Fusion Implementation Scenarios

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http://energystudies.pppl.gov

Study Goal

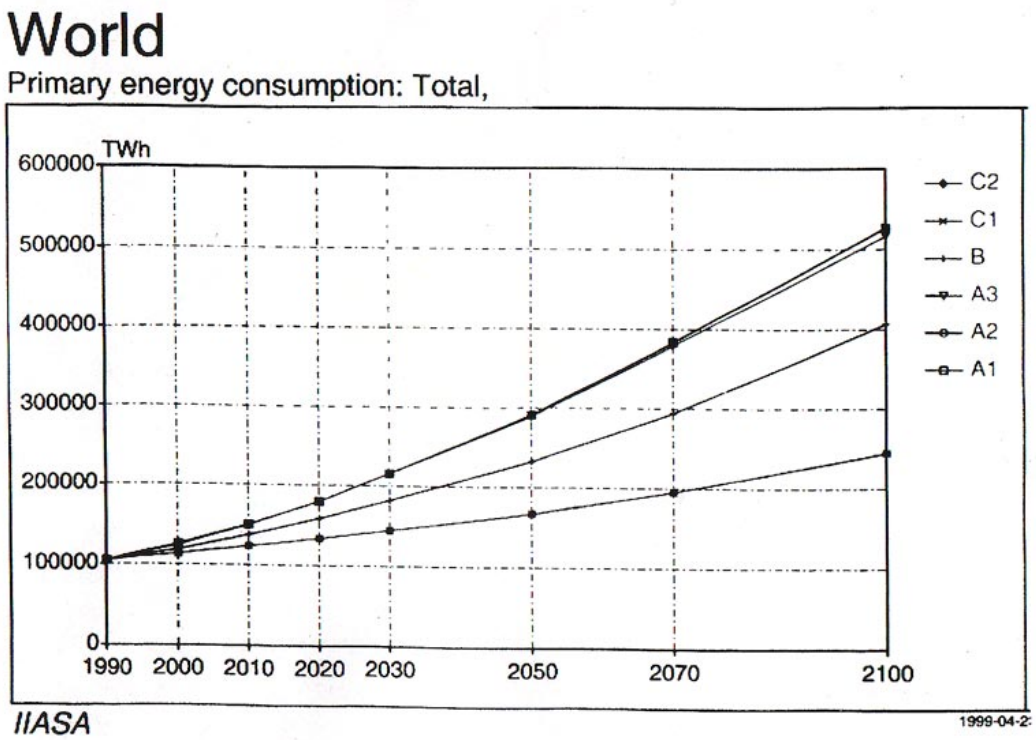
Examine the implications of fusion scenarios that attempt to begin to significantly impact the need for clean energy during one of three future periods: 2000-2050 or 2050-2100 or 2100-2150.

This study focuses on world energy issues as opposed to regional energy issues.

Abstract

Fusion implementation scenarios were developed to demonstrate fusion's role in reducing carbon dioxide emissions. These scenarios are used to quantify the construction material, requirements and waste production associated with fusion.

