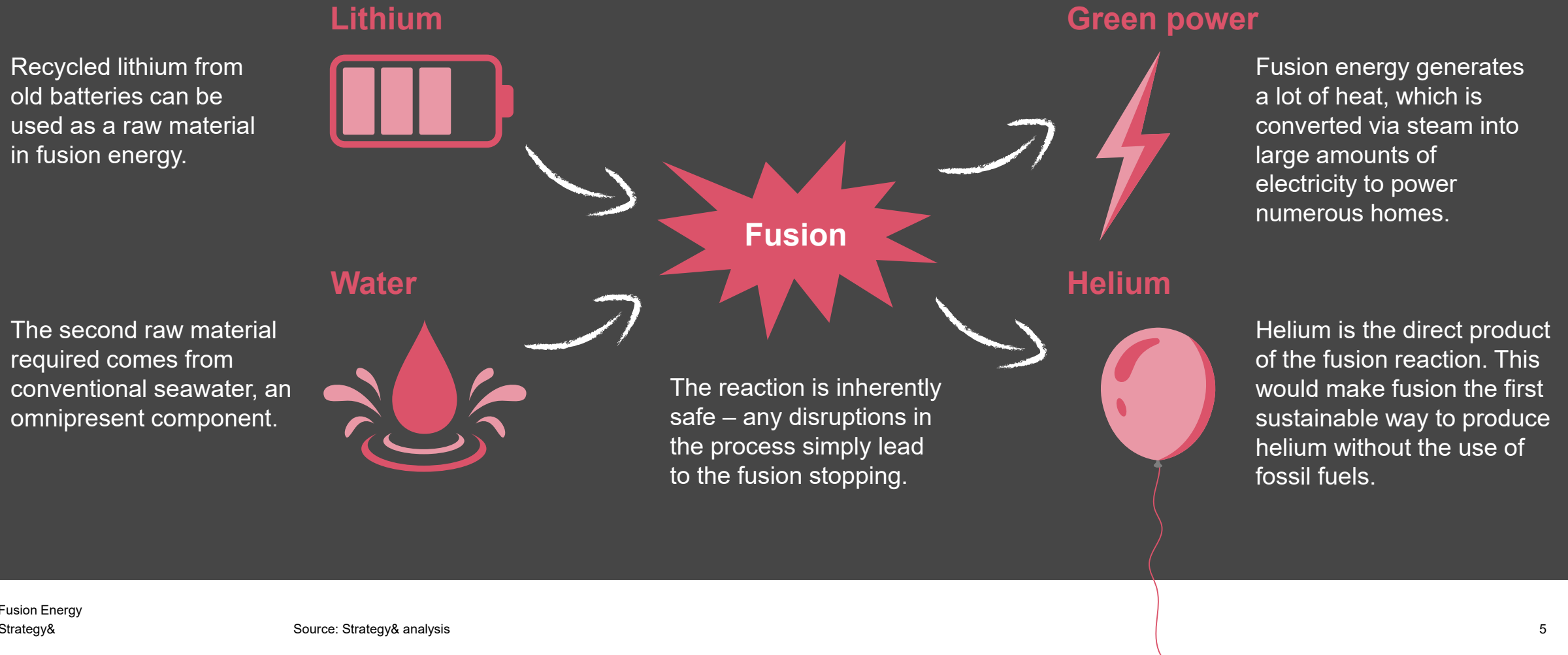


Fusion energy can end residual dependence on 13 PWh of electricity from fossil sources by 2050.

Electricity from fusion energy
Electricity from renewables
From hydrogen etc.
From nuclear energy
From fossil fuels

Fusion energy: What is that? – The principle, simply explained

The “fusion” of the raw materials lithium and water produces a lot of green electricity and helium



Why only now: New technologies might bring the “Holy Grail” within reach

Breakthroughs in materials, computing, and laser research

Technological and social megatrends drive progress: Scientific know-how meets society's need for a non-restrictive supply of sustainable and affordable energy.

