# Desirable Fusion Reactor Qualities for Commercial Electrical Generation Applications

Vince Page
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- The mechanics of power generation have changed little since Hero invented his “toy” engine in ~100 B.C.
- The nuclear powerplants of today are still glorified steam kettles which replace fossil fuel with nuclear fuel.
- This is true of all fission cycles, but only true of some fusion cycles.
- Finding a method of converting fission or fusion energy directly into electrical energy is of great interest, PROVIDING that it can be done at an equal or greater efficiency compared to steam turbines and rotating electric generators.

- Safety will be critical to selling both fission and fusion reactors in the 21st century.
- When the team headed by Edward Teller tested the first fission reactor, they quickly extracted all of the control rods.
- The reactor pulsed briefly, then — by the very physics of the design — the reactor brought itself under control without human, mechanical or computer intervention.

# Desirable Fusion Reactor Qualities

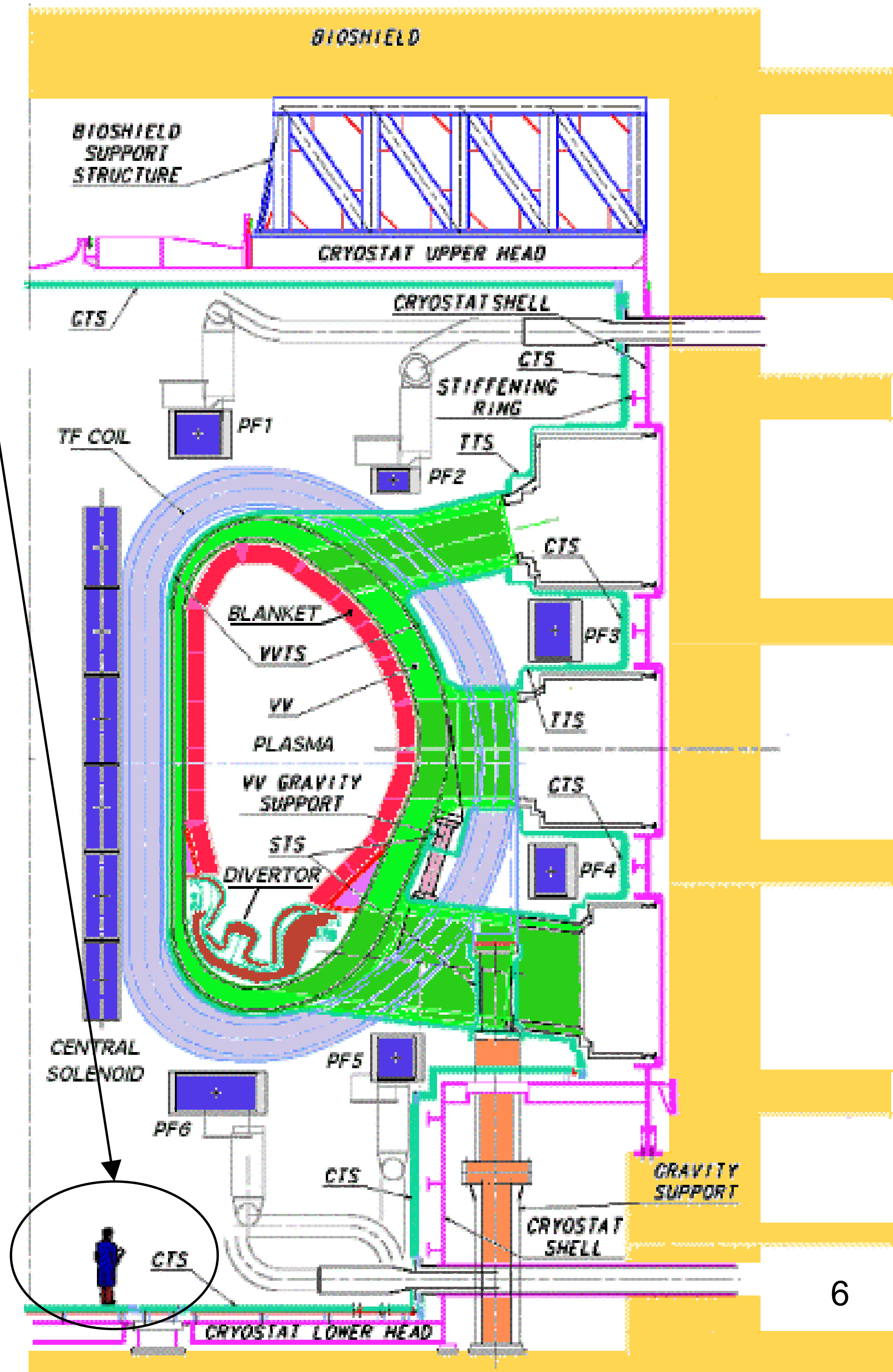
This “inherent safety” was later replaced by “engineered safety” which relies on human or computer intervention and mechanical systems for control.

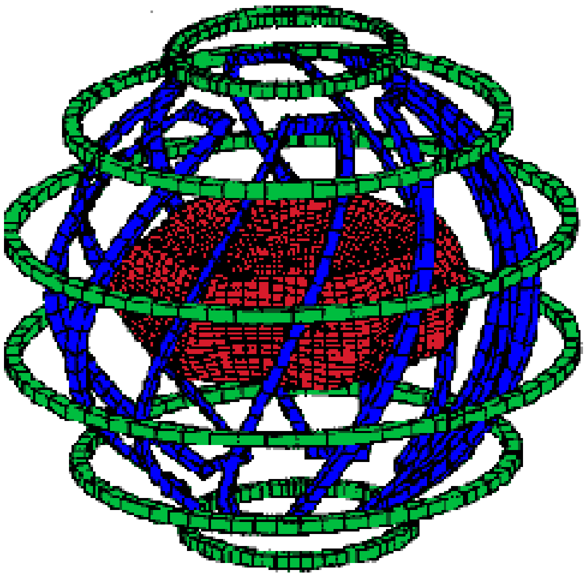
The public will only accept inherently safe designs for new nuclear reactors.