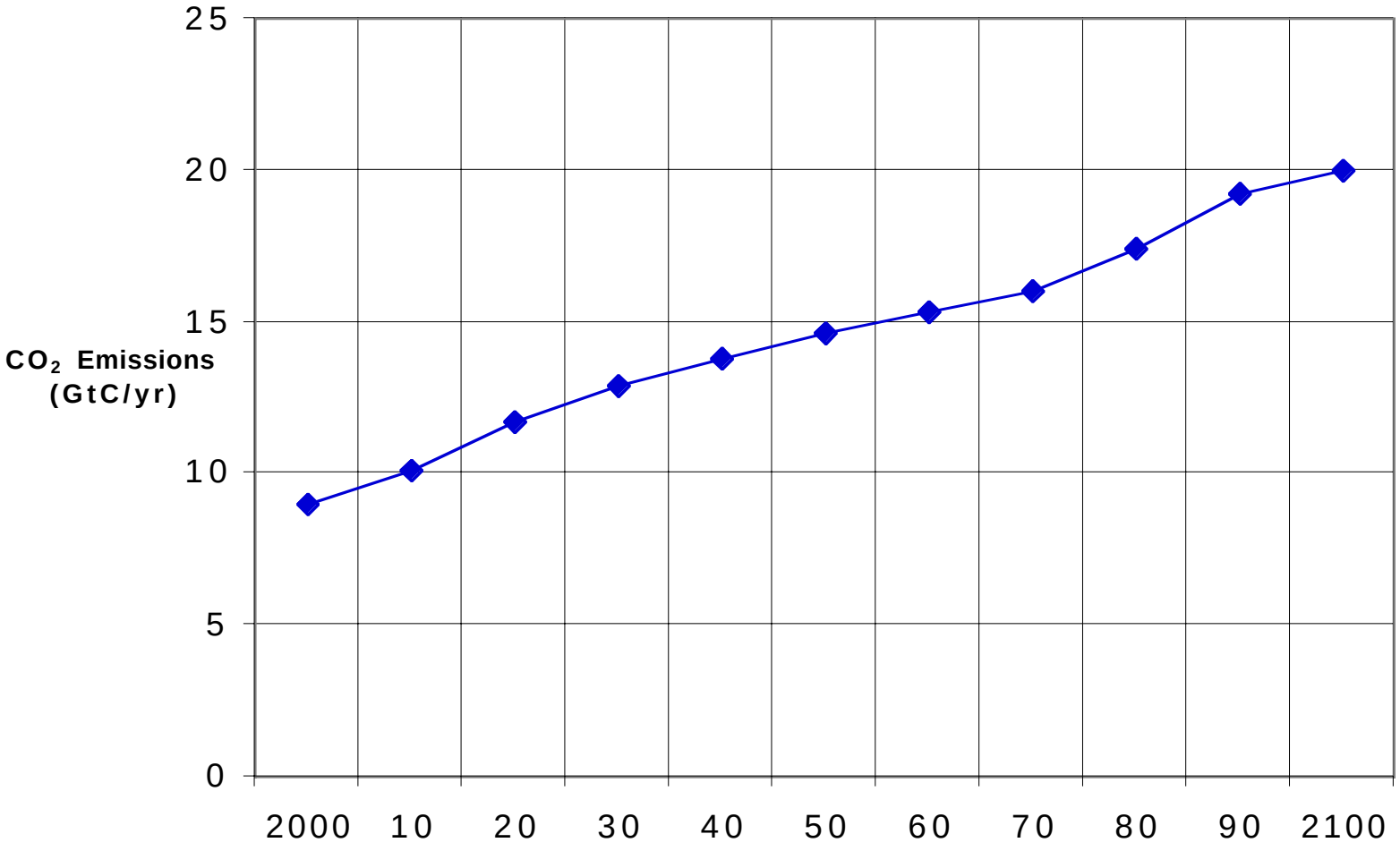
Projected World Energy Consumption Scenarios



Wide ranges of future world energy requirements have been projected depending on population growth, economic growth and the availability of environmentally benign energy options.