High-temperature superconducting magnets



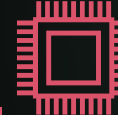
- New generation of high-performance magnets: Most important mechanical reactor component
- Superconducting at much higher temperatures and thus for the first time both significantly more powerful and more efficient in operation

Artificial intelligence



- In R&D, AI significantly accelerates innovation cycles for designing new materials and processes
- In operation, for the first time AI enables complex optimization and control of parameters in real time

High-performance and quantum computers

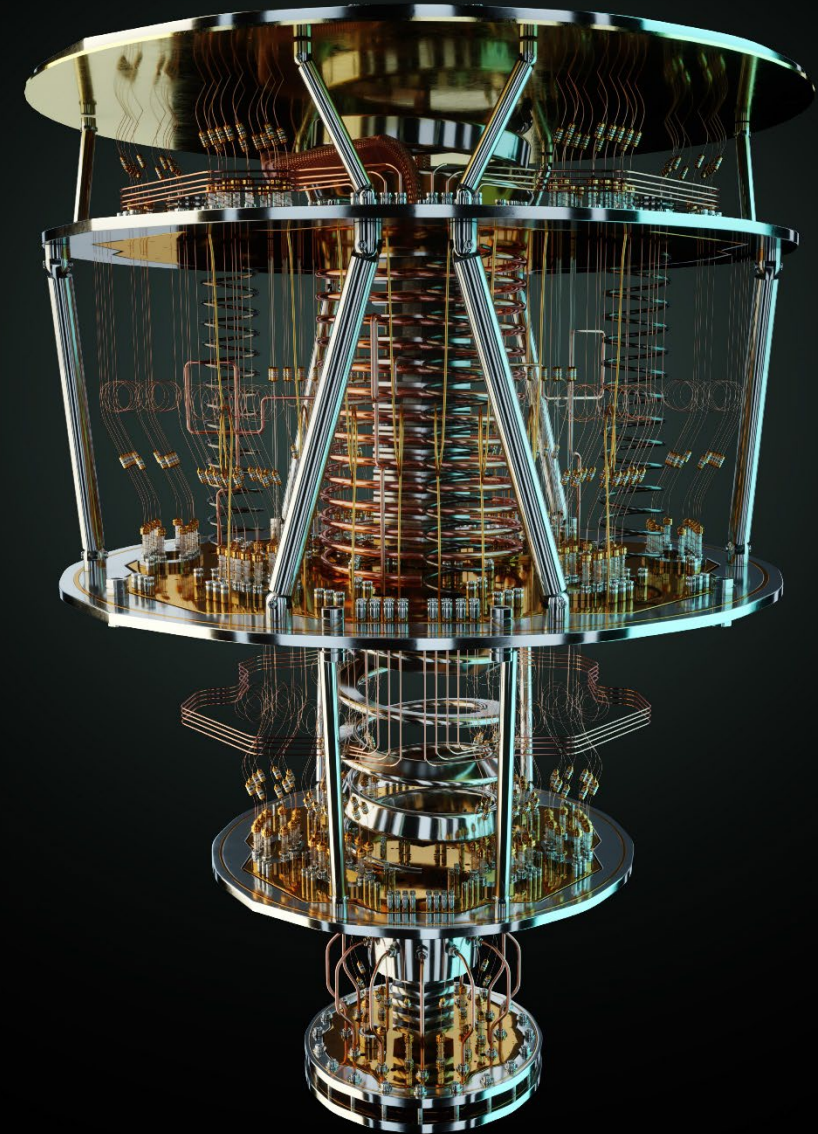


- Too-complex-to-handle control of fusion reactors has been a deal-breaker so far
- Computing power increasingly reaches required levels
- Quantum computers can enable unprecedented parallelization of control tasks

High-power lasers



- Significant increase in laser peak power (by a factor of 20 in a decade^{1,2}) in a more compact package enables new designs for inertial fusion
- Simultaneously, laser power costs have reduced rapidly (by a factor of 200 per PW power in a decade^{1,2})



Thus, countries are increasingly positioning themselves for the race to the first commercial use of fusion energy

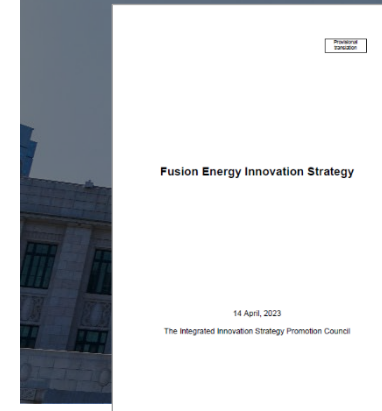
UK, USA, Japan, and most recently Germany too, have published initial strategy papers on fusion energy



United Kingdom

1 October, 2021¹

Strategy on building domestic fusion industry, commercial demonstration, creation of a legal framework, and promotion of public-private partnerships.



Japan

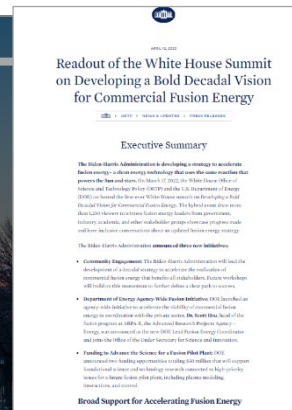
14 April, 2023³

Commercialization through strategic and financial promotion of domestic high-tech industries, creation of a legal framework, and promotion of public-private partnerships.

