Fusion Energy

FROM DREAM TO REALITY

IAEA
6-10 June 2022
Technical Meeting on Synergies Between Nuclear Fusion Technology Developments and Advanced Nuclear Fission Technologies

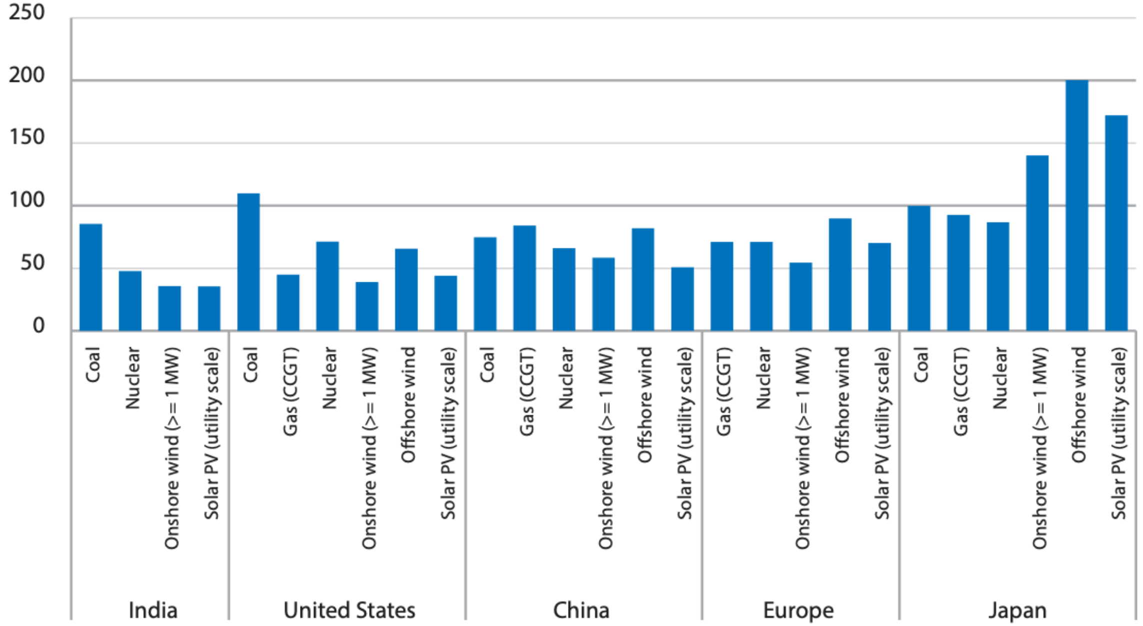
Anna Soldatova

- Current industry challenges
- Target state
- Fusion prospects

Evidence of pivotal moment for Power industry

EU carbon permits price, EUR/t

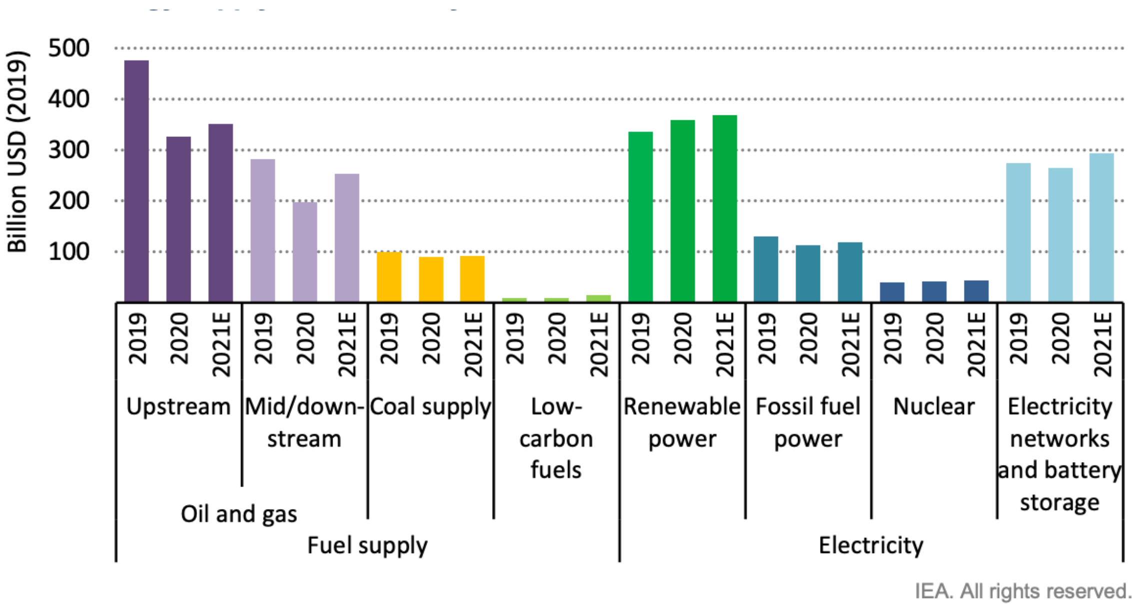
Median LCOE by region, USD/MWh



Source: [radingeconomics.com](), [IEA]()

Market signals: half of Fortune 500 companies made CO2 reduction commitments, investors go there too

Renewables (RES) funding is catching up with upstream funds, majors have to diversify their asset bases



Company	2030 absolute reduction	2050
Eni	25%	Net Zero
TotalEnergies	30%	
bp	30-40%	
Shell	-	
equinor	-	
REPSOL	-	
ConocoPhillips	-	