- The public is under the impression that fusion reactors are not radioactive.
- There will be a backlash if they must be told otherwise.
- Although deuterium and tritium are currently being used in an effort to produce the first net power output from fusion, these fuels should not be considered satisfactory for a final solution.
- Non-radioactive fuels such as Boron-11 must be constantly in our thoughts as we go forward. Commercial fusion reactors must be capable of igniting non-radioactive fuels.
- We must also do our best to mitigate radioactivity at the first wall juncture and elsewhere.
- The public perception of radioactivity and radioactive waste is not good — IT DOES NOT SELL.

- Fusion reactors must be sized reasonably.
- Current cost estimates for the ITER project are approximately $6 billion.
- GE's present quarterly earnings are "only" $4 billion.
- We don't want governments to build fusion reactors, we want private industry to build them.
- Designs need to be feasible with power output in the 15 MWe to 1500 MWe range and cost < $6700 per KWe.

  **(MWe = MW electrical, KWe = KW electrical)**
- More expensive machines will not be commercially viable.
- Competition will only occur if private industry is involved.





Spherical Stellarator

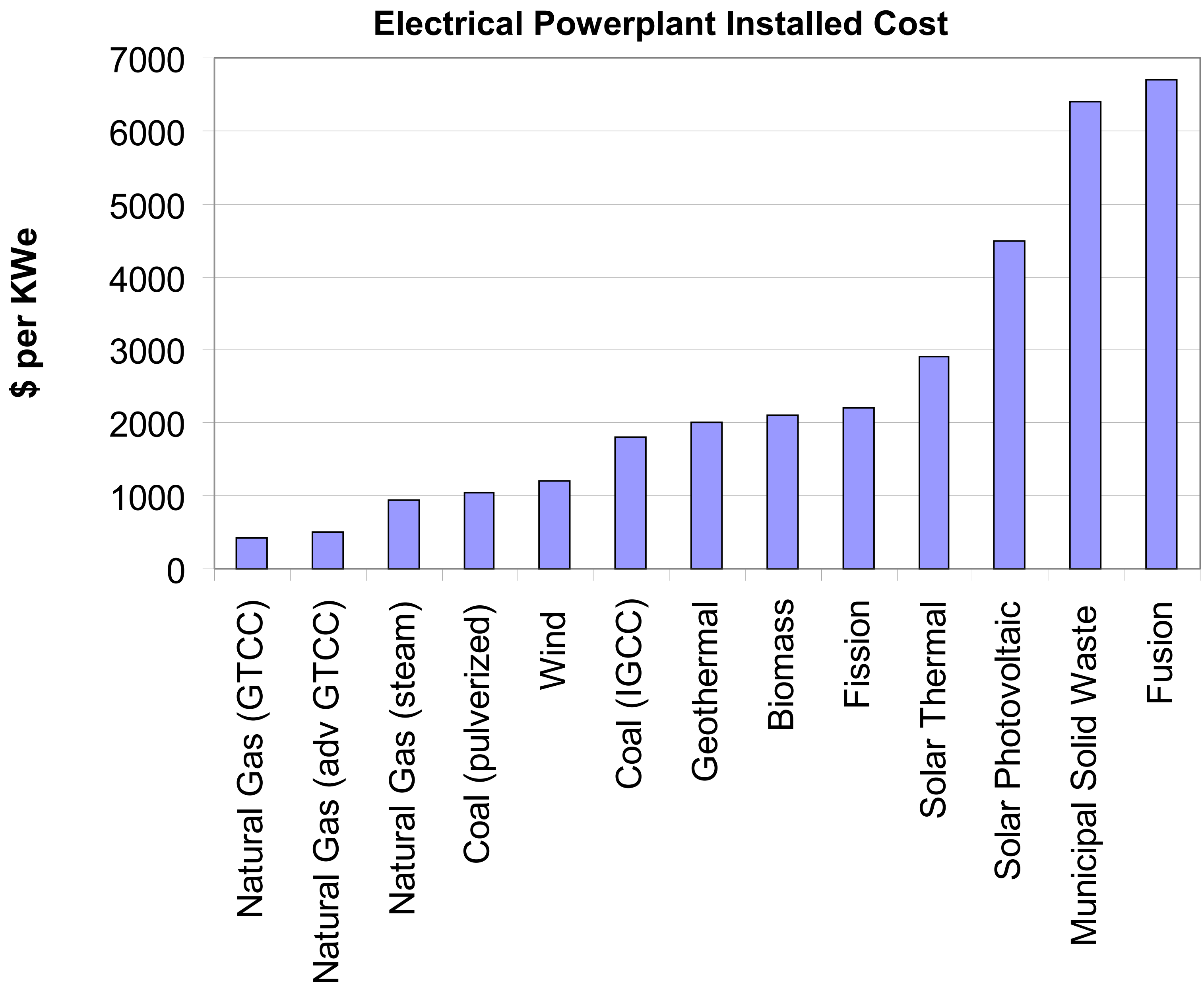
- There is a place for government at the table in the area of research & development.
- 60+ years after its debut, the U.S. government still spends > $400 million per year on gas turbine research & development.
- Many fusion reactor designs are not being investigated (funded) sufficiently.
- A brief analysis of a few promising designs shows the following:

| Concept Description | Time to small-scale net energy production | Cost to achieve net energy production | Probability of success for larger plant sizes if the small-scale energy concept works |
|---|---|---|---|
| Koloc Spherical Plasma | 10 years | $25 million | 80% |
| Field Reversed Configuration | 8 years | $75 million | 60% |
| Plasma Focus | 6 years | $18 million | 80% |

