Placing Fusion in the spectrum of energy development programs

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Where innovation starts

Put fusion in same plot with other energy sources/options

Fusion is *'clean, safe, for all and forever'*. That is good.

Fusion also has the name *'expensive and takes forever'.* Not so good.

To gauge the latter judgment, it is useful to compare fusion to other energy sources in development.

This comparison should be based on an existing representation of the other energy sources, with the fusion data plotted plotted in.

I found the plot of effective total installed power versus time, in the article 'No quick switch to low carbon energy', by G-J Kramer and M Haigh, Nature, Dec 2009, a good starting point. It uses historical data from IEA and future projection from Shell scenario studies (so called 'blue-print' scenario).

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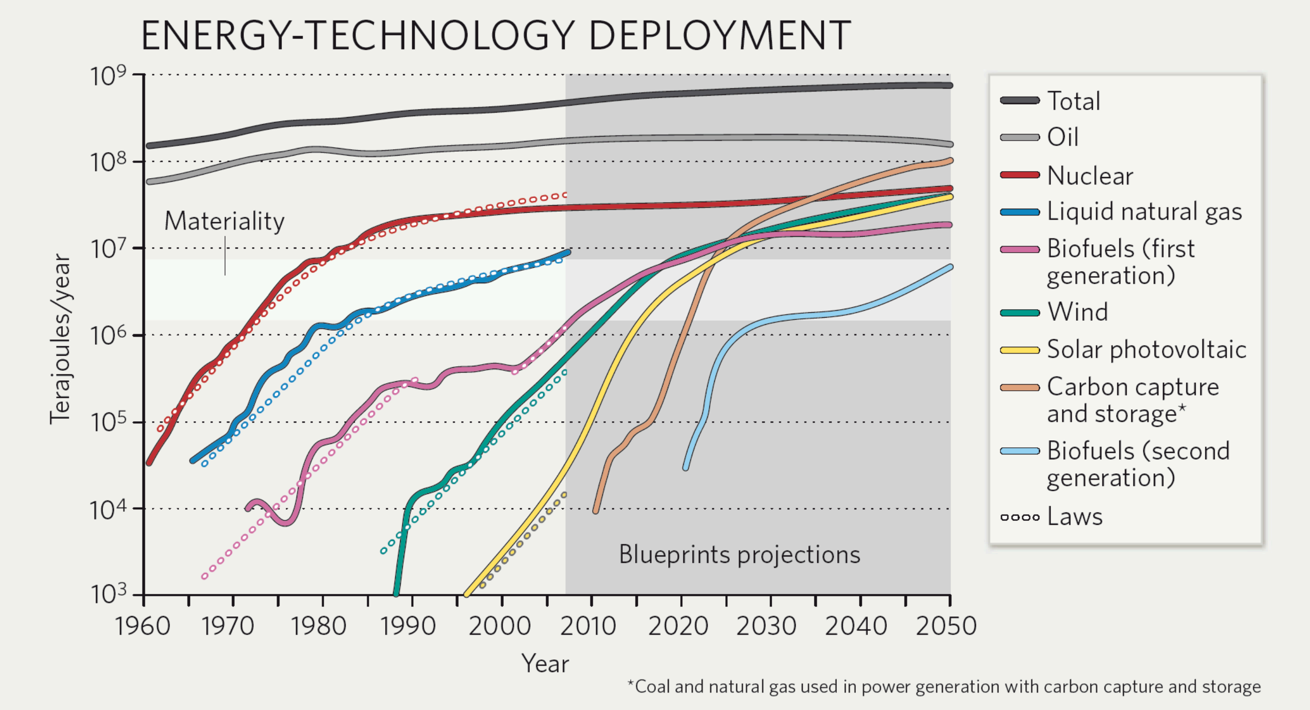
Starting point: G-J Kramer and M Haigh, *No quick switch to low carbon energy*, Nature, Dec 2009



- All new energy sources have exponential growth up to 'materiality'
  - Materiality typically 1-10% of final installed power
  - Doubling time during exponential growth typically 2-3 year
- Followed by Linear growth: typically during 1 replacement time (50 years)
- Therefore: 'no quick switch to low carbon energy'

Exponential growth phase: energy production irrelevant

My observations based on this graph.

- First of all: since the exponential growth stops at typically 1% of the final capacity, the energy production during this phase is irrelevant.
- Moreover: during exponential growth only the doubling time, i.e. the last few years, count
- Moreover: if *doubling time* is shorter than *energy payback time* then clearly net energy production is negative. (this is e.g. the case for photovoltaic).

Bottom line: exponential growth phase is irrelevant for energy production.

Exponential growth phase: energy production irrelevant

-continued-

- All of this is not a criticism. It just states that a system has to go through a growth phase before it starts to produce. This phase is needed to build up capacity. Energy production during that phase is irrelevant.

- Therefore: also for Fusion we do not need to look at net power output. But characterize state of development by fusion power level.

