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Fusion Energy

The key to the future energy architecture

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

Source: Strategy& analysis

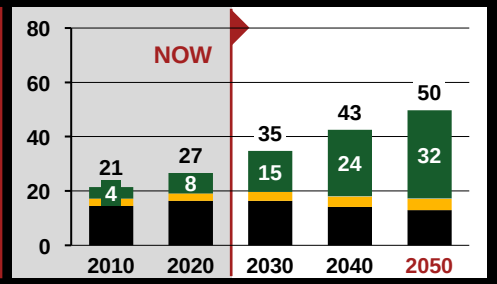
Forecasts show: The global expansion in renewable energy is not sufficient for emission-free power generation by 2050

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 Scenario[1]
–
Conservative scenario ("Realistic path")

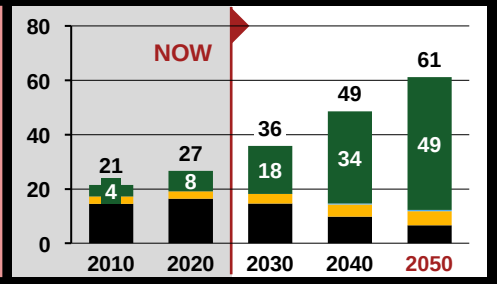
of the International Energy Agency



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

APS: Announced Pledges Scenario[1]
–
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 2050[1]
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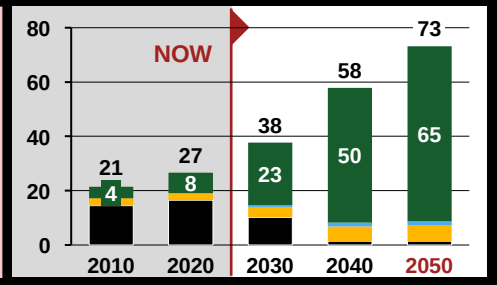
Ambitious scenario ("Desired target")

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 decade[2] 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

Source: 1) IEA World Energy Outlook 2022: GEC Global Energy and Climate Model; 2) IEA GEC Global Renewables development over the period from 2010 to 2020; Strategy& analysis

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

Potential solution:

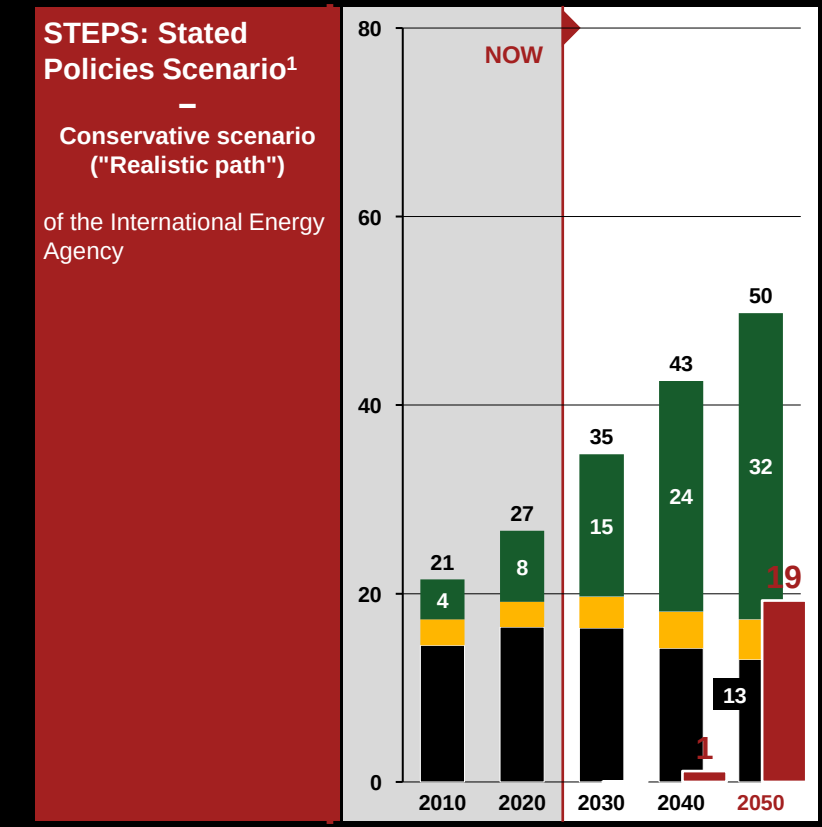
Fusion energy may be the missing key to timely realization of a sustainable energy architecture

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 Scenario[1]
–
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.