NONE ARE CURRENTLY FUNDED AND G.E. CANNOT FUND THEM ALL

250 Teraflop Cray X2

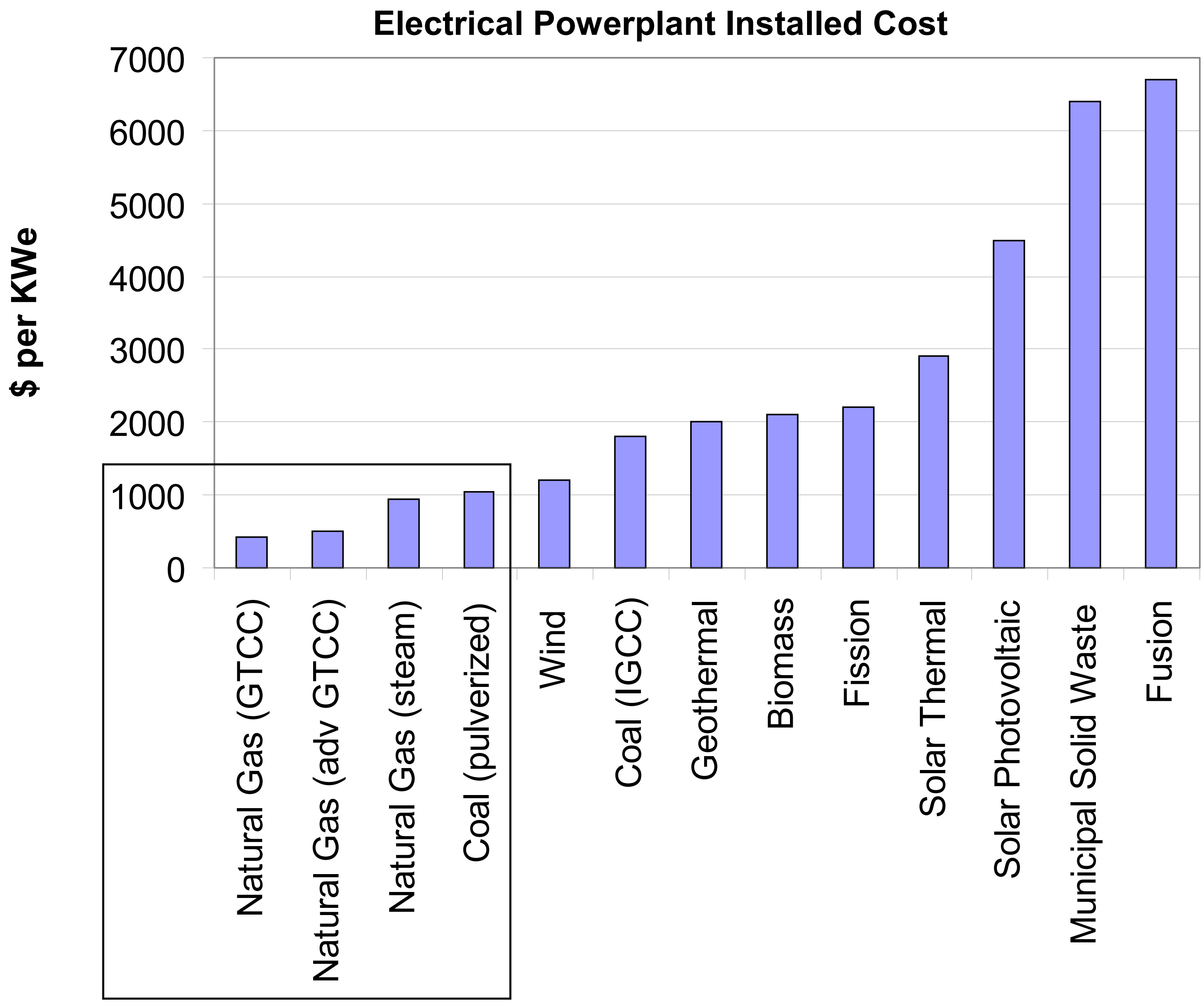
- Research & development is also needed in the area of computing power.
- Many fusion researchers of necessity still use MHD theory to validate their designs.
- MHD theory assumes perfect diamagnetism and perfect conductance.
- These qualities may not always exist in the real world, particularly during continuous operation.
- More computing power is needed to allow use of a more realistic validation theory such as the Vlasov equations.
- ORNL is in the process of adding some impressive computing power.
- Researchers now need to develop more realistic validation methods up to the limits of the available computing power.
- Governments need to fund these efforts.