United States

19 April, 2022²

Accelerated commercial implementation, collaboration of government and private innovation, coordination by US Dept. of Energy, increased financial subsidies.



Germany







23 June, 2023⁴

Building a “fusion ecosystem” and “technology hubs”, creation of a legal framework, and promotion of public-private partnerships.



The decisive advantage over existing renewables: Fusion energy is simultaneously base-load capable and easily scalable

Today, only fossil energy is base-load capable, only renewables are emission-free.
Fusion is the first to manage the balancing act

	 Coal	 Natural gas	 Hydro	 Wind	 Solar	 Fusion
Environmental impact	✗	●	✓	✓	✓	✓
Resource requirements (construction)	●	●	✗	●	●	●
Resource requirements (operation)	✗	✗	✓	✓	✓	✓
Dependency (on outside EU)	✗	✗	✓	●	✗	●
Scalability	●	●	✗	✓	✓	✓
Base-load capability	✓	✓	✓	✗	✗	✓

✓ Low ● Medium ✗ High



No greenhouse gas emissions



Only base-load capable renewables technology



Availability independent of weather and time of day



Fusion fuel can be obtained domestically

The amount of energy from raw materials for fusion available worldwide is sufficient for secure and cheap energy oversupply

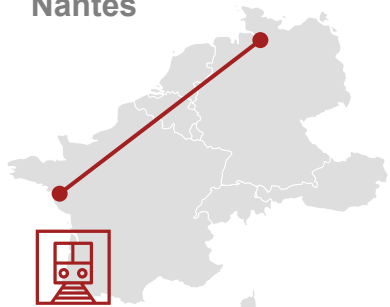
The smallest quantities are sufficient to cover our entire electricity demand:
Resource requirements for a “typical” 1,000 MW power plant



Coal

3.2 million tons annually

... or a freight train as long as Hamburg to Nantes



1,100 km length



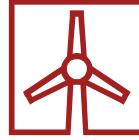
Natural gas

1.3 million tons annually

... or a freight train as long as Hamburg to Istanbul



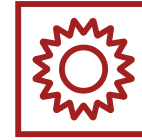
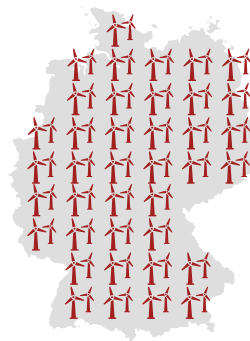
1,900 km length



Wind

250 turbines (4MW onshore class)

... or as much as Germany currently builds in four months



Solar

34 million m² of photovoltaics

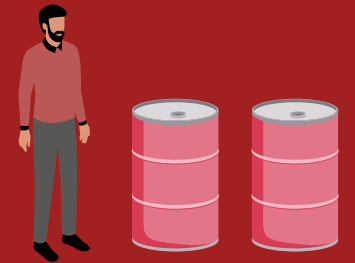
... or the total surface area from Berlin's Mitte district