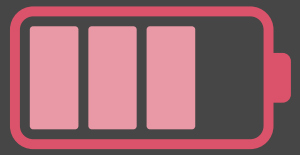
Source: 1) IEA World Energy Outlook 2022: GEC Global Energy & Climate Model; Strategy& analysis

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

Lithium

Recycled lithium from old batteries can be used as a raw material in fusion energy.



Water

The second raw material required comes from conventional seawater, an omnipresent component.

Fusion

The reaction is inherently safe – any disruptions in the process simply lead to the fusion stopping.

Green power

Fusion energy generates a lot of heat, which is converted via steam into large amounts of electricity to power numerous homes.

Helium

Helium is the direct product of the fusion reaction. This would make fusion the first sustainable way to produce helium without the use of fossil fuels.

Source: Strategy& analysis

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

High-performance and quantum computers

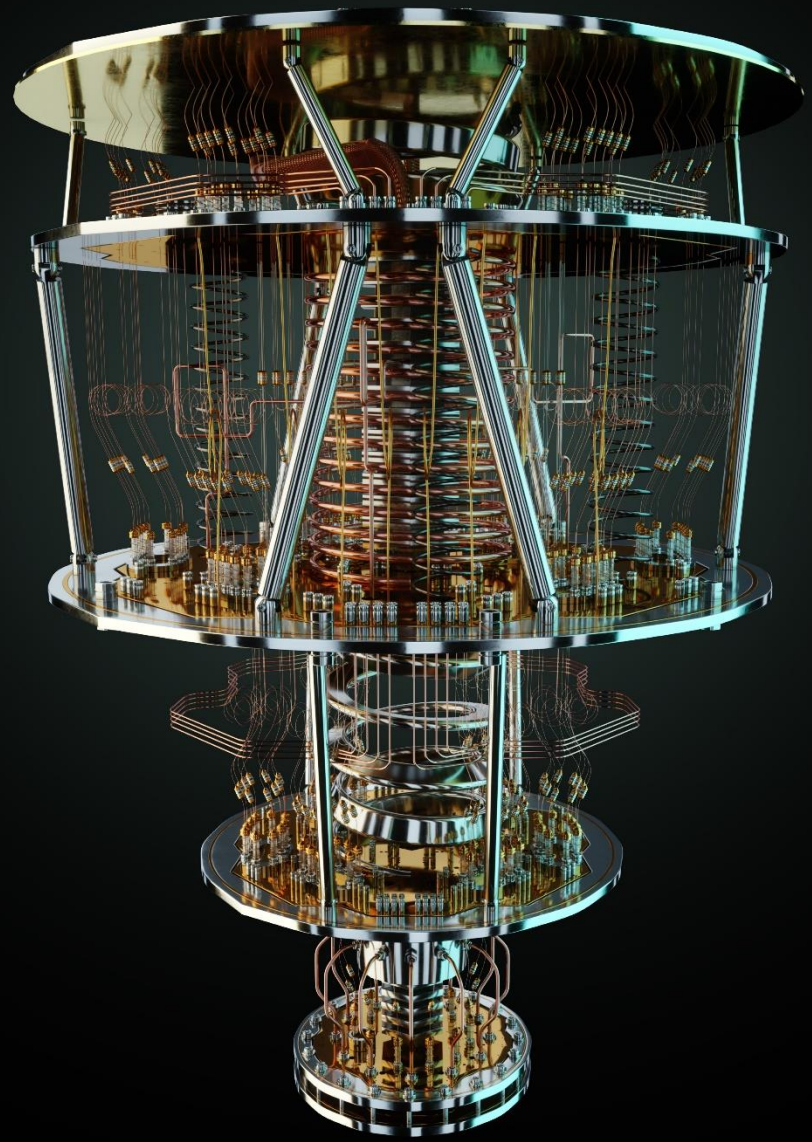
- Too-complex-to-handle control of fusion reactors has been a deal-breaker so far
- Computing power increasingly reaches required levels
- Quantum computers can enable unprecedented parallelization of control tasks