- But include – to be comparable to numbers of other energy sources -
  - (hypothetical) efficiency of electricity generation, and
  - (hypothetical) availability

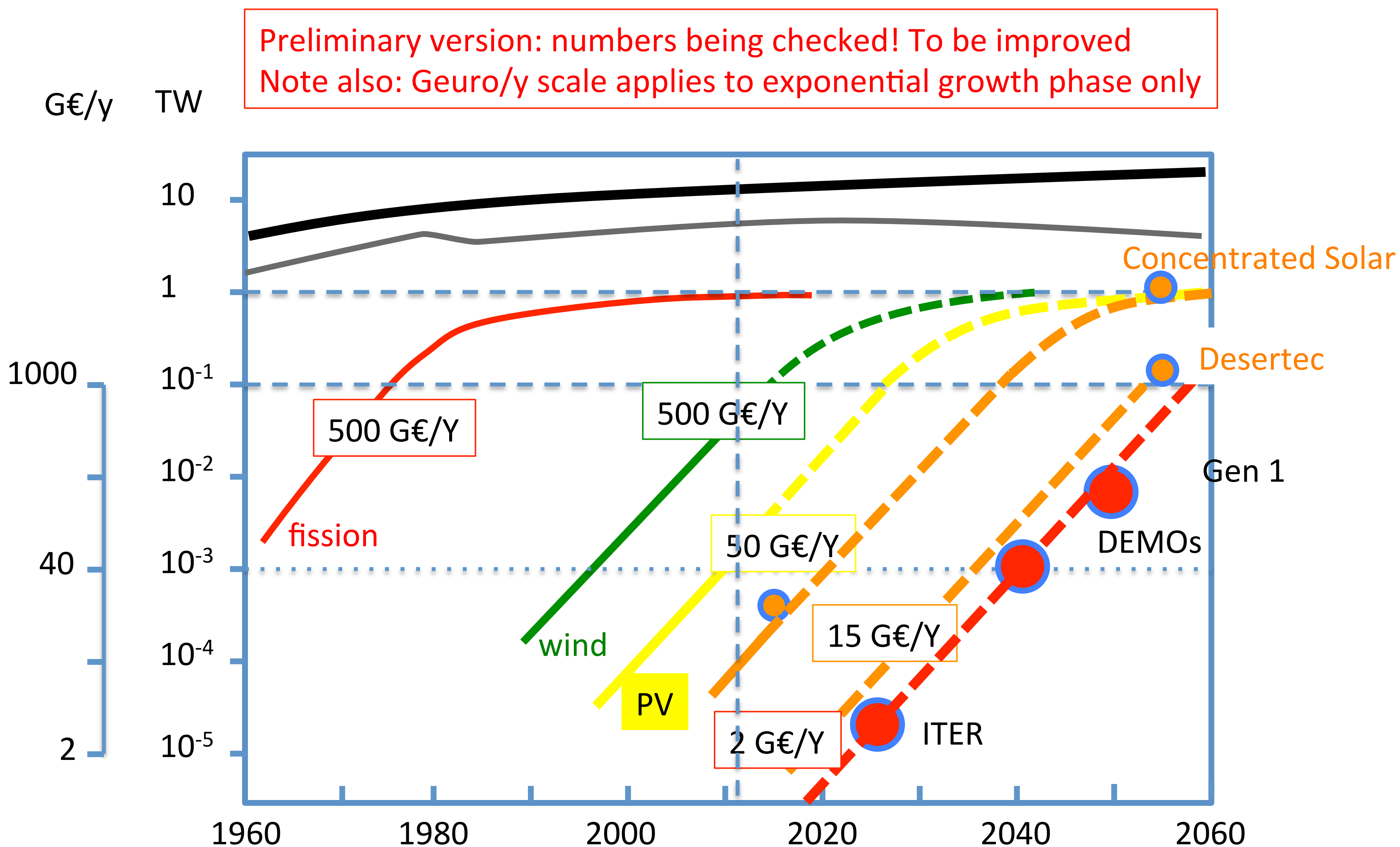
Exponential growth phase: serious money involved!

- Having realized that energy generation is irrelevant (or negative) during the exponential growth, it is interesting to note the budgets involved.
- During exponential growth: economy dominated by capital investment (overnight cost).
- This is well-documented for different sources, typically in the range 3-6 $/We. (Watts of effective installed electrical power), and during development decreases (learning curve).
- Folding that with exponential growth gives annual budget (i.e. required to realize the growth.) Figure in next slide gives some rough numbers.

During exponential growth, at 1 to 100 MWe total installed power, budget required: tens to hundreds Billion Euro/year!

This is taxpayers money, invested in a future energy source.

Future = decades later



Preliminary version: numbers being checked! To be improved
Note also: Geuro/y scale applies to exponential growth phase only
G€/y
TW
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1000
40
2
Concentrated Solar
Desertec
Gen 1
500 G€/Y
500 G€/Y
fission
50 G€/Y
DEMOs
wind
15 G€/Y
PV
2 G€/Y
ITER
1960
1980
2000
2020
2040
2060

(Assumptions)

- ITER: Pfusion=400 MW.

  hypothetical Pelectric=150 MW. Availability = 10%.

  → hypothetical power: 15 MW.

- DEMO: 3 plants, 1.0 GWe each, availability 30%

  → hypothetical power: 1.0 GW.

- Gen1: 10 plants, 1.7 GWe each, availability 50%

  → hypothetical power: 8.5 GWe

Conclusions

- Fusion is NOT expensive
- Present Fusion Road Maps are very similar to development lines of other sources.
- But we must stick to those dates: Gen1 fusion in 2050. If not we are considerably slower than others. Then '*expensive and takes forever'.*

BUT

- To realize this roadmap, a reasonable budget is order 10 Beuro/year in the ITER Era, i.e. from 2020 or so. Don't pretend we can do it with steady budget.
- By that time the program should be technology/industry driven, not science driven.

This requires a dramatic change of the organization of the field: the funding structure, governance, human resource strategy.

I believe this outlook should impact our planning for the next 10 years.