Fusion

250 kg fuel annually

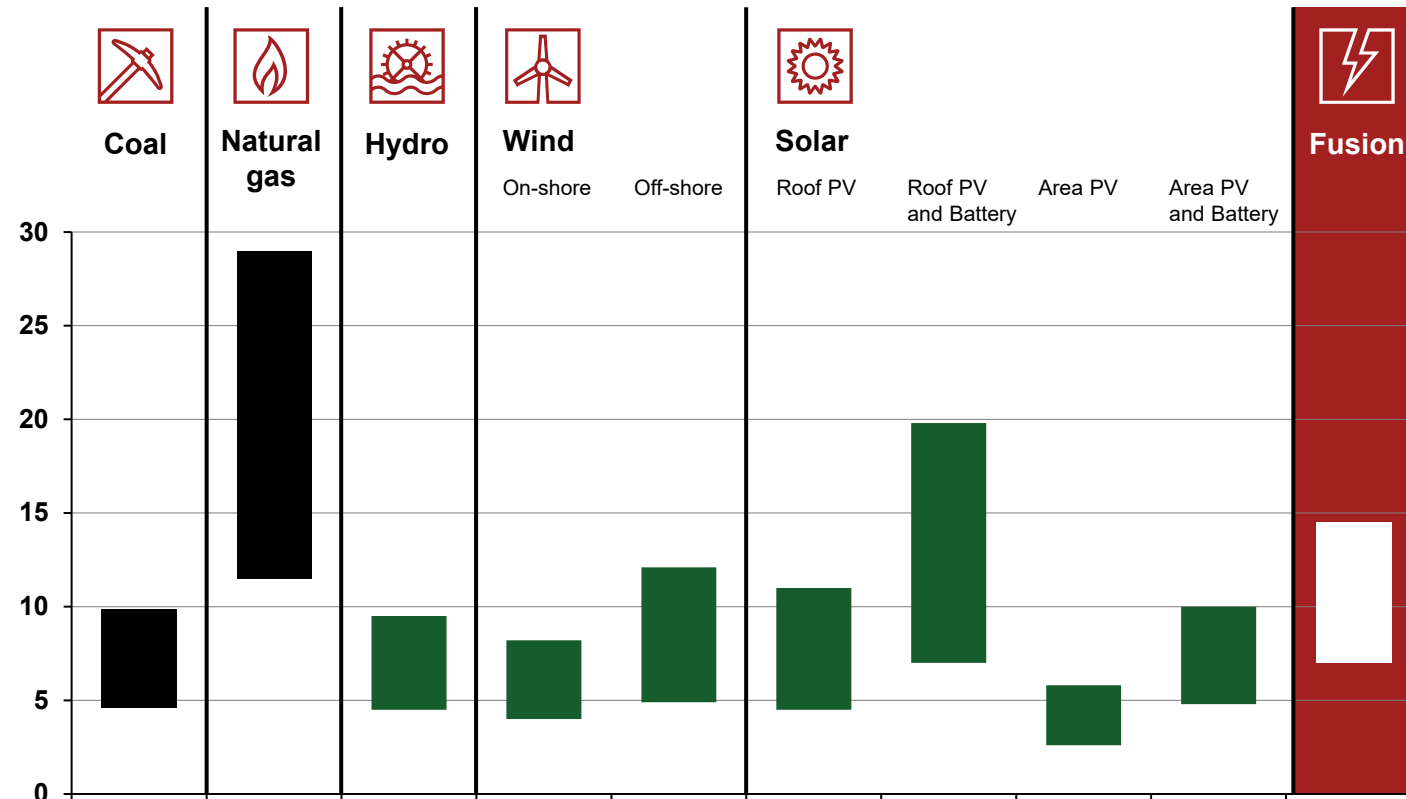
... or a single transport load to the power plant



Economies of scale can make it possible: Prices for electricity from fusion at the level of renewable energies – or even lower

Development and construction comprise over 70% of fusion's lifetime costs³ – with expansion, these will decrease significantly

Levelized cost of electricity¹⁻⁵ in € cents/kWh (lifetime costs of electricity in generation)



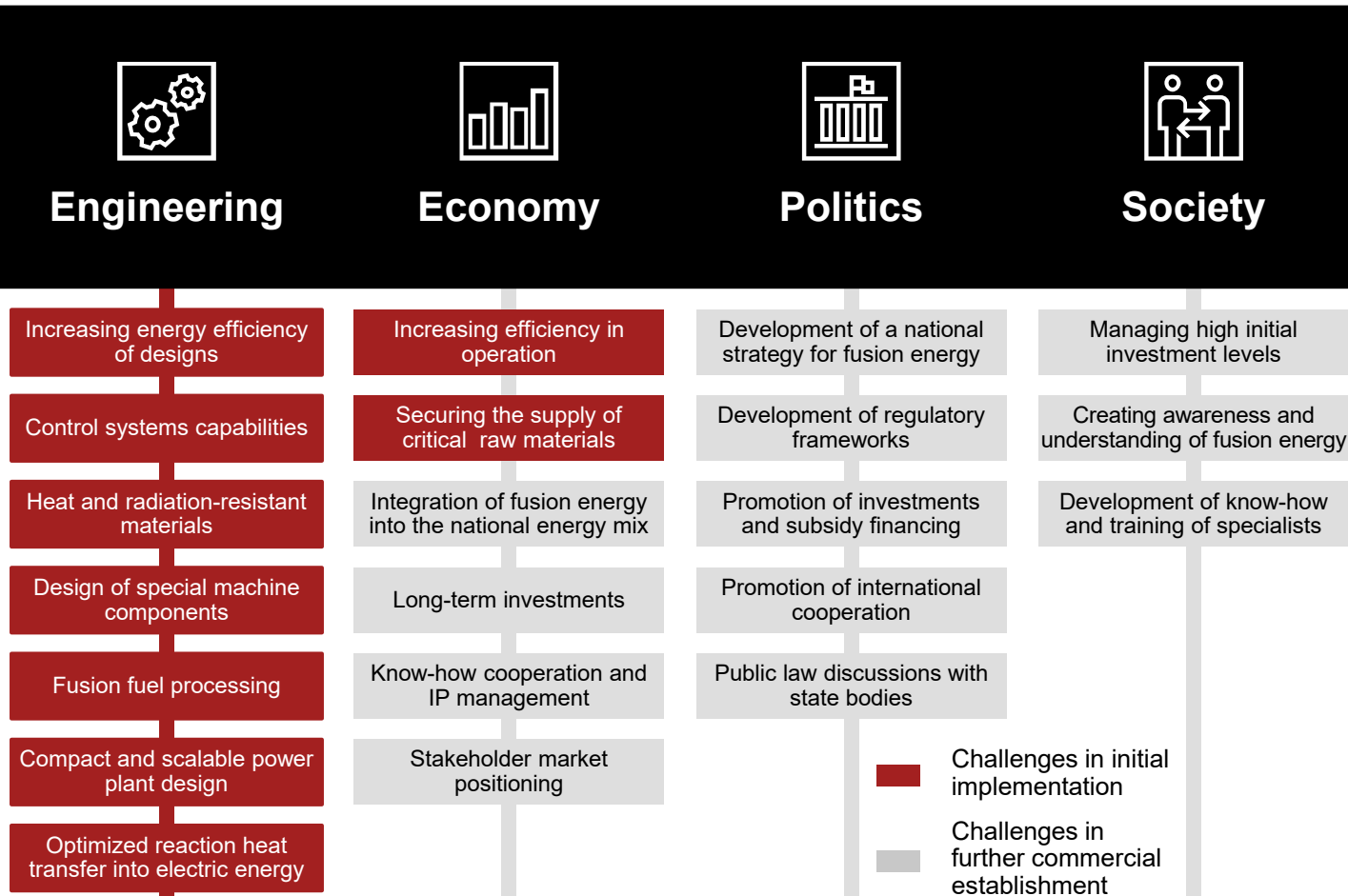
Current studies² expect fusion energy to achieve **electricity prices** comparable to **those of today's renewables**.