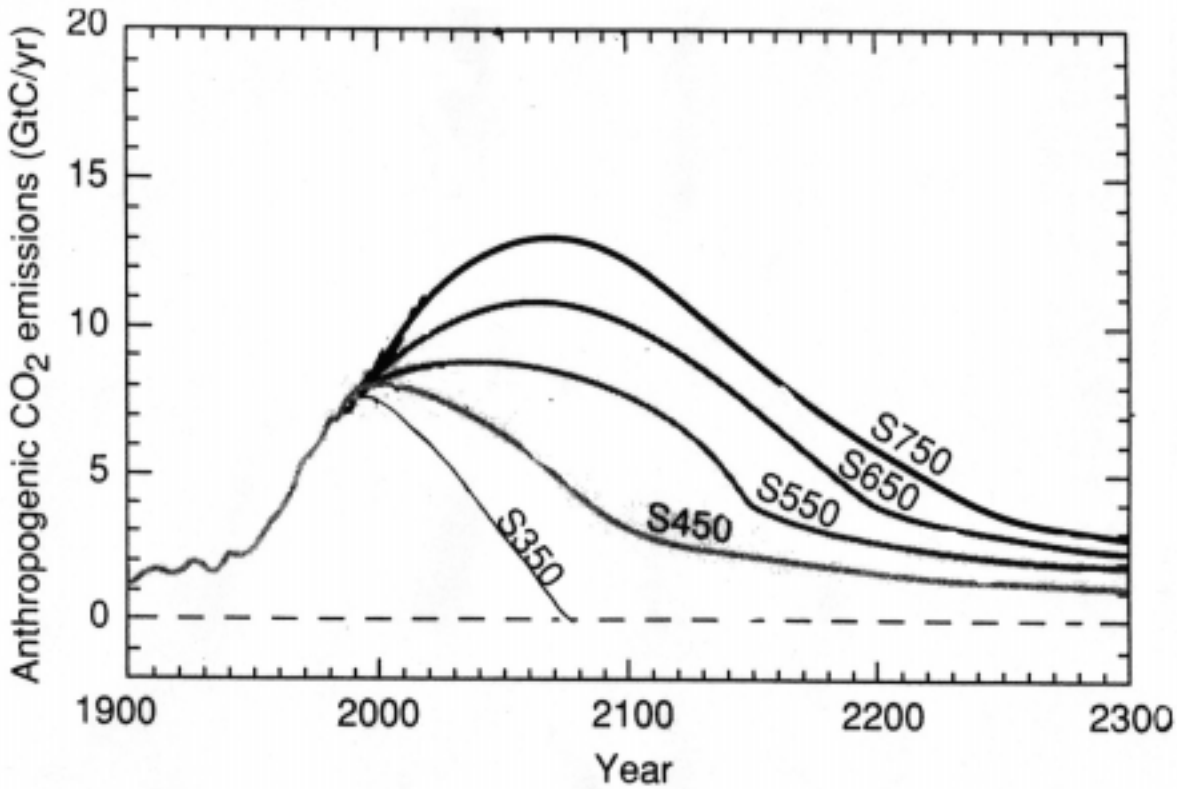
Reference: Nakicenovic, N., Grübler, A., and McDonald, A., eds., 1998 *Global Energy Perspectives*, Cambridge University Press, Cambridge, UK.

CO_2 Emission for Typical "Unconstrained" Scenario



Based on models of future energy requirements, the IPCC has developed a range of emission profiles for carbon dioxide production from unconstrained energy use. This shows a "typical" unconstrained emission profile that was used for further analysis. (IS92A)