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-power lasers

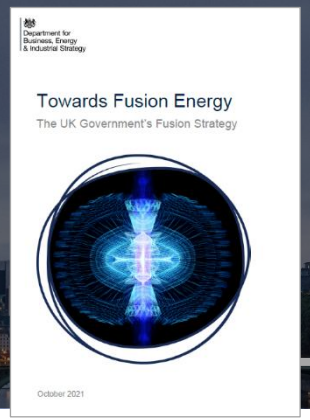
- Significant increase in laser peak power (by a factor of 20 in a decade[1,2]) in a more compact package enables new designs for inertial fusion
- Simultaneously, laser power costs have reduced rapidly (by a factor of 200 per PW power in a decade[1,2])



Source: 1) Lawrence Livermore National Laboratory, National Ignition Facility, United States 2009; 2) Extreme Light Infrastructure-Nuclear Physics (ELI-NP), Romania, 2019; Strategy& analysis

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

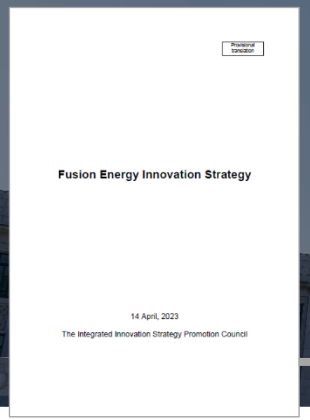
UK, USA, Japan, and most recently Germany too, have published initial strategy papers on fusion energy



United Kingdom

1 October, 2021[1]

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



Japan

14 April, 2023[3]

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, 2022[2]

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

Germany

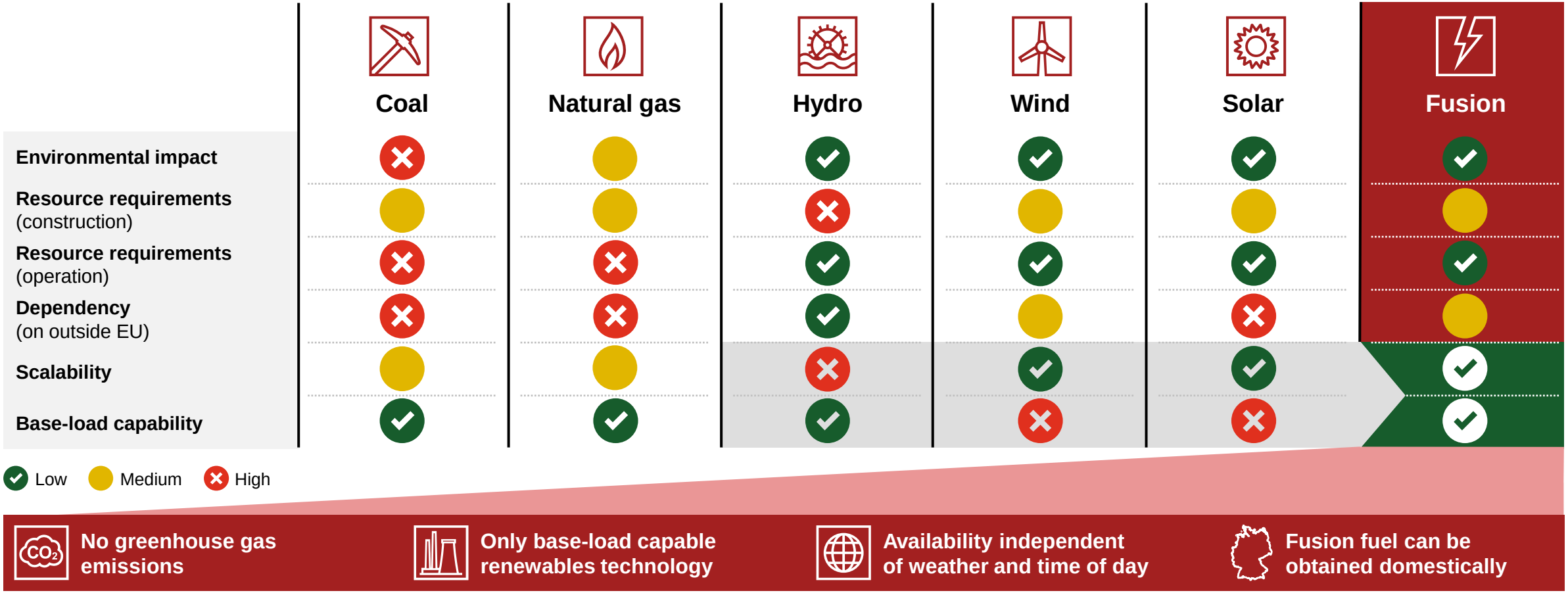
23 June, 2023[4]