Source: IEA

- Current industry challenges
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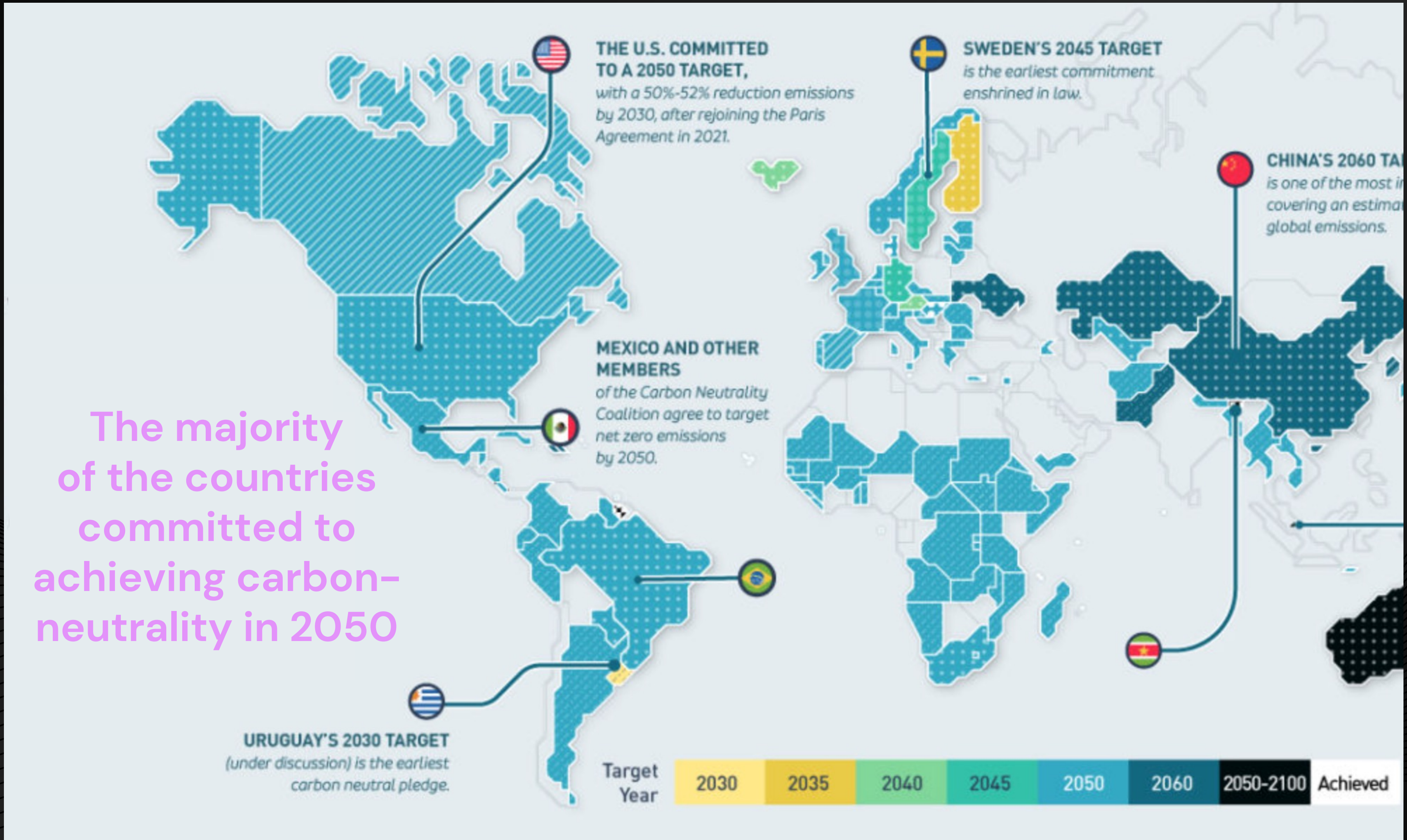
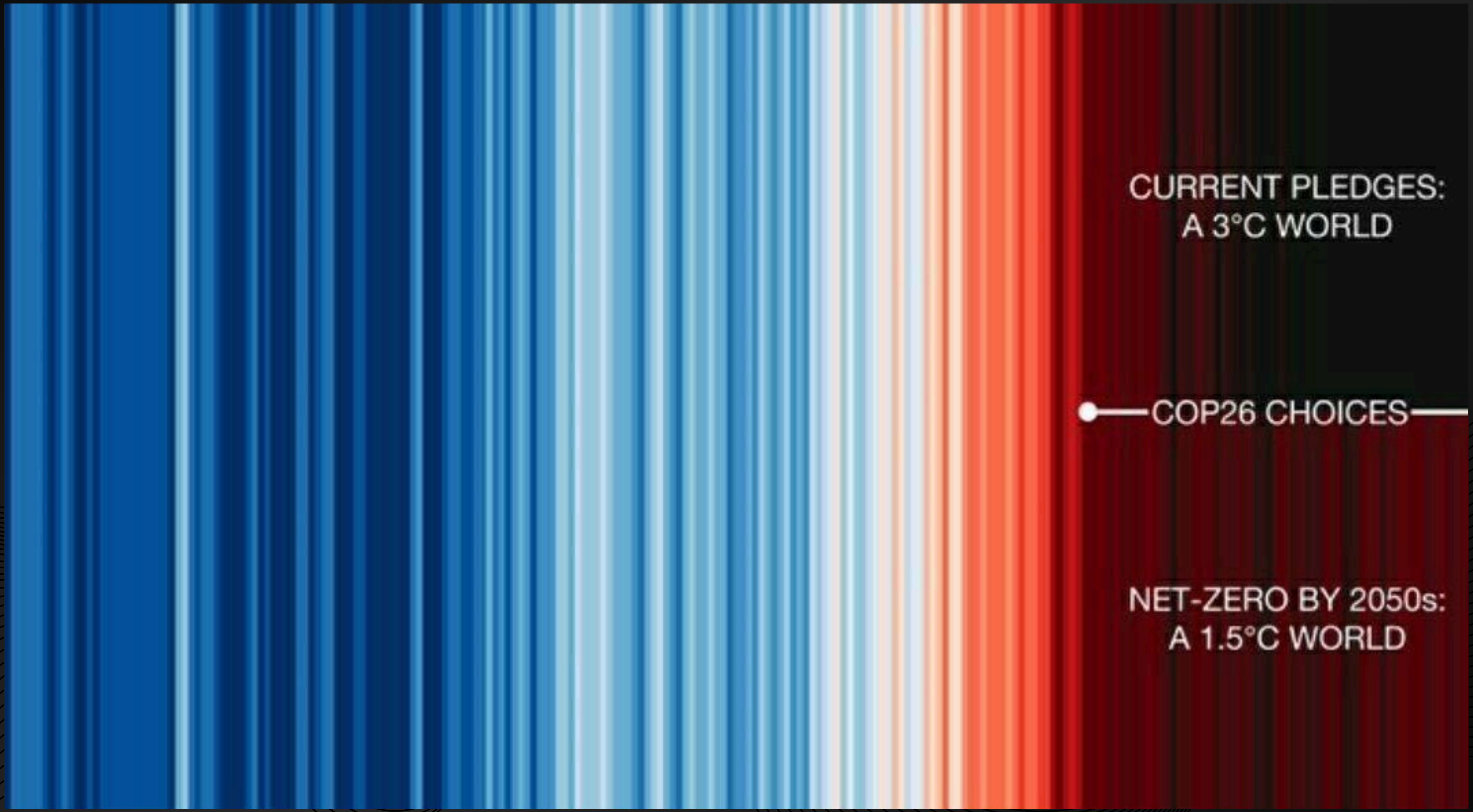
Race to Net-zero is on