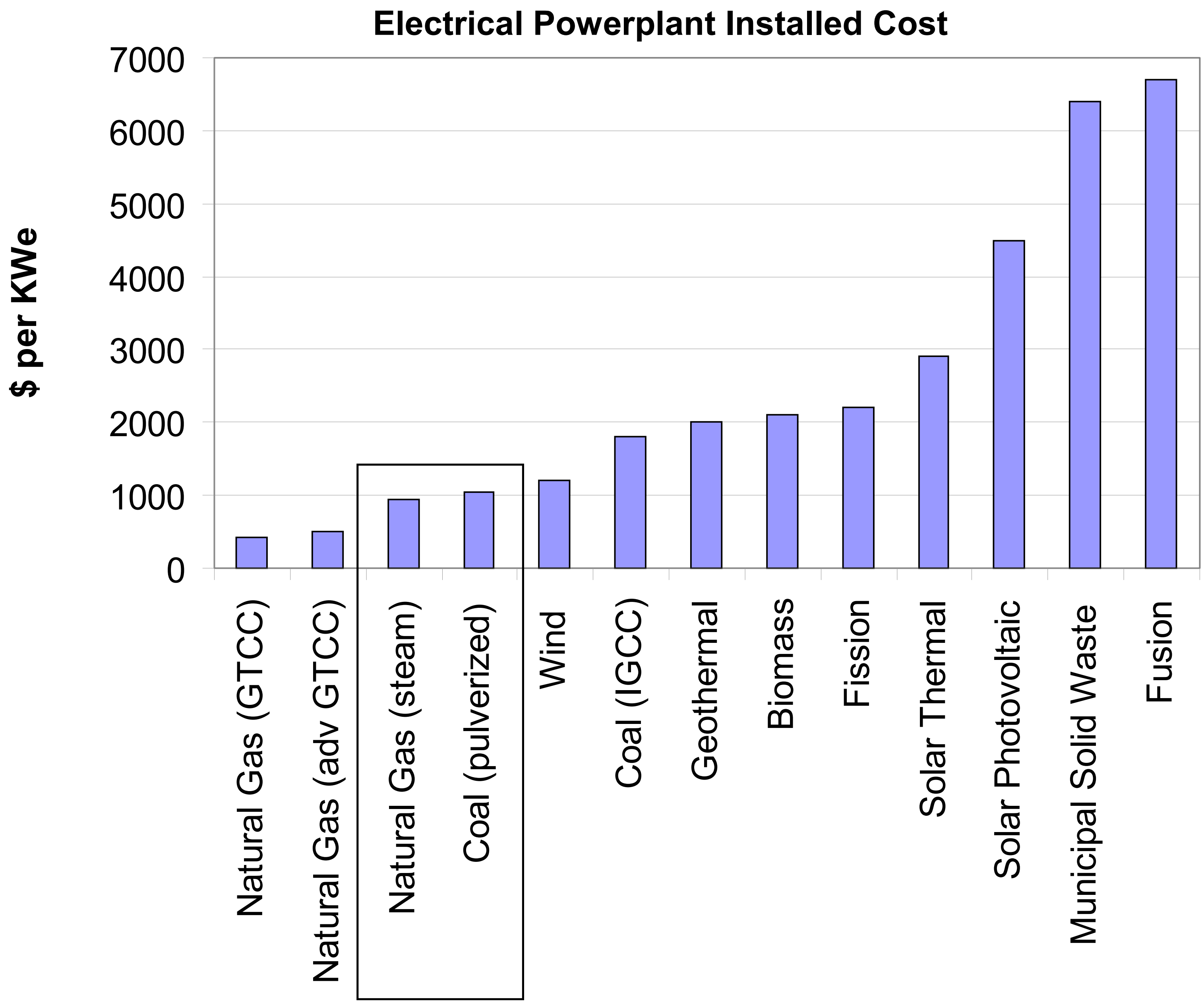

- **We are being generous when we say that fusion powerplants must come in at < $6700 per KWe.**
- **ITER (which receives the majority of federal fusion R&D money) does not meet the need.**

- A 1500 MWe fission plant which can be installed at $2200/KWe will cost $3.3 billion.
- This is a financial limit beyond which many companies will not go, even though fuel cost and lack of cleanup issues may, in some instances, justify the higher cost of a fusion plant.
- At $6700/KWe, a 500MWe fusion plant could be installed for about the same cost.
- A 500 MWe gas turbine combined cycle power plant operating at 60% thermal efficiency will consume 25.75 billion SCF of natural gas per year (8600 hours) at a cost of $128.73 million (at $5 per 1000 SCF).

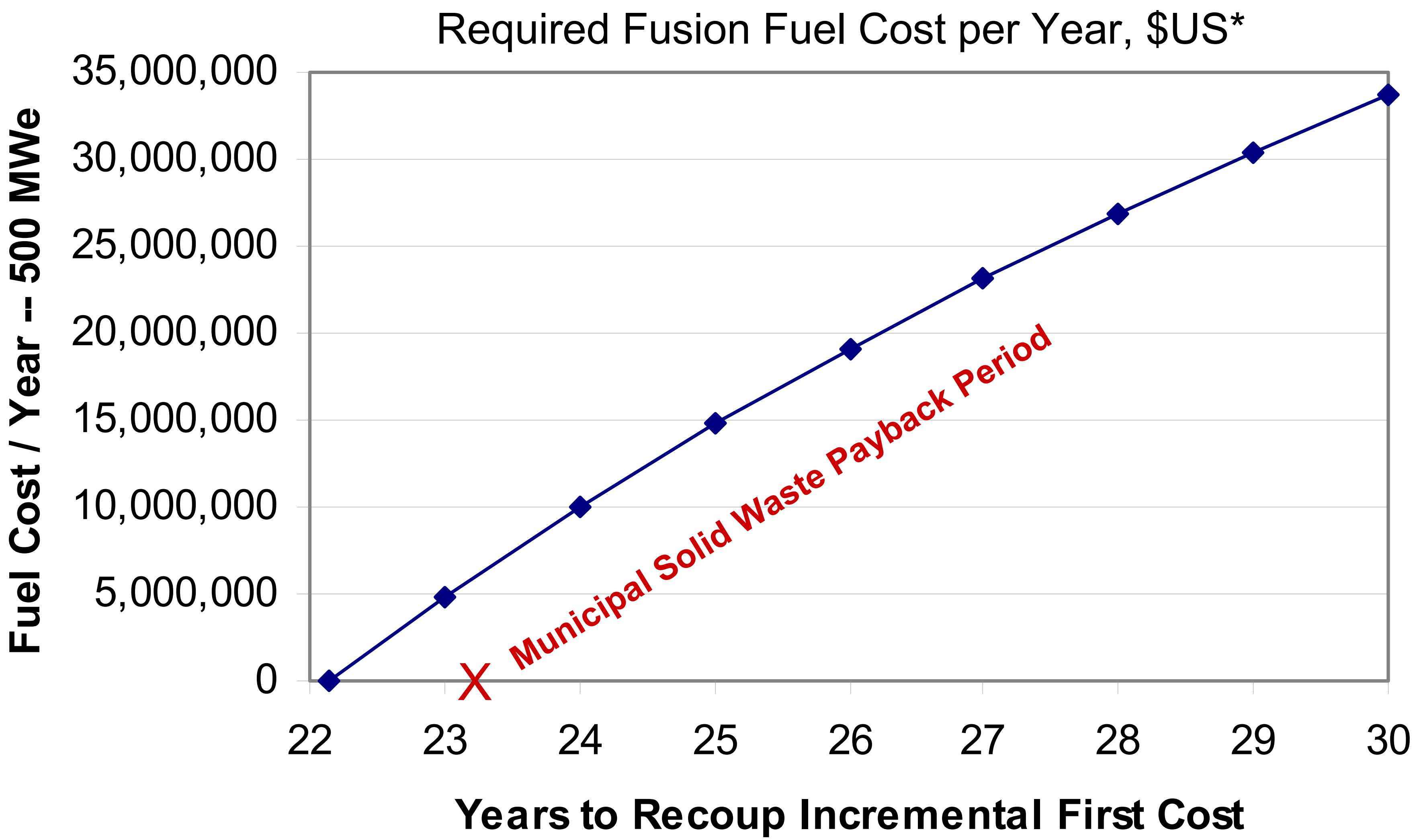
**G.E. 500 MWe Frame 9H gas turbine CHP (combined heat & power) plant in Wales**