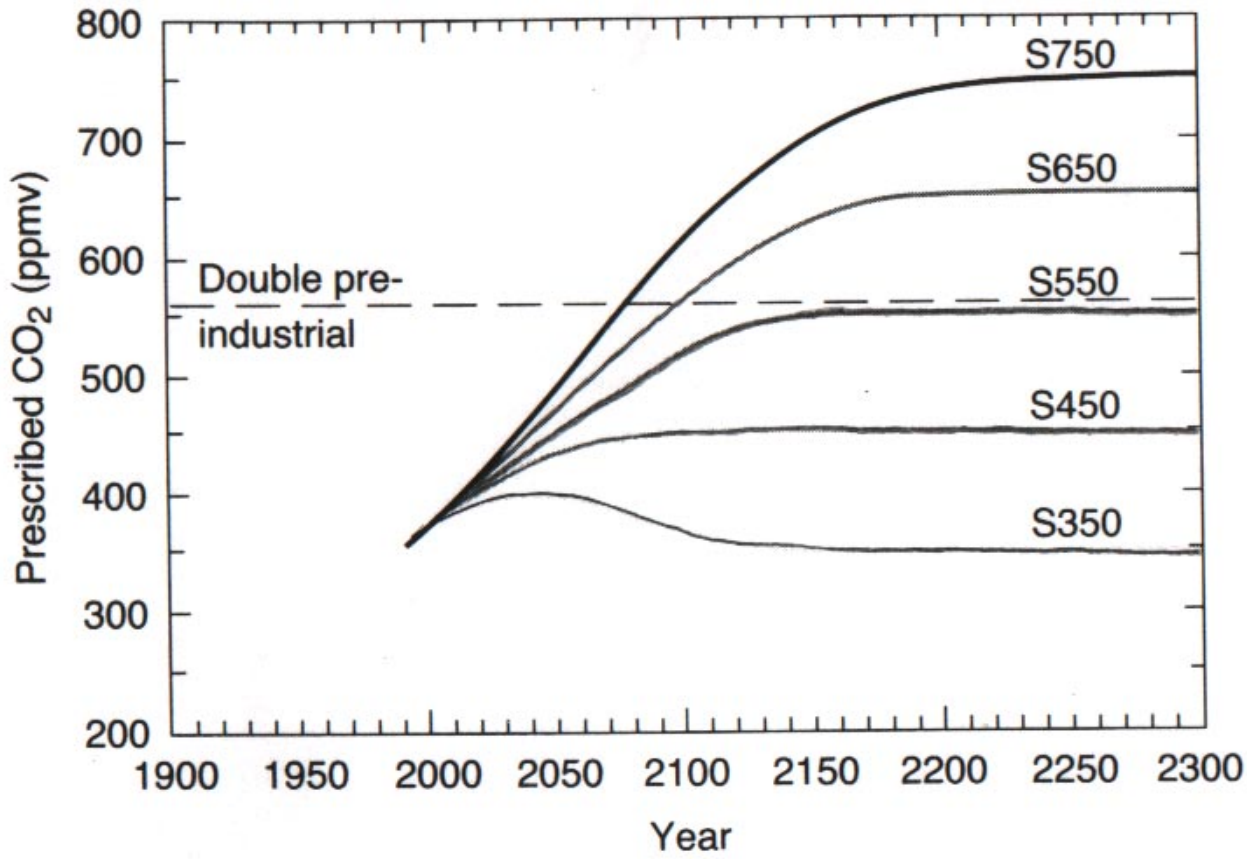
Possible Constrained CO_2 Emission Scenarios



The IPCC has developed the emission profiles required to constrain atmospheric carbon dioxide to a range of future saturation levels.