Small commercial fusion designs – and thus lower initial investment volumes – may even enable **electricity prices below today's renewables**.

As technology matures, fusion (like all other sources of energy technology with low operating costs) will decrease in cost after the initial investment.

For comparison, costs for electric energy from wind have fallen by 70% and from PV by 90% in recent years⁴.

The remaining challenges until fusion's commercial maturity are expected to be manageable with technology available today



There are still a number of challenges to be solved before the first high-performance fusion power plant can be built – these mostly include engineering tasks.

The current focus is on building a reactor that generates more electricity output than it consumes in continuous operation (“demonstration reactor”).

As with previous major technology breakthroughs – mankind’s first flight, first nuclear power – the demonstration can radically accelerate further developments like a spark.

For interested readers, all the details at a glance

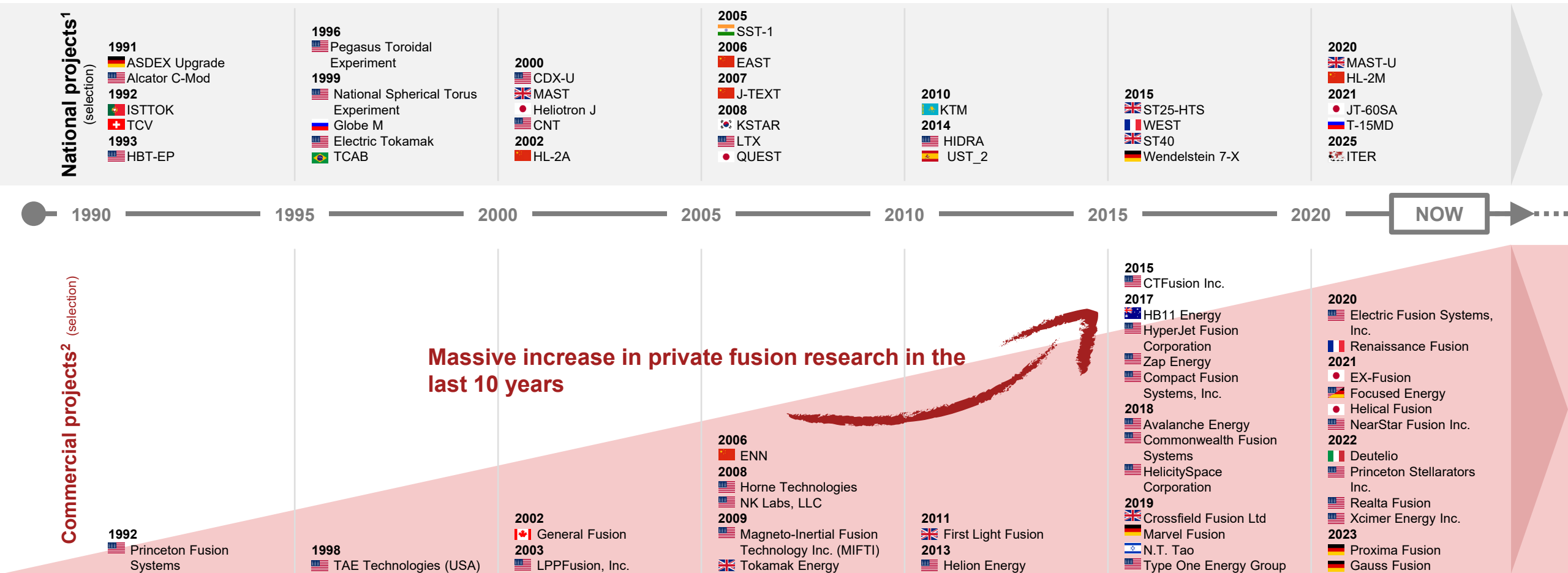
The fusion energy skills tree: skills on the path to carbon-neutral, secure & affordable energy for everybody