This will be the main area of competition for fusion powerplants.

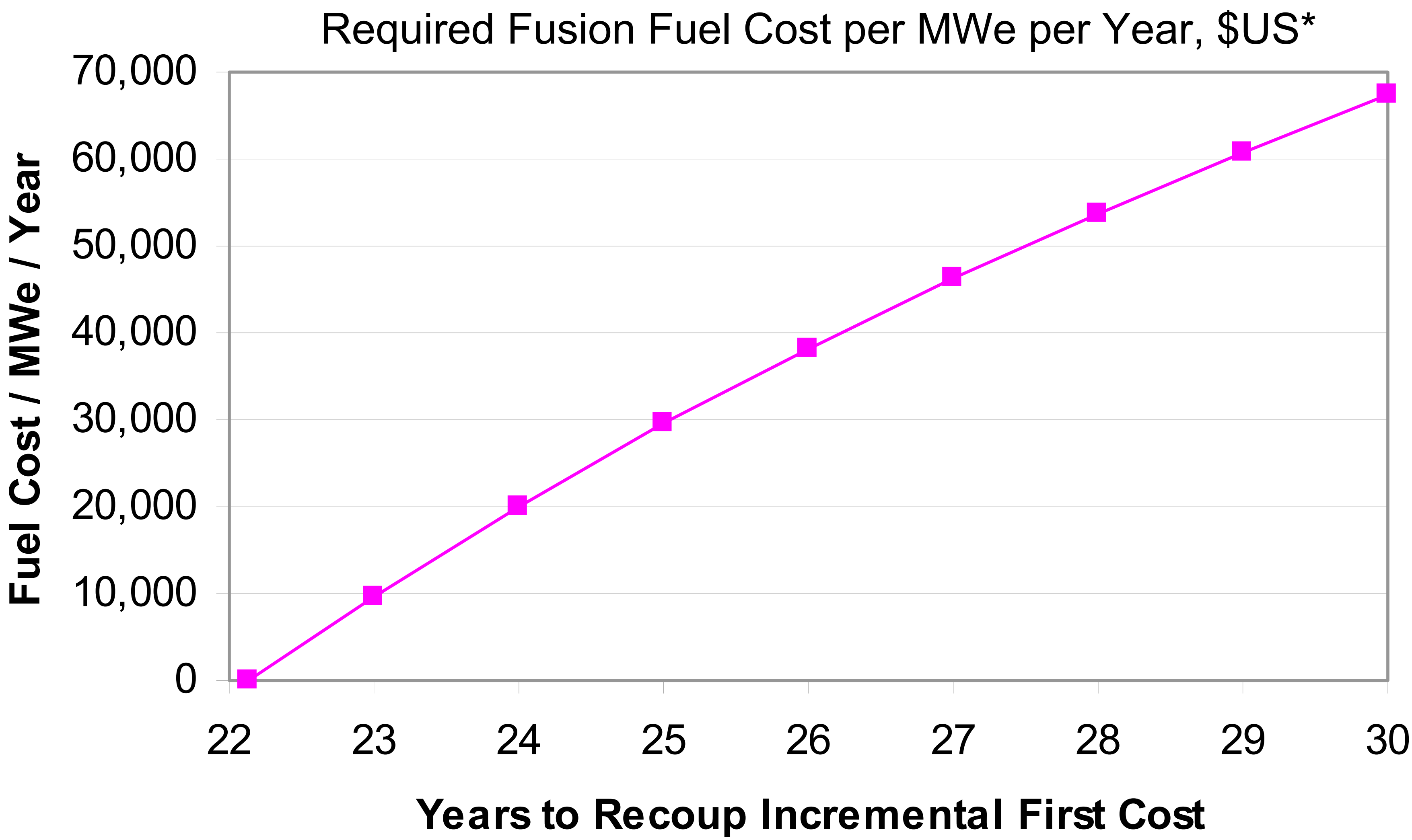



CHP & steam plants are on the upper end of the competitive spectrum and cost about $1000/KWe.