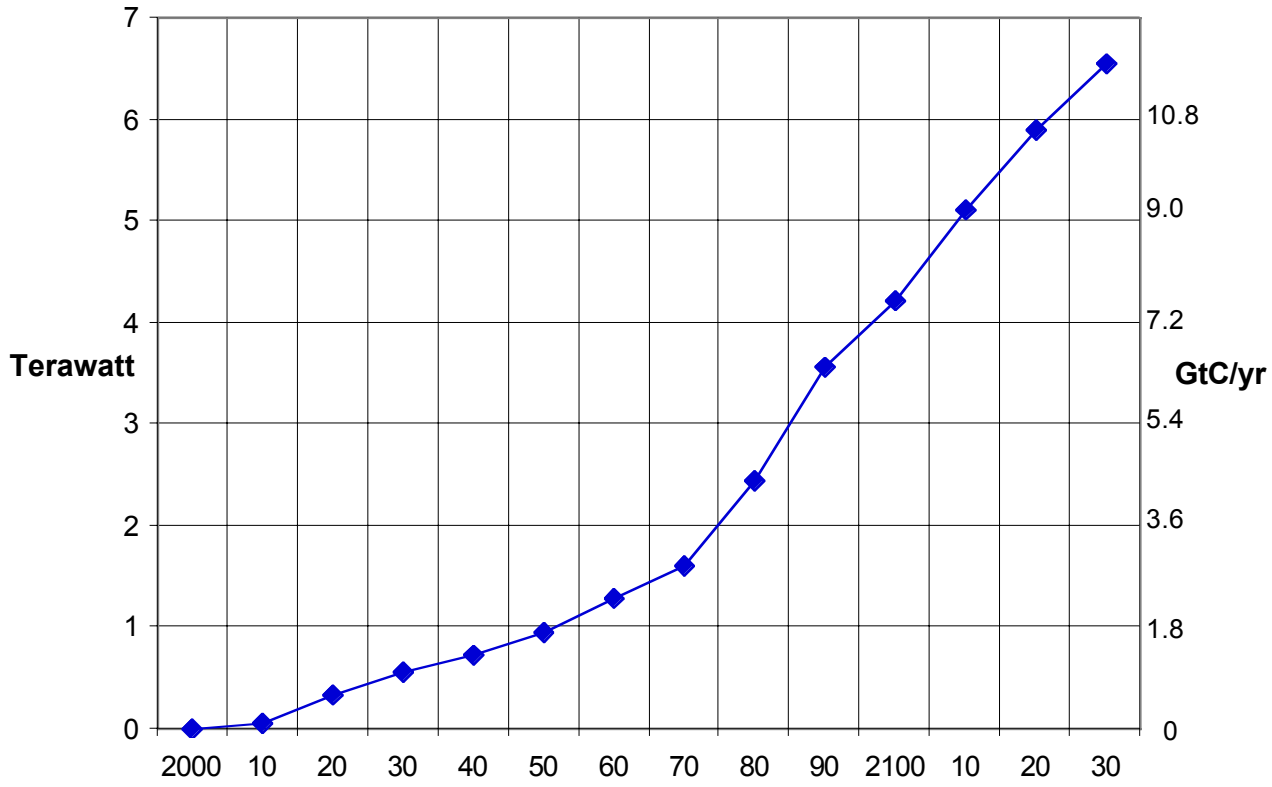
Reference: www.ipcc.ch

Projected CO_2 Concentrations



The emission profiles shown in the last figure are projected to result in the following atmospheric concentrations (with corresponding labels) of carbon dioxide.