The majority of the countries committed to achieving carbon-neutrality in 2050

Source: Visual Capitalist

Growth of CO2 is a game-changing for climate…



Source: Ed Hawkins

…and could increase the number of natural disasters

Source: France 24

To charge our smartphones, cook, storage food, pump water we still need abundant baseload power

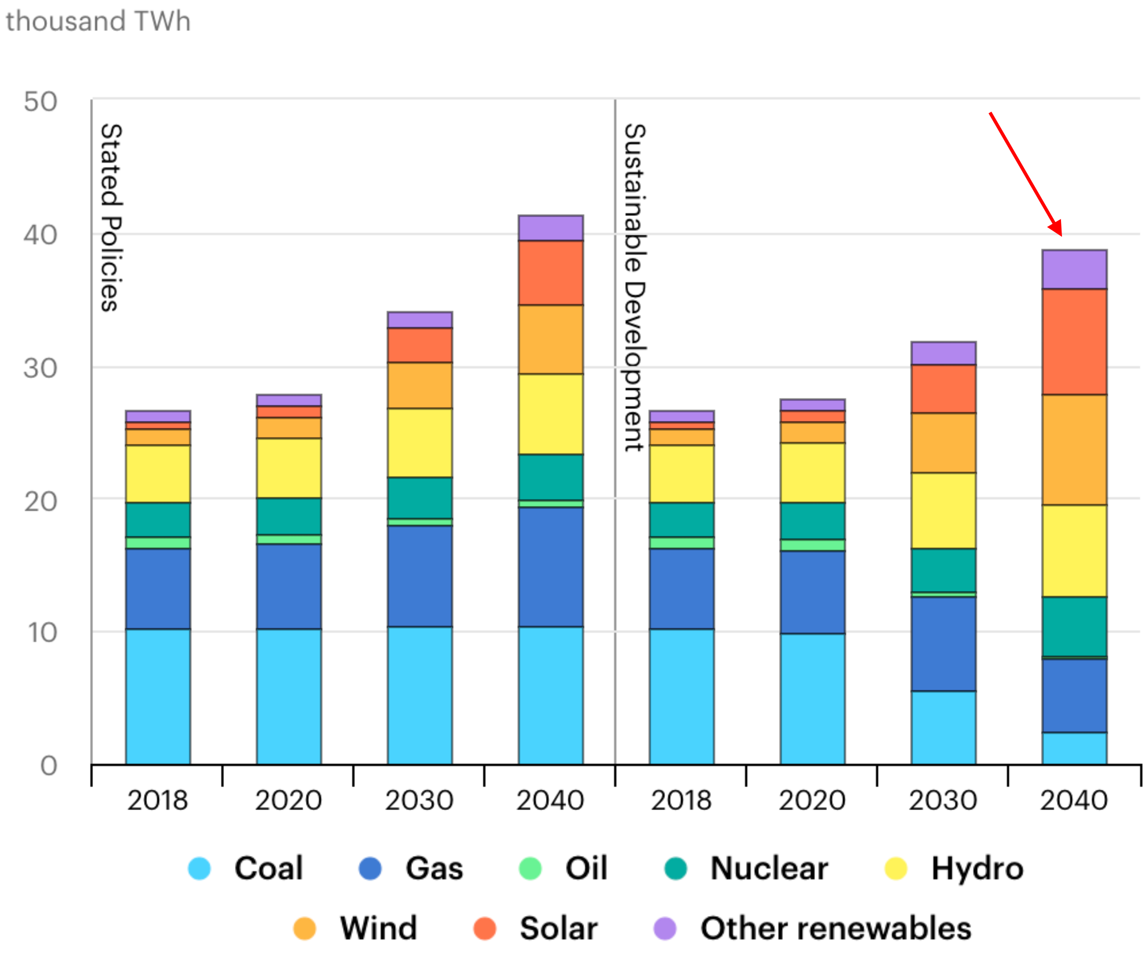