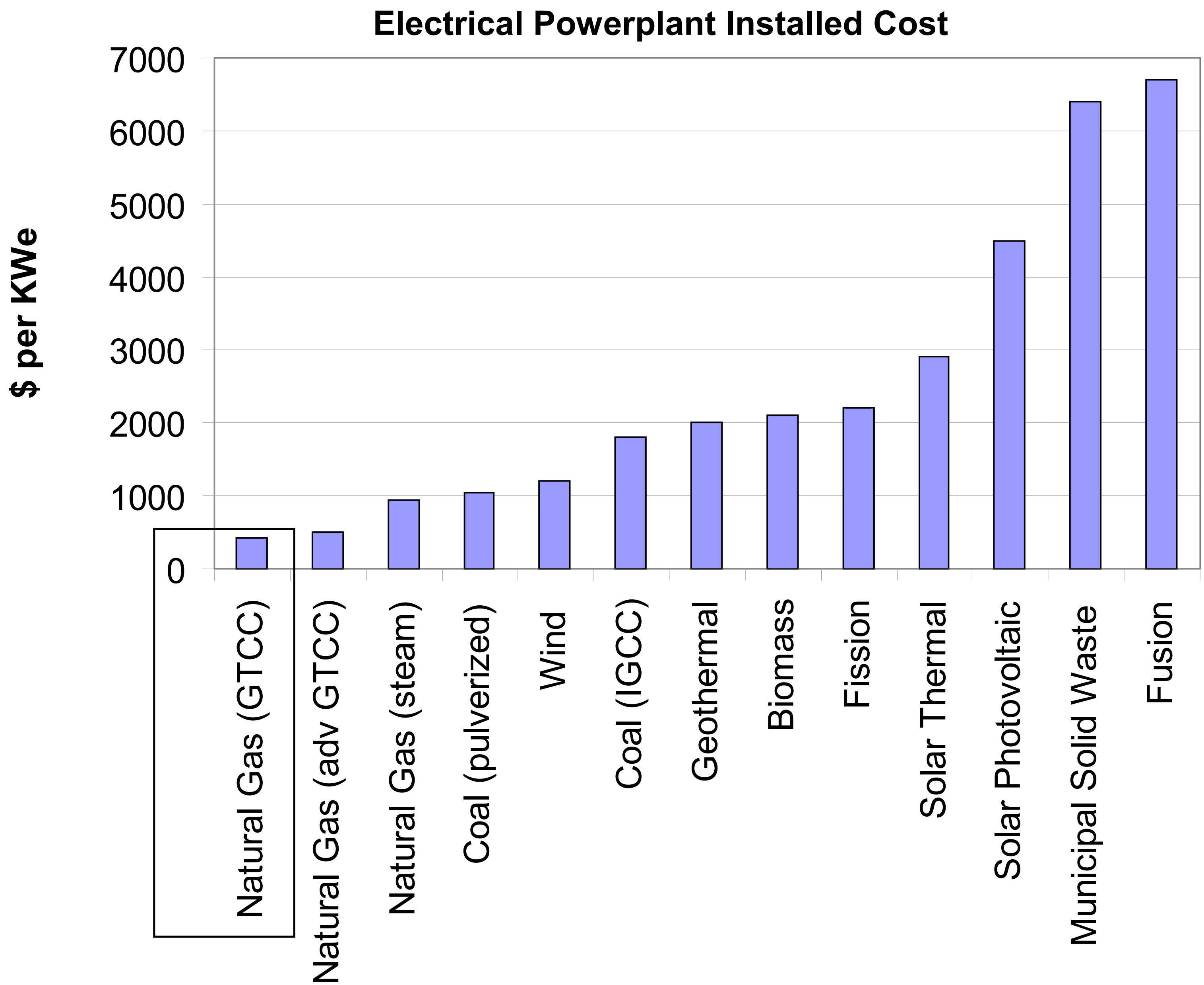

Compared to a power plant with an installed cost of $1000/KWe, the fuel cost for fusion must come in at < $5 million / year for a 500 MWe plant to justify an installed cost of $6700/KWe and recoup the incremental cost over a 23 year period.