Projected Need for Non-Carbon Producing Energy



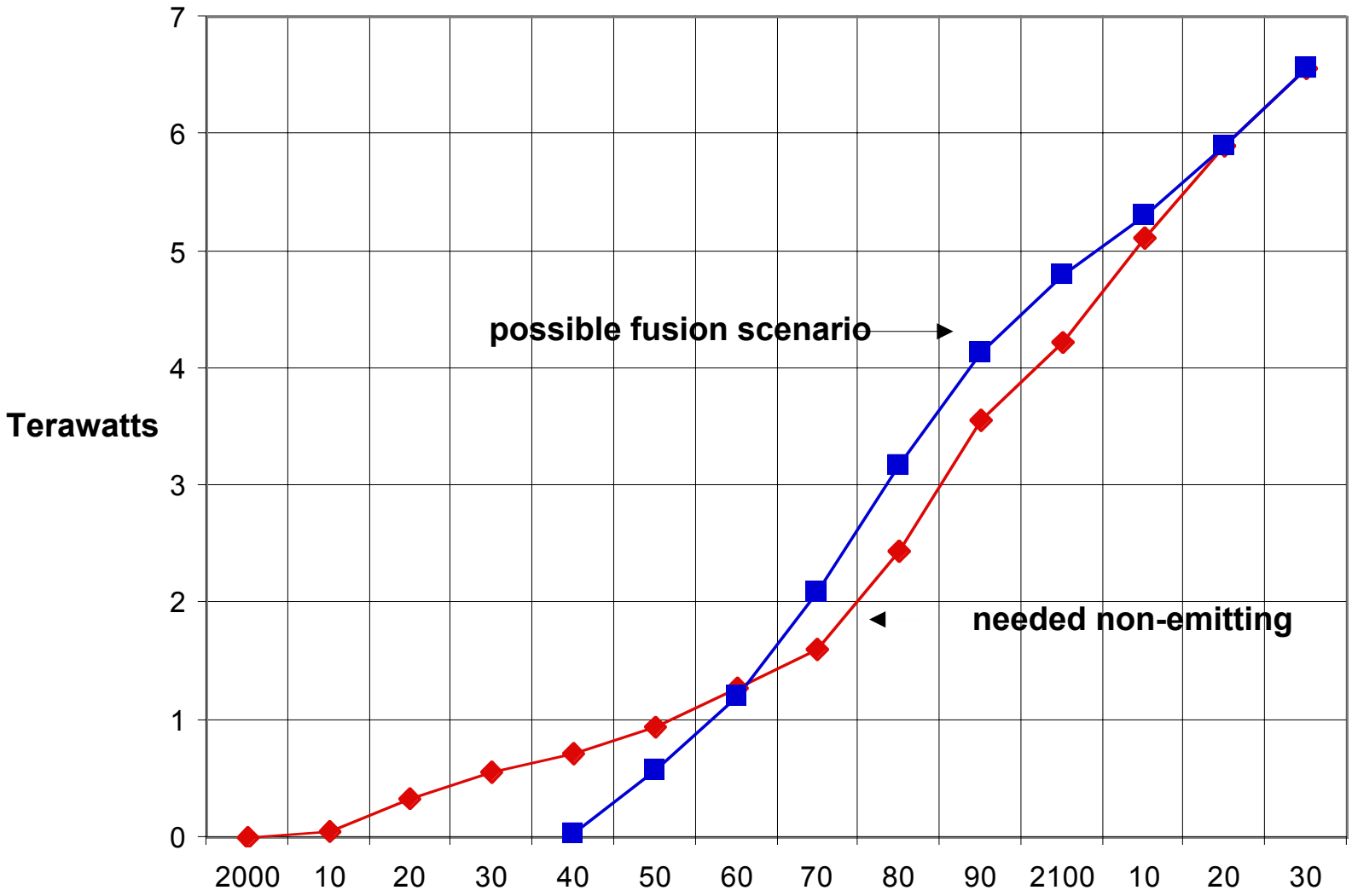
A measure of the need for non-carbon dioxide producing energy sources (e.g. fusion) can be generated by subtracting the constrained emission profile from the unconstrained emission profile.

The least aggressive (highest concentration) constrained emission objective was used (i.e. 750 ppm). The emission rates can be converted to equivalent terawatts of power production per year, roughly as shown, by using a carbon dioxide production per unit power that is typical of fossil fuels (i.e. 1.8 Mtonne C/GW-el-yr).

What is the Role for Fusion Energy?