FUSION

low carbon, safe, continuous, dispatchable
and sustainable source of energy

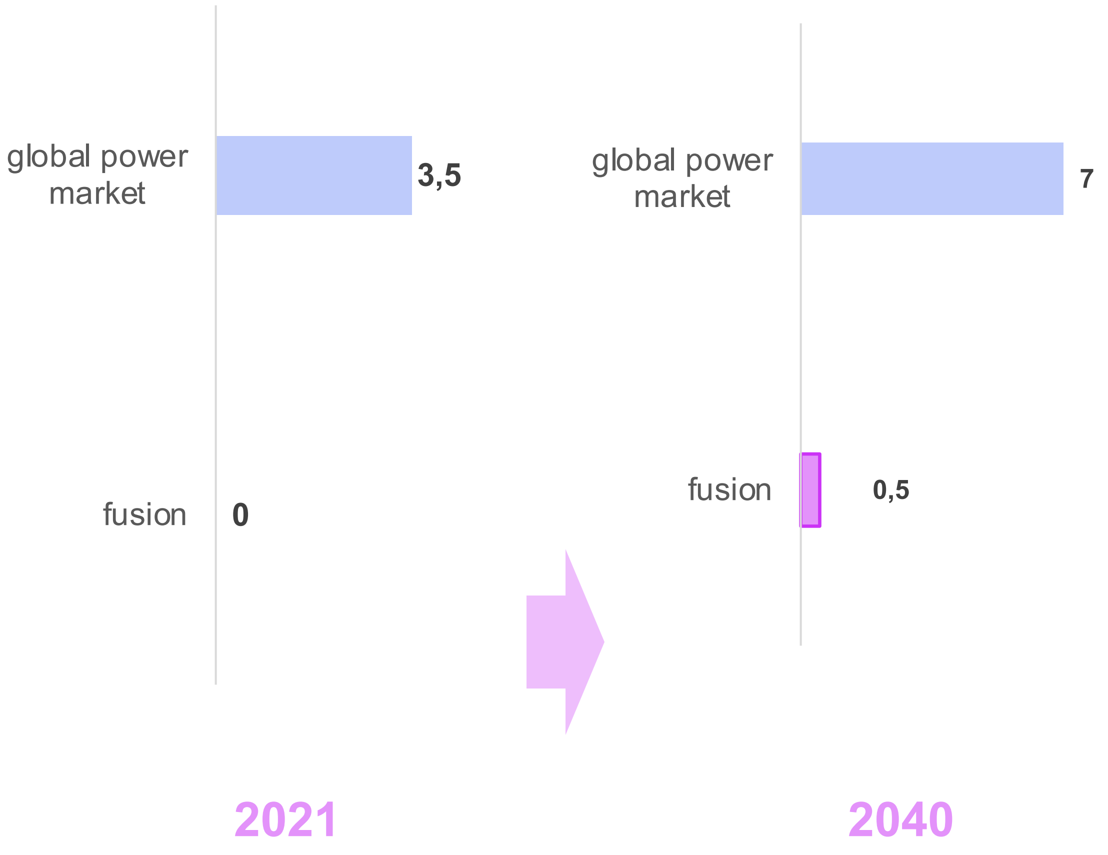
- Current industry challenges
- Target state
- **Fusion prospects**

Possible fusion energy market size in 2040 – floor estimation

Actual and forecasted generation by fuel



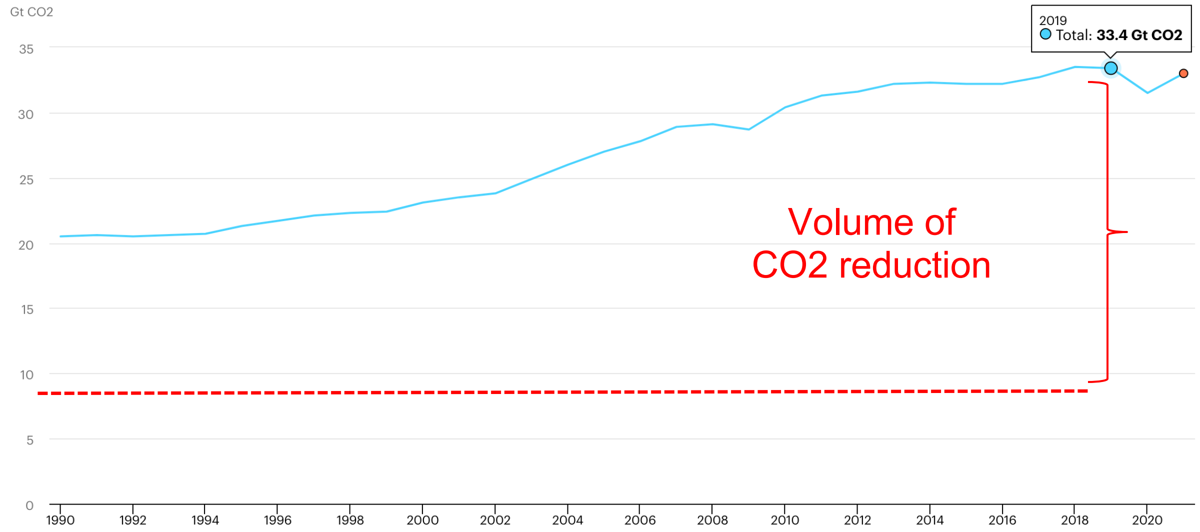
Power market size and fusion share, $ trln