*** Based on $6700/KWe installed cost for fusion plant, $1000/KWe & 60% thermal efficiency for competing plant.**

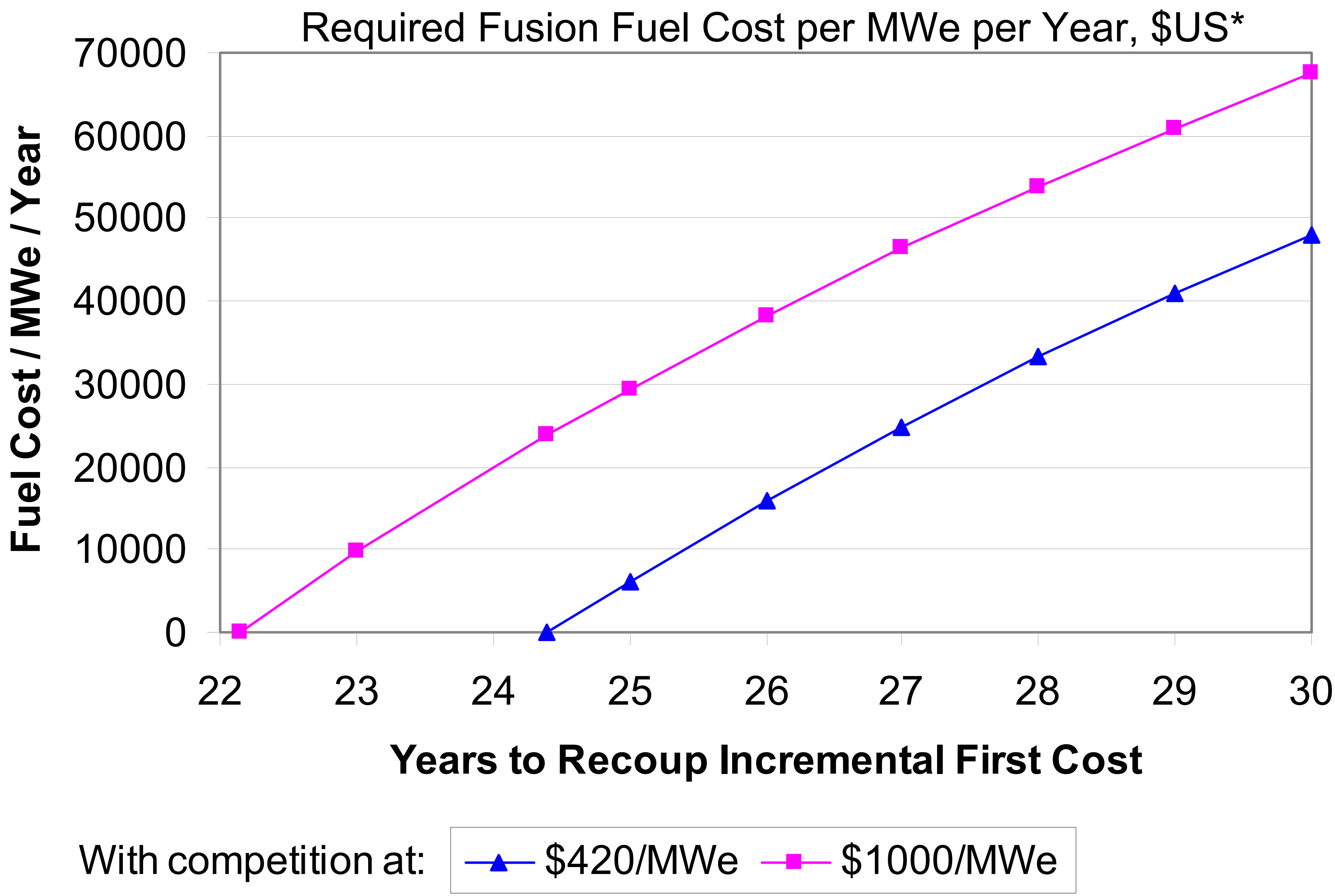



And here is the normalized data, in fuel cost per MWe per year.

*** Based on $6700/KWe installed cost for fusion plant, $1000/KWe & 60% thermal efficiency for competing plant.**

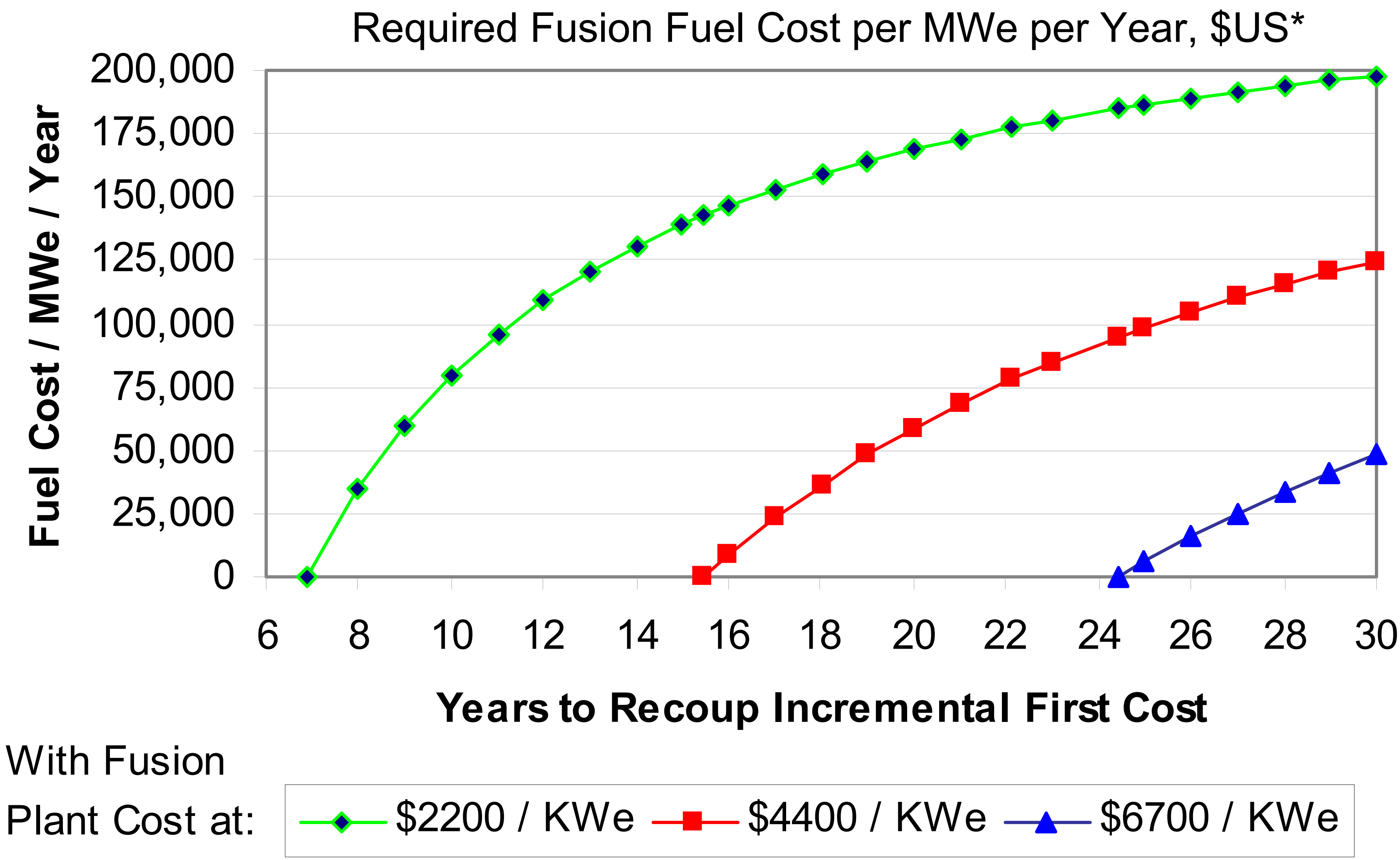



Now let's perform a perturbation study on a gas turbine combined cycle powerplant at an installed cost of $420 per KWe to see how the results are affected.