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

Source: 1) Towards fusion energy: the UK government's fusion strategy; 2) White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy; 3) Japanese Fusion Energy Innovation Strategy; 4) BMBF position paper on fusion research; Strategy& analysis

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



Source: Strategy& analysis

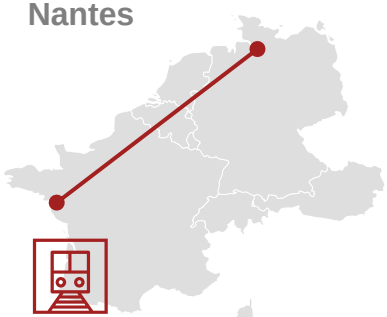
The amount of energy from raw materials for fusion available worldwide is sufficient for secure and cheap energy oversupply

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

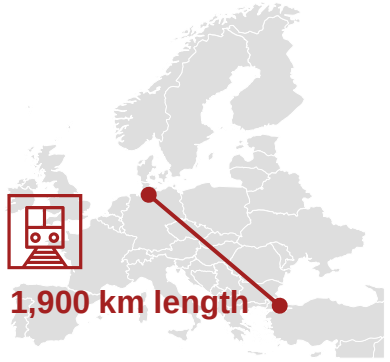


1,100 km length

Natural gas

1.3 million tons annually

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

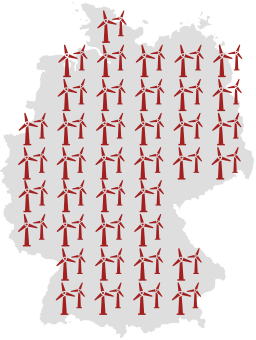


1,900 km length

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

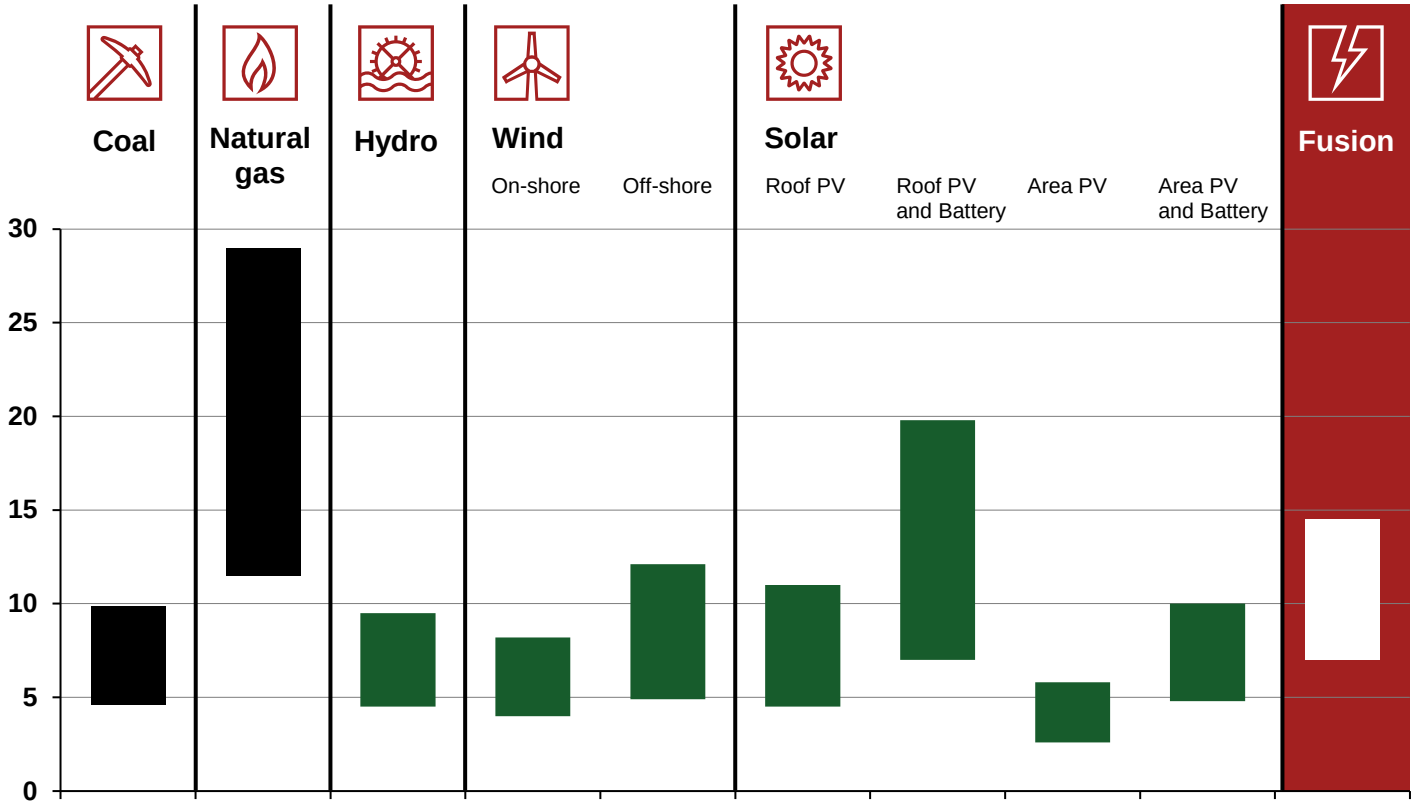
... or a single transport load to the power plant

Source: Strategy& analysis

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 costs[3] – with expansion, these will decrease significantly

Levelized cost of electricity[1-5] in € cents/kWh (lifetime costs of electricity in generation)



Current studies[2] 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 years[4].

Source: 1) Fraunhofer ISE; 2) Thomas Griffiths et al. 2022 Prog. Energy 4 042008; 3) An Energy Technology Distillate from the Andlinger Center for Energy and the Environment at Princeton University; 4) Lazard's levelized cost of energy analysis – Version 15.0; 5) German Bundestag; Strategy& analysis

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

Engineering	Economy	Politics	Society
Increasing energy efficiency of designs	Increasing efficiency in operation	Development of a national strategy for fusion energy	Managing high initial investment levels
Control systems capabilities	Securing the supply of critical raw materials	Development of regulatory frameworks	Creating awareness and understanding of fusion energy
Heat and radiation-resistant materials	Integration of fusion energy into the national energy mix	Promotion of investments and subsidy financing	Development of know-how and training of specialists
Design of special machine components	Long-term investments	Promotion of international cooperation	
Fusion fuel processing	Know-how cooperation and IP management	Public law discussions with state bodies	
Compact and scalable power plant design	Stakeholder market positioning		
Optimized reaction heat transfer into electric energy			