Source: IEA

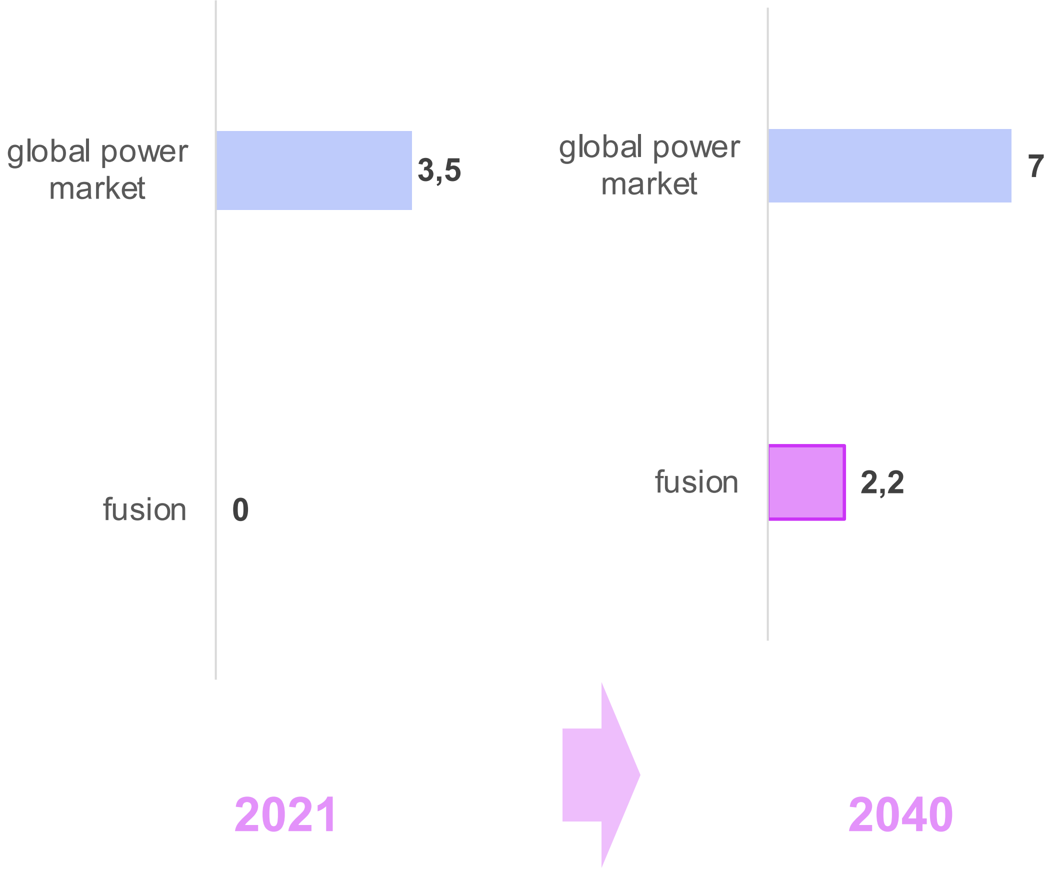
Possible fusion energy market size in 2040 – ceiling estimation

Global energy related CO_2 emissions, Gt



EU emission permit price = $89/t
CCUS price = $20-200/t

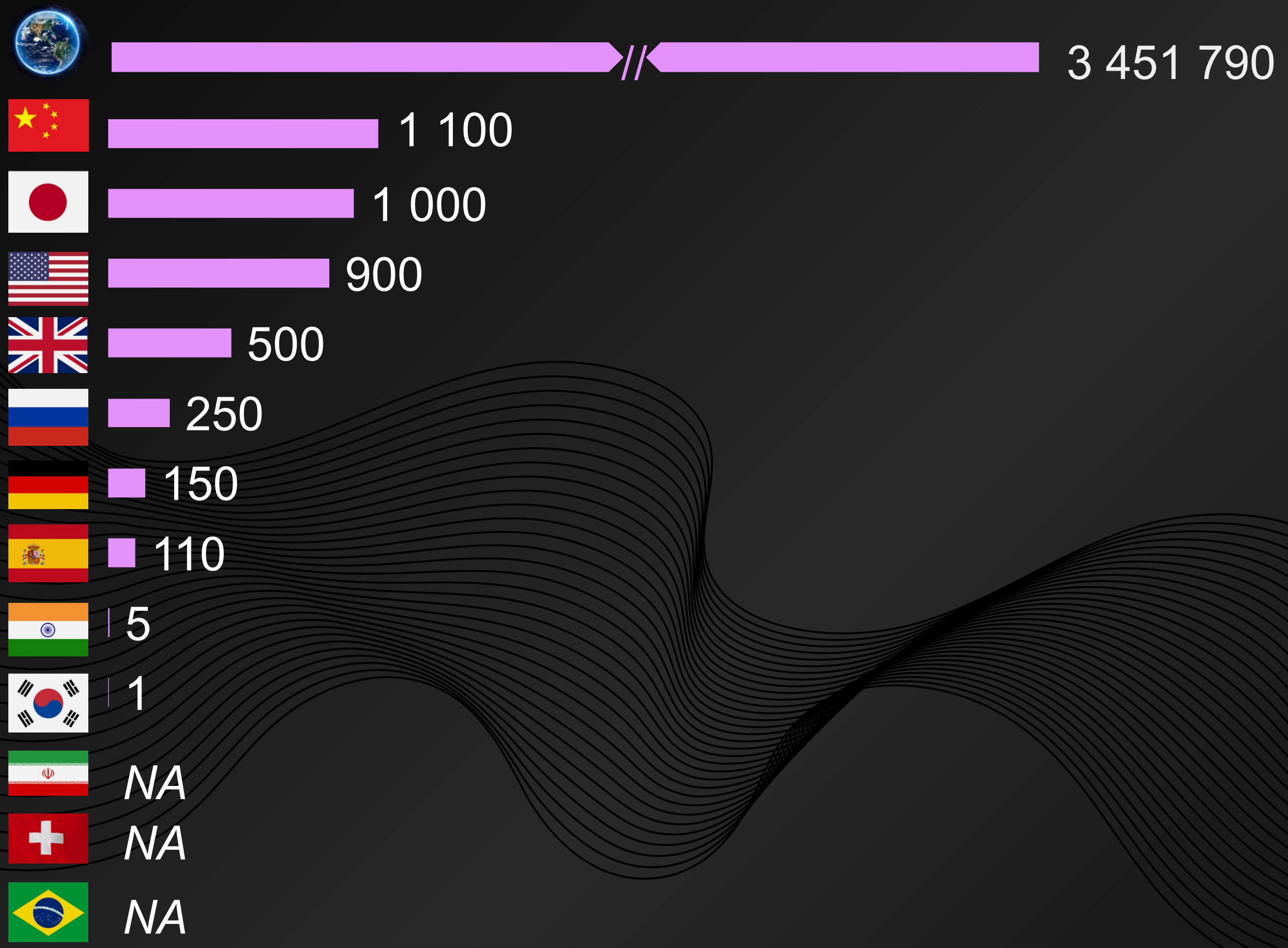
Power market size and fusion share, $ trln