At constant fuel cost, the payback period is extended by 2 to 3 years when the competition can install at $420/KWe instead of $1000/KWe.

*** Based on $6700/KWe installed cost for fusion plant, & 60% thermal efficiency for competing plant.**




- If we must build an expensive powerplant, the fuel cost must be low.
- If we can build a less expensive powerplant, the fuel cost can be higher.

*** Based on $420/KWe installed cost & 60% thermal efficiency for competing plant.**

# Recap

- Finding a method of converting fission or fusion energy directly into electrical energy is of great interest providing it can be accomplished at an equal or greater efficiency than when using steam + rotating equipment.

- New nuclear powerplants (fission or fusion) need to be inherently safe by the very physics of the design.

- Fuels for commercial fusion powerplants need to be non-radioactive for broad customer acceptance.

- Commercial fusion reactors must be capable of igniting non-radioactive fuels.

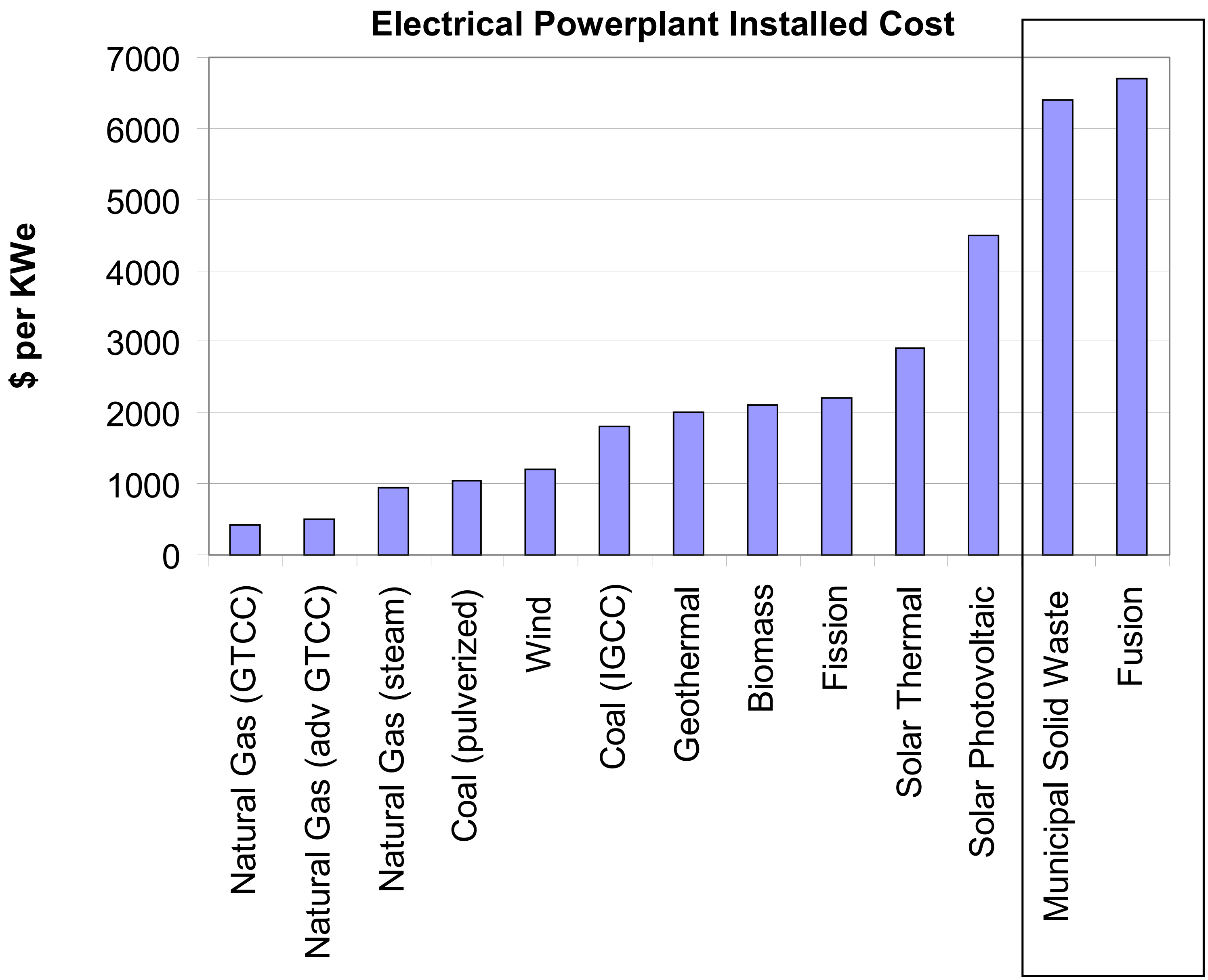
- Government needs to be generous in its funding for alternative approaches to fusion. Only in this way can the time to net energy production be minimized.

- Government also needs to fund research activities aimed at developing more realistic computational validation methods for fusion reactors as well as the computers needed to run the more realistic algorithms.

## Recap

- We don't want governments to build commercial fusion reactors, we want private industry to build them.
- Fusion powerplants must be able to compete against gas turbine and coal-fired units which have much lower installed cost, but much higher fuel cost.
- The maximum allowable fusion powerplant installed cost for commercial viability is $6700/KWe.
- If the installed cost of the fusion powerplant is high, its fuel cost must be low.
- If the installed cost can be reduced, the allowable fuel cost can be increased.

# and …




- If cities have installed municipal solid waste power plants, then fusion power plants should be readily accepted if the design adheres to the constraints presented herein.

*Questions?*