Online link update

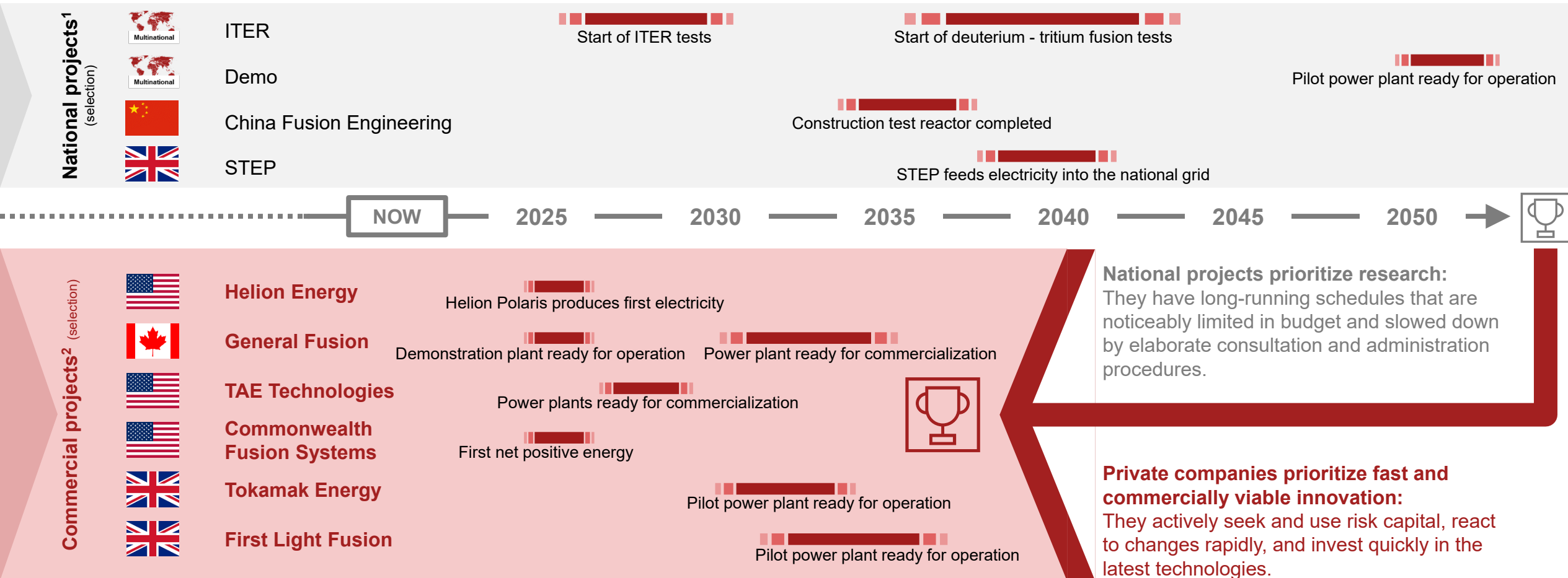
Progress towards commercialization is reflected in the recent significant increase in the number of private fusion startups

The international race to commercial fusion energy has begun: Start date of various fusion projects



Private companies aim for a much earlier breakthrough than their government research counterparts: Realization in 2030s