Source: IEA

Fusion still mainly funded by public

Global energy market vs estimated upcoming public funding on Fusion energy R&D, $ mln*

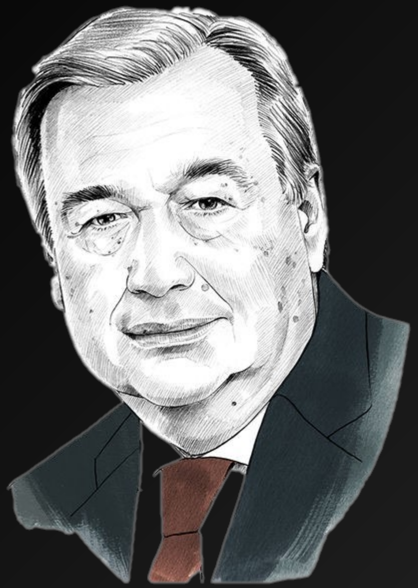


25 number of countries with public fusion programs

69 universities, labs, and organizations involved

95 operating fusion reactors

*Except spending on ITER project



António Guterres

“the climate crisis is a code red for humanity and that urgent action is needed before it is too late”

Strategic targets of leadership nations

	UK	USA	China	Japan
Strategic goals	demonstrate the commercial viability of fusion by building a prototype fusion power plant in the UK Build a world-leading fusion industry which can export fusion technology around the world	accelerate viable commercial fusion energy	operate fusion machines economically and permanently	achieve technological solution for DEMO Promote balanced research on helical and laser fusion
Strategic document	the UK fusion strategy	expected	–	expected in the second half of 2022
Time horizon	up to 2040 and further	up to 2032 and further	not specified	up to 2035 and further
Regulation principles declared	alternative to fission	inventory regulated by NRC alternative regulation for facilities	not specified	not specified

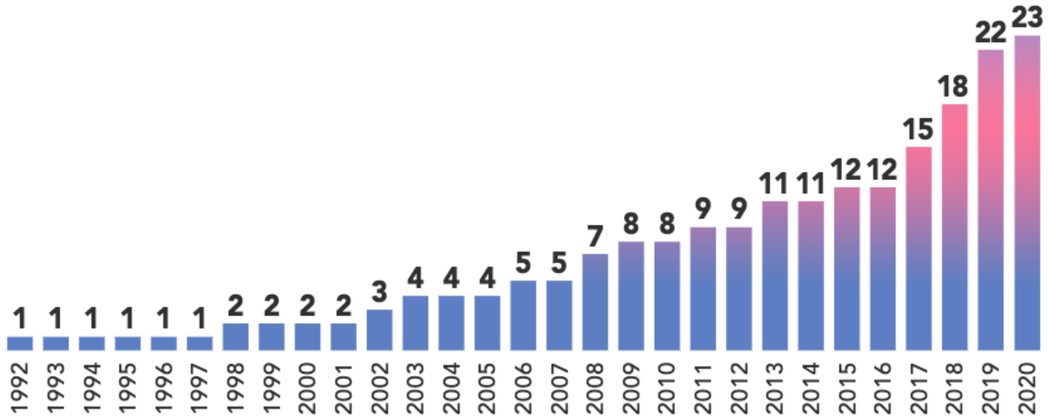
Public projects: too slow and too expensive

Inefficiency and extremely high costs of Russian state corporation responsible for space flights give an opportunity for the private sector in aerospace manufacturing

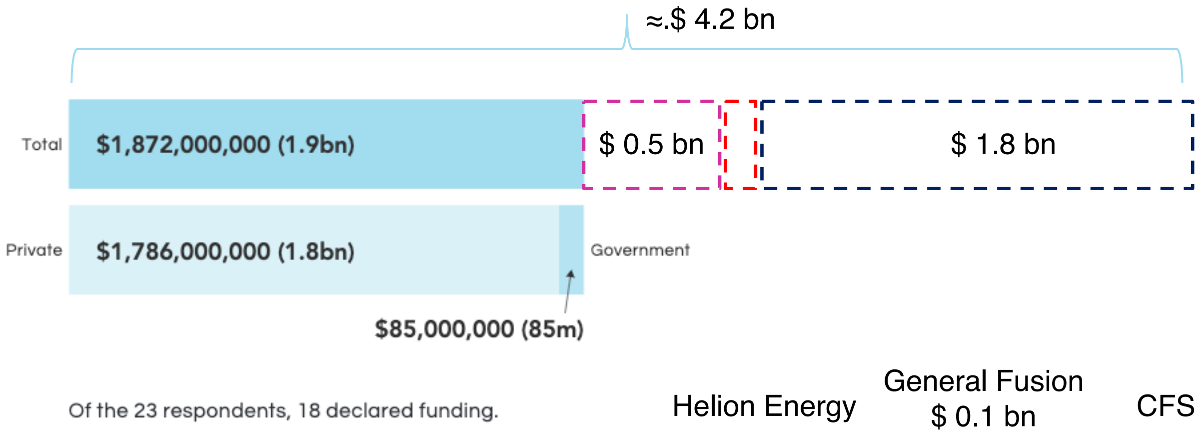
SpaceX moment of fusion industry

Climate urgency and tech breakthroughs bring private fusion companies on the stage