Challenges in initial implementation

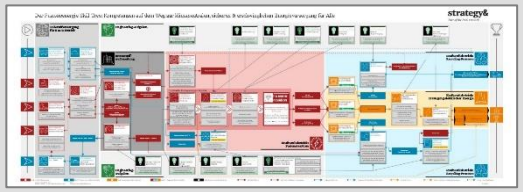
Challenges in further commercial establishment

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



available on request

Fusion Energy
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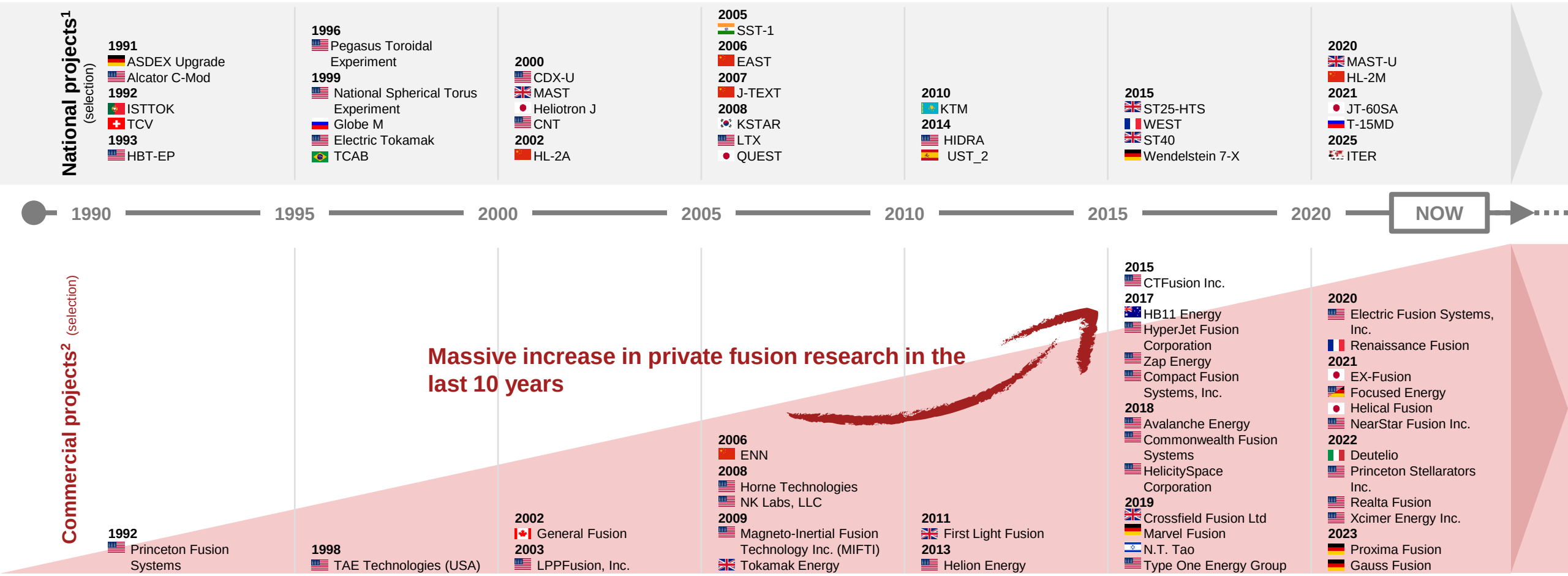
Source: Strategy& analysis