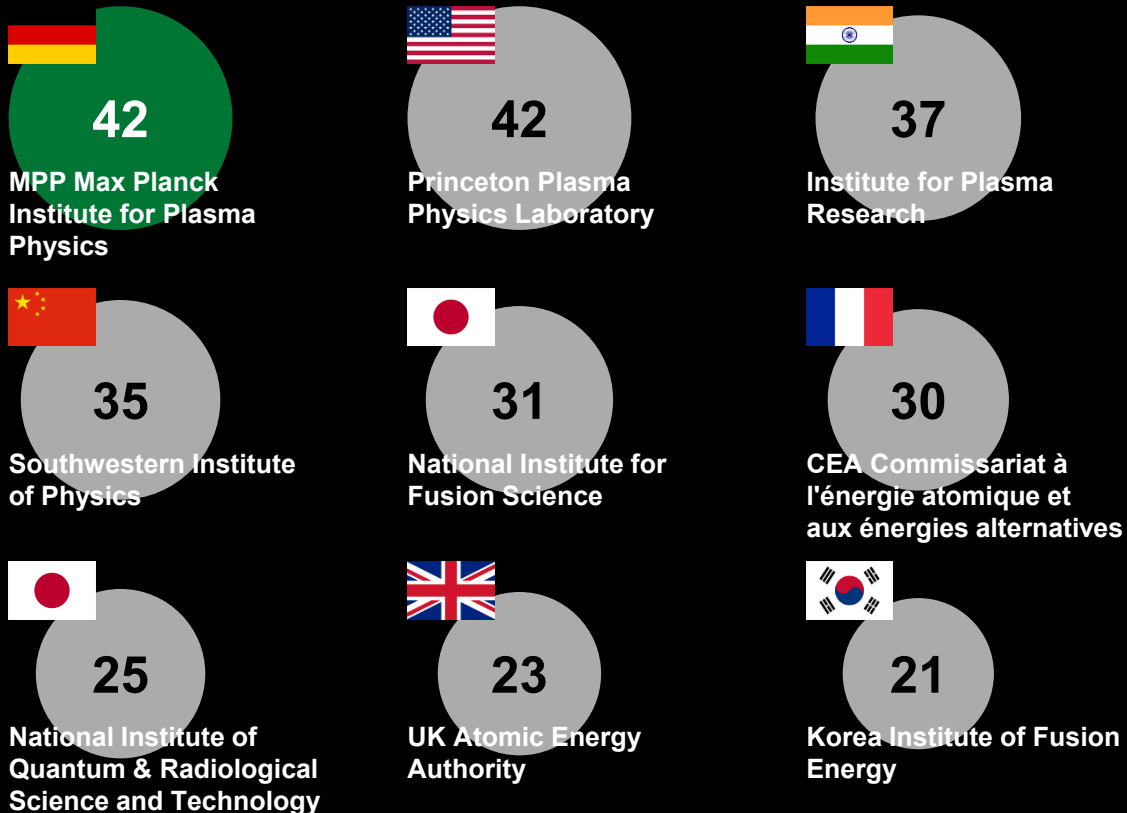
Acceleration through more modern, scalable approaches and faster innovation and decision cycles



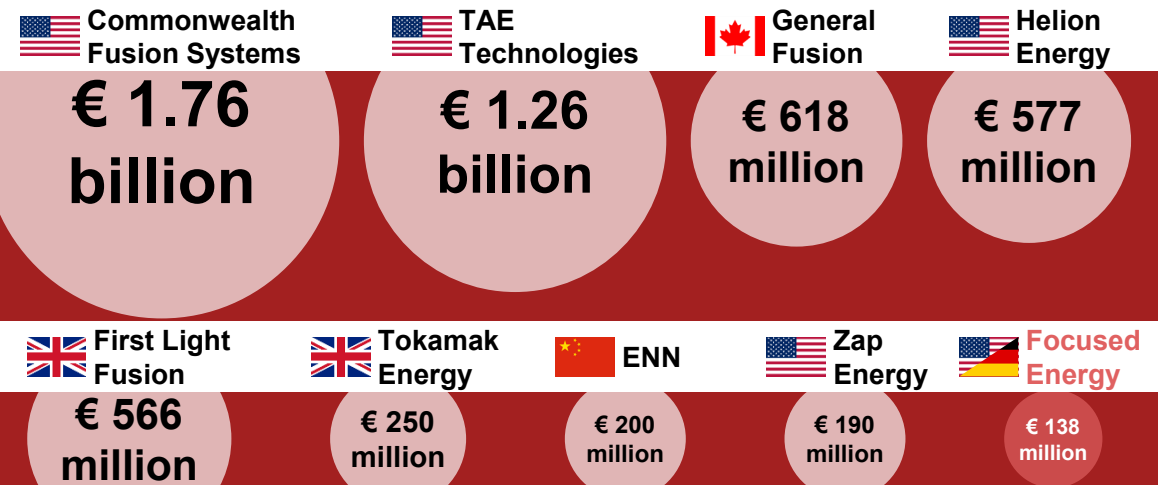
In this race to first commercial fusion energy, Germany's position is (time-)critical right now