Number of private fusion companies,



Funding for fusion companies, $ M



Technical approach taken by fusion companies

General approach

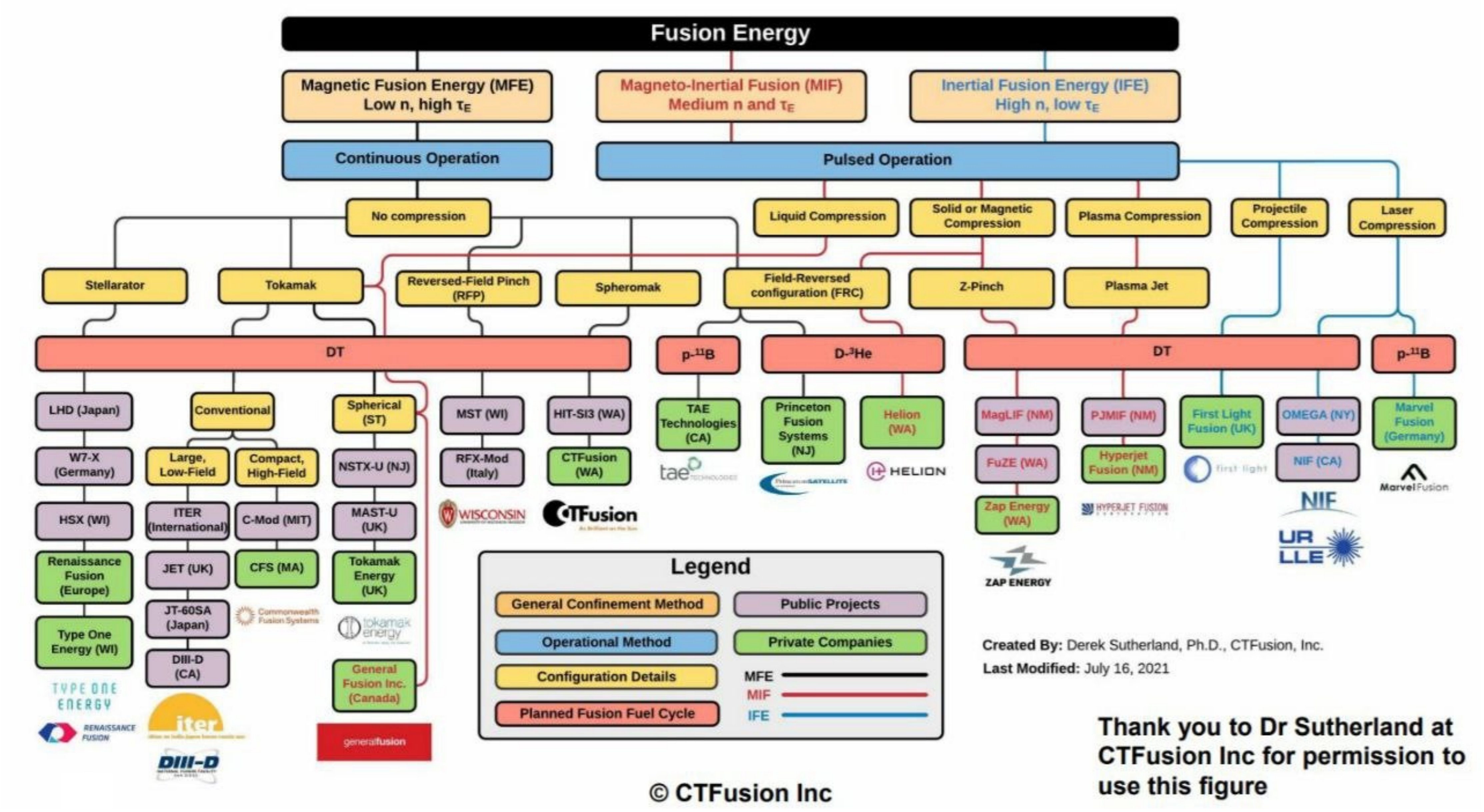
- 13 Magnetic confinement
- 5 Magneto-inertial
- 2 Hybrid electrostatic confinement
- 2 Inertial confinement
- 1 Non-thermal laser fusion
- 0 Cold fusion/LENR
- 0 Muon-catalysed fusion

Specific approach

- 3 Field Reversed Configuration
- 3 Tokamak
- 2 Spherical tokamak
- 2 Stellarator
- 2 Z-pinch
- 1 Dense plasma focus
- 1 Direct laser-driven pB11
- 1 Inertial-electrostatic confinement
- 1 Laser-driven inertial confinement (quantum enhanced)
- 1 Magnetic-electrostatic confinement
- 1 Magnetized target fusion
- 1 Plasma jet driven magneto-inertial fusion
- 1 Plectoneme
- 1 Shock-driven inertial confinement
- 1 Spheromak
- 1 undeclared
- 0 Laser-driven inertial confinement

Source: FIA

Global Fusion landscape



Thank you to Dr Sutherland at CTFusion Inc for permission to use this figure

Unicorn start-up companies

Only these three have raised more than $3 B of private funding, all of them are building their generation facilities and actively test technical viability

Commonwealth Fusion Systems

Year founded: 2018
Approach: magnetic confinement
Fuel mix: DT
Total Investment: $2.5 B
CEO: Bob Mumgaard

Helion Energy

Year founded: 2013
Approach: magneto-inertial confinement
Fuel mix: DHe3
Total Investment: $578 M
CEO: David Kirtley