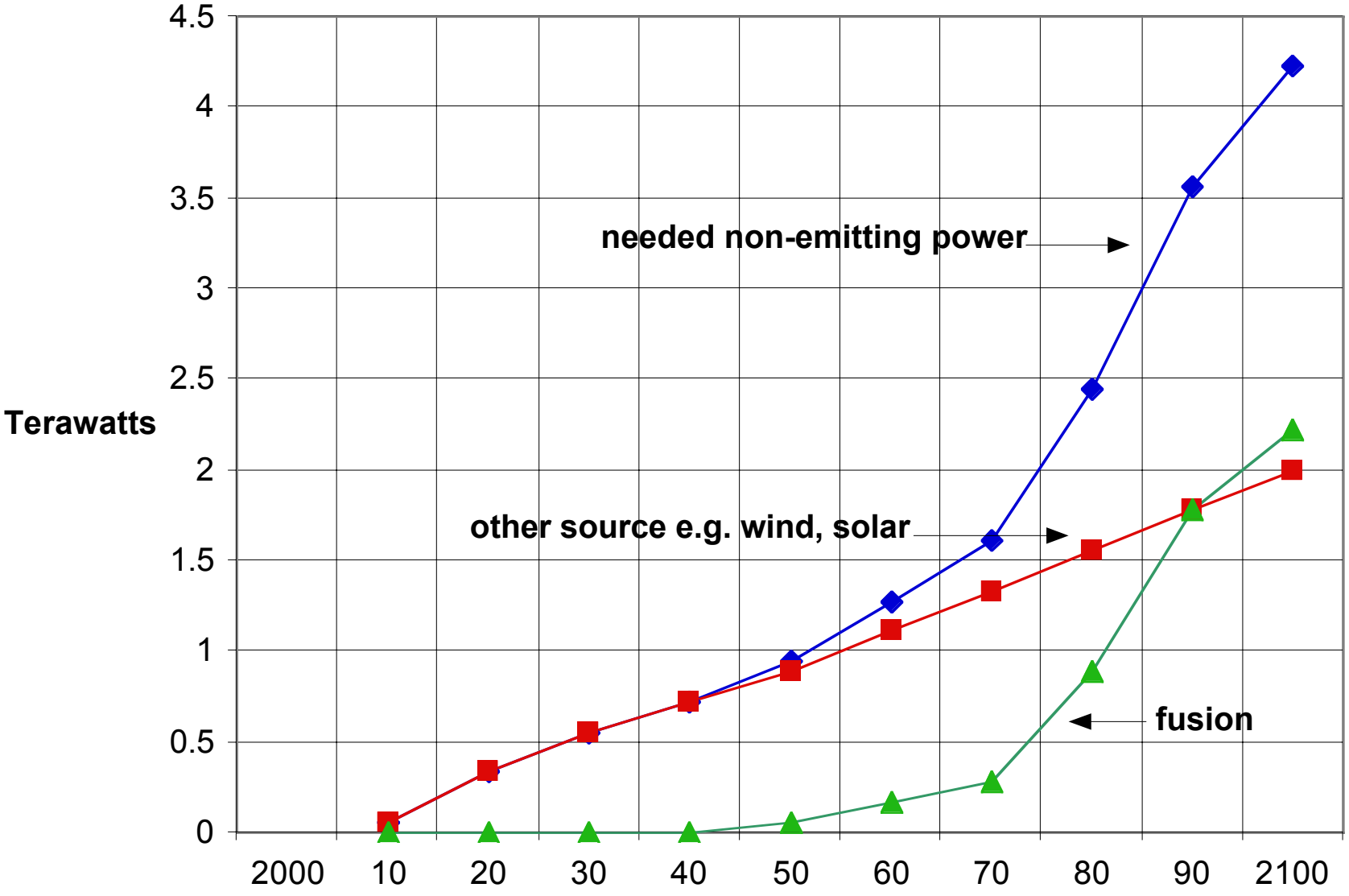
A realistic fusion commercialization schedule would preclude fusion from contributing to the initial ramp (i.e. 2000-2050) of needed non-emitting energy. However, since this initial ramp is not key to the long term atmospheric concentrations, this would not preclude fusion from being a long term contributor. With this in mind, a range of possible fusion power production scenarios can be developed.

Can Fusion Fulfill the Need for Non-Co_2 Emitting Power?



Could fusion contribute a power production that starts later than, but is equivalent to, the needed non-emitting power as shown above? This is a very aggressive and likely impractical fusion implementation scenario.

Fusion Can Contribute in a Portfolio



Could fusion share the glory of non-emitting energy production with another source that "shoulders the early load"?

Fusion must be Developed Expeditiously

If we focus our attention on the portfolio approach as an intermediate fusion scenario, keeping in mind:

- This leads to a relatively high saturation level for atmospheric concentration of carbon dioxide (i.e. 750 ppm); i.e., more fusion power production would be better.
- Fusion shares the "load"