Germany is a leader in academic research – but about to be left behind in entrepreneurial efforts

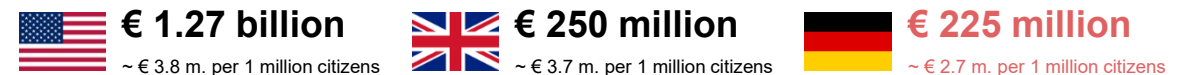
Top 9 academic institutions by recent publications¹: Germany is in top position



Top 9 fusion energy start ups by capitalization^{2,3}: Germany is barely represented



Annual national fusion energy research budgets^{4,5}: Compared internationally, Germany is underfunded



What needs to be done now? A National Fusion Energy Strategy can turn Germany's current position into an agenda for success

This strategy is the backbone of the required close coordination between government and economy

National priorities for a carbon-neutral, secure and affordable energy supply.

Guidelines for development and deployment of fusion energy, enablement through regulation and **reduction of bureaucratic hurdles** in licensing procedures and financing processes.

Coordination and promotion of collaboration between government agencies and industry partners.

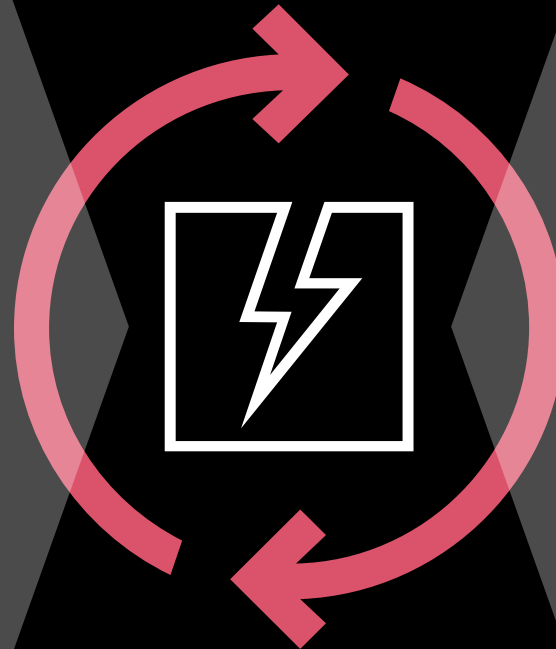
Government subsidies and financing programs at national and European level.

Governmental reinsurance for private venture capital as a breeding-ground for startups and private-sector innovation.

Formation of a decision-making role at the federal level for coordination of national energy topics in order to make strategic future technologies ready for the market more quickly – US Department of Energy as potential blueprint.

Strategic supply chain enablement and protection for critical raw materials, technologies, components and talents.

Government



Economy

Clarification of market role in an economy with fusion energy.

Asset management in preparation for the integration of fusion power plants into existing infrastructure.

Development of transparent financing strategies including requirements for investors, scenario investment for risk minimization of “stranded assets”.

Organizational structuring on the growth path from startup to operator of critical asset infrastructure.

Strategic partnering and M&A for cross-sector technology utilization and non-natural business growth.

Talent management in order to acquire and develop the best talents worldwide.

Innovation strategy and IP management for optimized balancing of knowledge exchange, result-oriented use of funds and safeguarding critical know-how.

Marketing and communication strategy to political decision-makers and the general public (**public relations**).

If Germany acts in time, fusion energy has the potential to become a new engine for the German national economy

Calls for action: our recommendations



Strategy: Implementation of the fusion energy roadmap with success-based incentivization to implement the first power plants as quickly as possible



Coordination: Establishment of a national decision-making role for energy topics at the federal level, for effective coordination of R&D and funding



Simplified funding: Establishment of effective and non-bureaucratic funding and support mechanisms for private-sector innovation



Economic development: Implementation of an enabling legal framework for development of a strong fusion industry in the Germany economy



Training: Development of required know-how in Germany through incentives, broad public relations, and targeted talent acquisition

Fusion Energy: Your link to Strategy&



Christian von Tschirschky
Partner

Energy, Utilities and Resources

+49 175 2081327
christian.von.tschirschky@pwc.com



Artur Korinski
Manager

Energy, Utilities and Resources

+49 1515 5808989
artur.korinski@pwc.com

Thank you

strategyand.pwc.com

© 2023 PwC. All rights reserved.

PwC refers to the PwC network and/or one or more of its member firms, each of which is a separate legal entity. Please see pwc.com/structure for further details.

Disclaimer: This content is general information purposes only, and should not be used as a substitute for consultation with professional advisors.