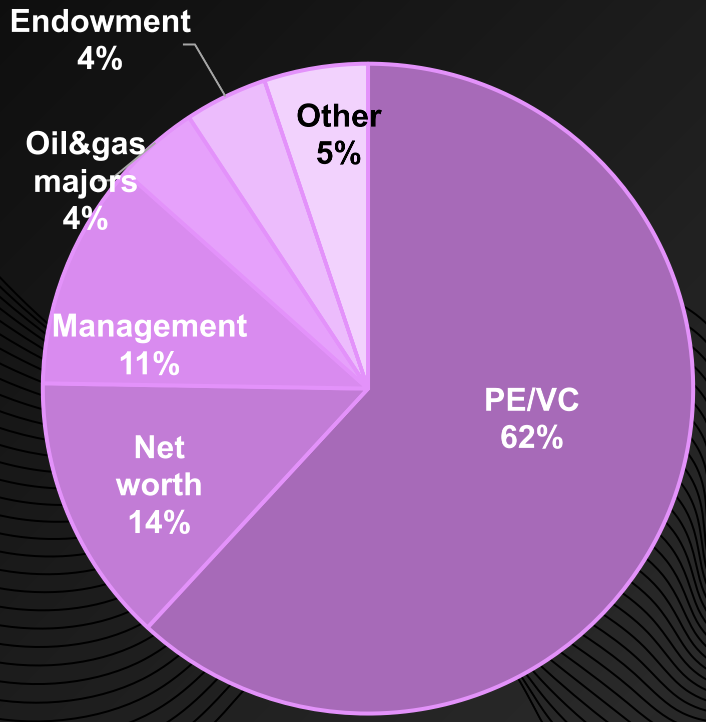
General Fusion

Year founded: 2002
Approach: magneto-inertial confinement
Fuel mix: DT
Total Investment: >$300 M
CEO: Christofer M. Mowry

Fusion investor: who, why, how much?

Over 100 capitalists have already funded Fusion for more than $4.2 B. 48%[1] of fusion companies have raised 73% of total industry investment

Structure of Fusion investors



Funds invested in >1 company

- *Temasek*
- *Google Ventures*
- *Jameel Investment*
- *LowerCarbon*

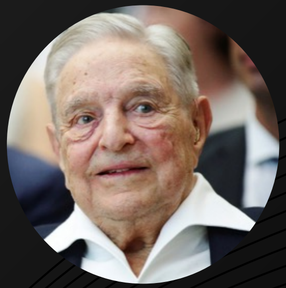
Started funds focused on Fusion

- *Energy Impact Partner*
- *LowerCarbon*

Who has funded Fusion among the billionaires?

Jeff Bezos

Bill Gates



George Soros

Oil and gas majors believing in Fusion

1. Estimation based on the list of companies – members of FIA

Fusion LCOE estimation vs mature technology

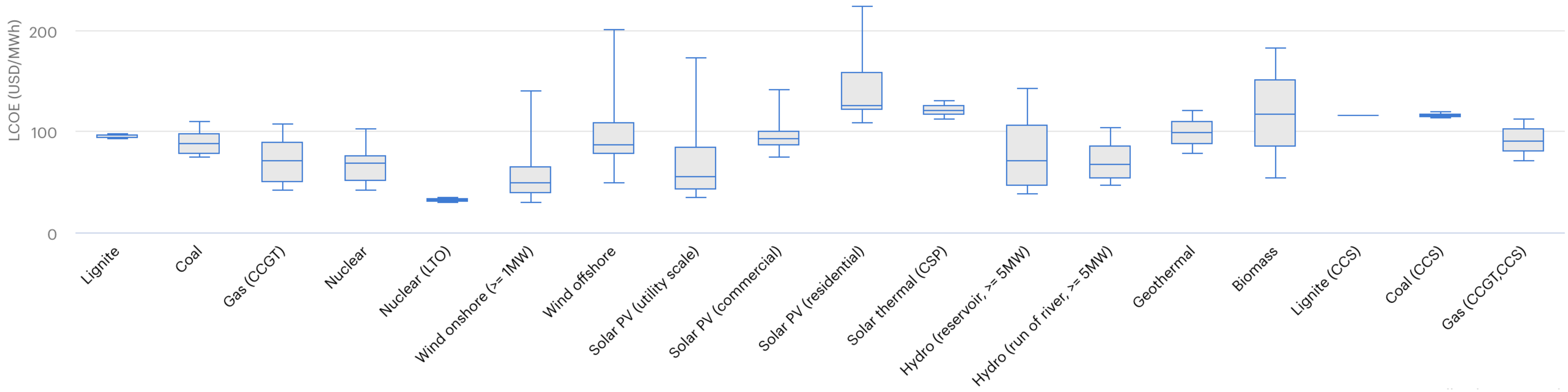
Sensitivity analysis of LCOE depending on CAPEX & OPEX levels, $/MWH estimation in 2020 prices

		CAPEX, $M/MW							
		1,00	4,14	5,17	6,46	8,08	10,10	11,11	12,22
OPEX, $M/MWh	2,57	57,52	79,58	86,86	95,95	107,32	121,53	128,63	136,45
	3,22	58,45	80,51	87,79	96,88	108,25	122,46	129,56	137,38
	4,02	59,61	81,67	88,95	98,04	109,41	123,62	130,72	138,54
	5,02	61,06	83,13	90,40	99,50	110,86	125,07	132,18	139,99
	6,28	62,88	84,94	92,22	101,31	112,68	126,89	133,99	141,81
	7,85	65,15	87,21	94,49	103,58	114,95	129,16	136,26	144,08
	8,64	66,28	88,35	95,62	104,72	116,08	130,29	137,40	145,21
	9,50	67,53	89,59	96,87	105,96	117,33	131,54	138,65	146,46

CAPEX & OPEX references in 2020 prices

#	Project Name	Capacity to the grid, MW	Project's cost, $B	CAPEX, $M/MW	OPEX, $/MW•h
1	DEMO2	1 000	9.39	9.39	6.5
2	ARC	200	4.3-5.4	22-27	-
3	ALPHA	150	0.76-2.1	5.1-14	14.8-31.2
4	BETHE	400	2	5	5
5	Estimation	400	1.2	3	2.69
			Weighted average	**10.1**	**7.85**

LCOE by technology



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