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

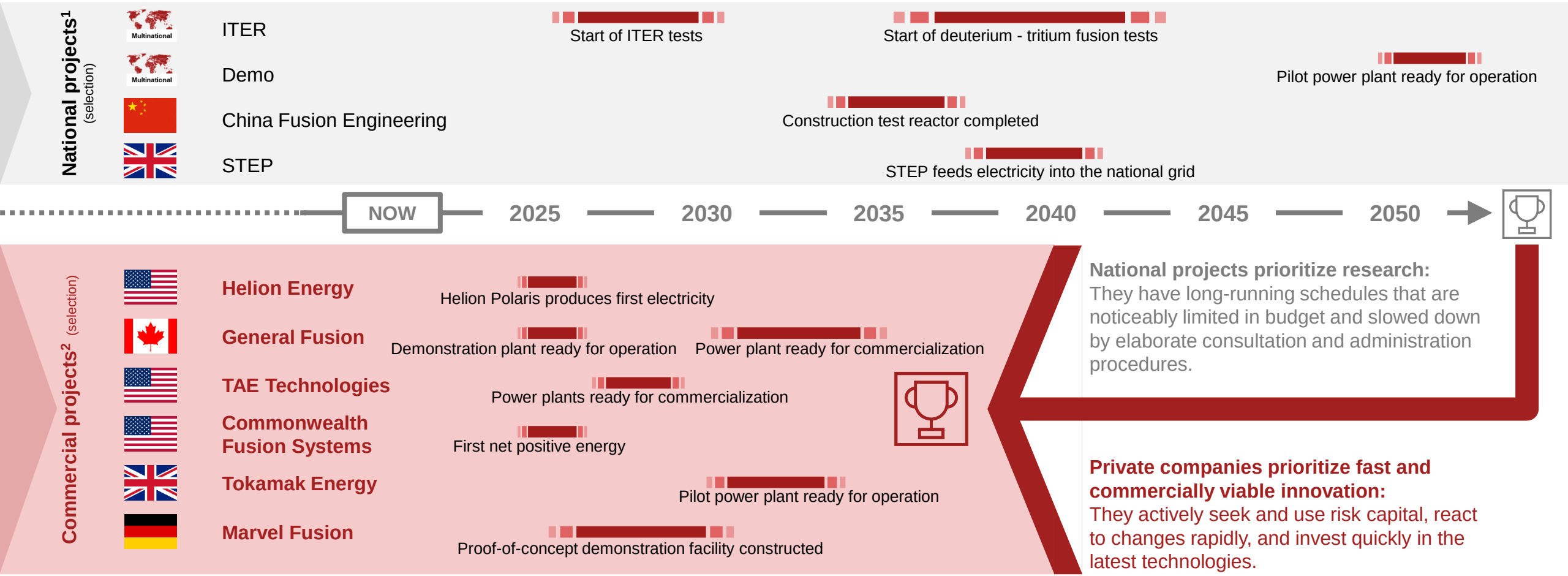
The international race to commercial fusion energy has begun: Start date of various fusion projects



Source: 1) Wikipedia; 2) Fusion Industry Association; Strategy& analysis

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



National projects prioritize research:
They have long-running schedules that are noticeably limited in budget and slowed down by elaborate consultation and administration procedures.

Private companies prioritize fast and commercially viable innovation:
They actively seek and use risk capital, react to changes rapidly, and invest quickly in the latest technologies.

Source: 1) Wikipedia; 2) Fusion Industry Association; Strategy& analysis

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 publications[1]: Germany is in top position

- 42 — MPP Max Planck Institute for Plasma Physics
- 42 — Princeton Plasma Physics Laboratory
- 37 — Institute for Plasma Research
- 35 — Southwestern Institute of Physics
- 31 — National Institute for Fusion Science
- 30 — CEA Commissariat à l'énergie atomique et aux énergies alternatives
- 25 — National Institute of Quantum & Radiological Science and Technology
- 23 — UK Atomic Energy Authority
- 21 — Korea Institute of Fusion Energy

Top 9 fusion energy start ups by capitalization[2,3,5,6]: Germany is barely represented

- Commonwealth Fusion Systems — € 1.83 billion
- TAE Technologies — € 1.16 billion
- SHINE Technologies — € 641 million
- Helion Energy — € 529 million
- ENN — € 366 million
- General Fusion — € 358 million
- Tokamak Energy — € 229 million
- Marvel Fusion — € 210 million
- Zap Energy — € 191 million

Annual national fusion energy research budgets[4,5]: Compared internationally, Germany is underfunded

- € 1.27 billion — ~ € 3.8 m. per 1 million citizens
- € 250 million — ~ € 3.7 m. per 1 million citizens
- € 225 million — ~ € 2.7 m. per 1 million citizens

Source: 1) IAEA International Atomic Energy Agency Fusion Energy Conference 2020; 2) Financial Times; 3) Pitchbook; 4) Bundestag; 5) FIA Fusion Industry Association; 6) Corporate self-disclosures for selected start ups; Strategy& analysis

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.

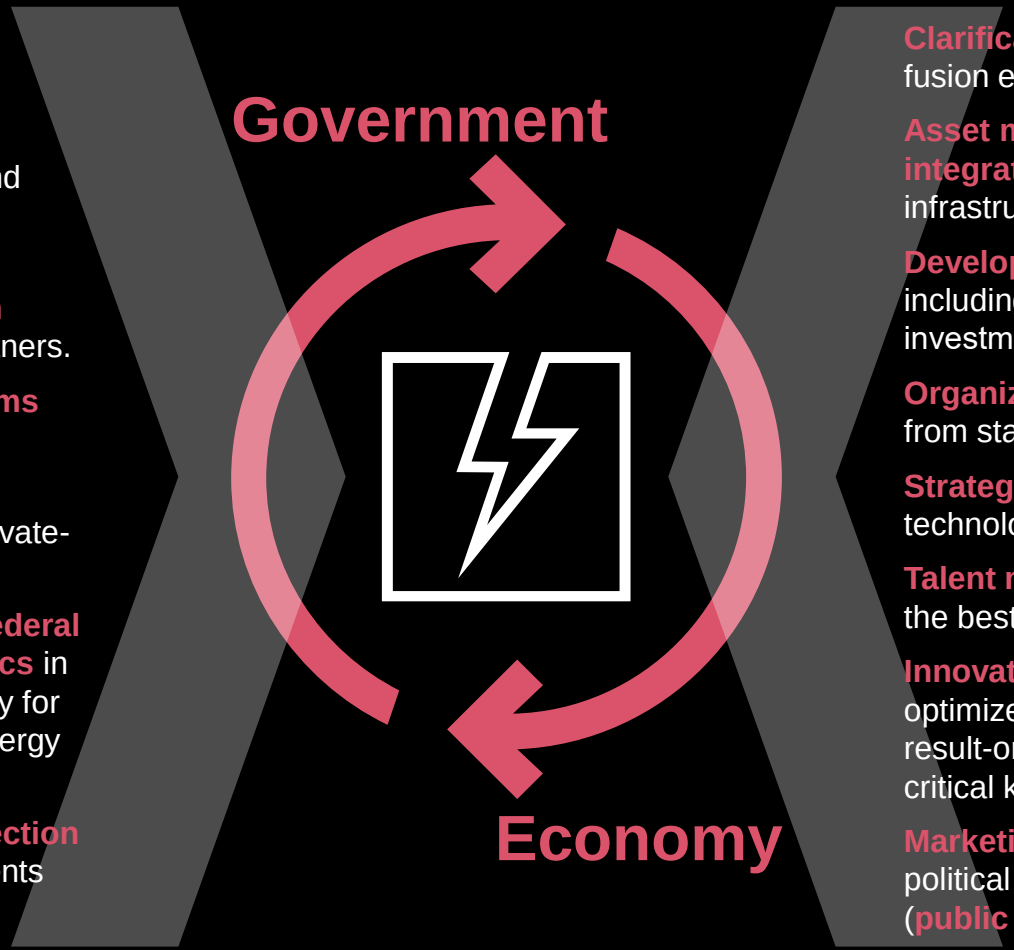
Coordination and promotion of collaboration between government agencies and industry partners.

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.



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**).

Source: Strategy& analysis

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

Source: Strategy& analysis

Fusion Energy: Your link to Strategy&

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