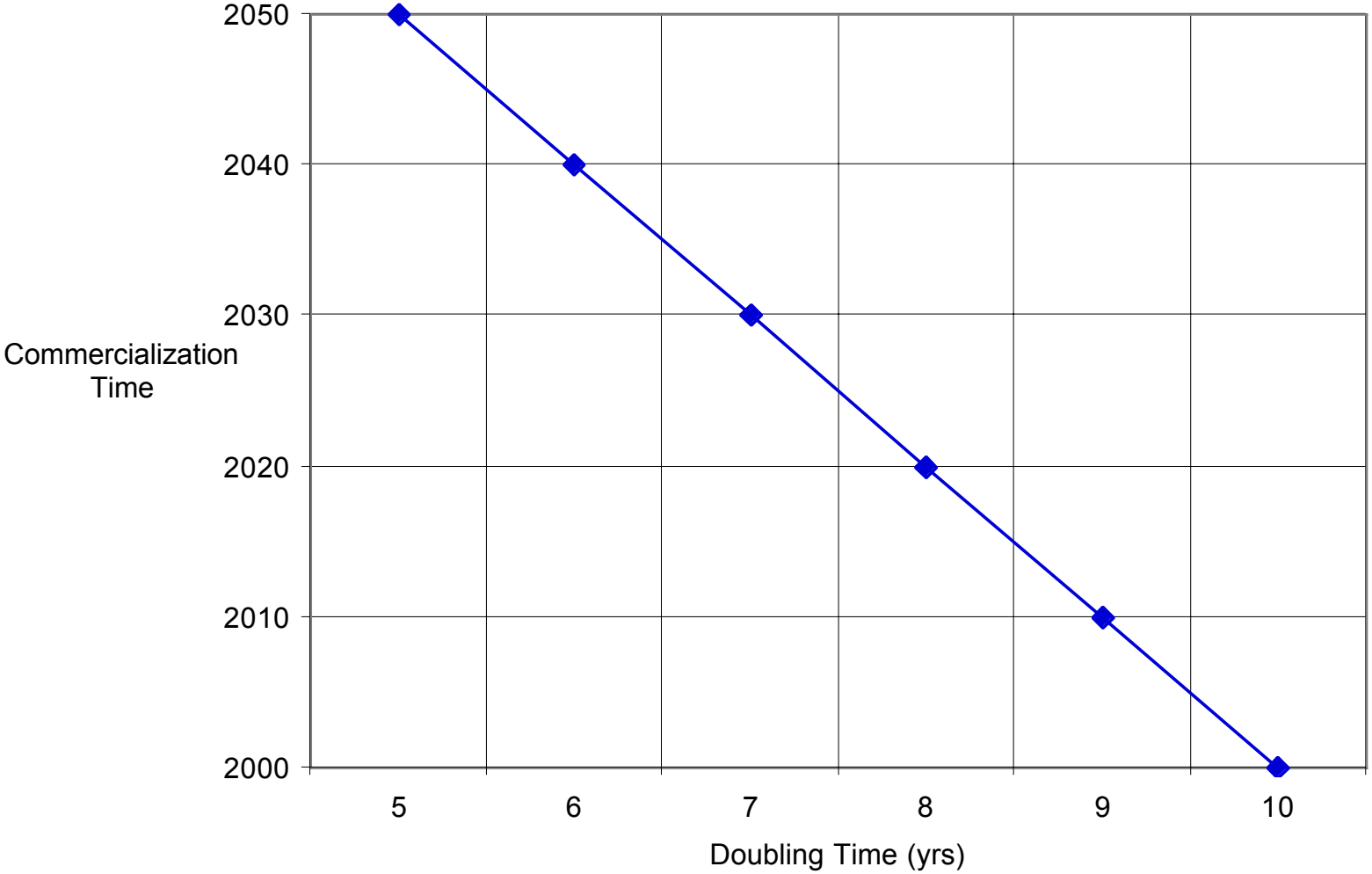
We observe that the profile for required fusion energy production has many of the characteristics of an exponential - i.e., a relatively constant doubling time. This mathematical form is a realistic model for the growth of fusion power production.

For fusion to have a significant impact during the period 2050-2100, we can imagine beginning around the middle of the next century with a couple of prototype fusion power plants (world wide) and expanding this power production to the two terawatt level implied by the portfolio approach for the end of the century. Since the factor of 1000 increase is about 10 doublings we can connect the time (T) for initiating this growth with the doubling time ($\tau_{1/2}$) with the equation:

$$10\,\tau_{1/2} = 2100 - T$$

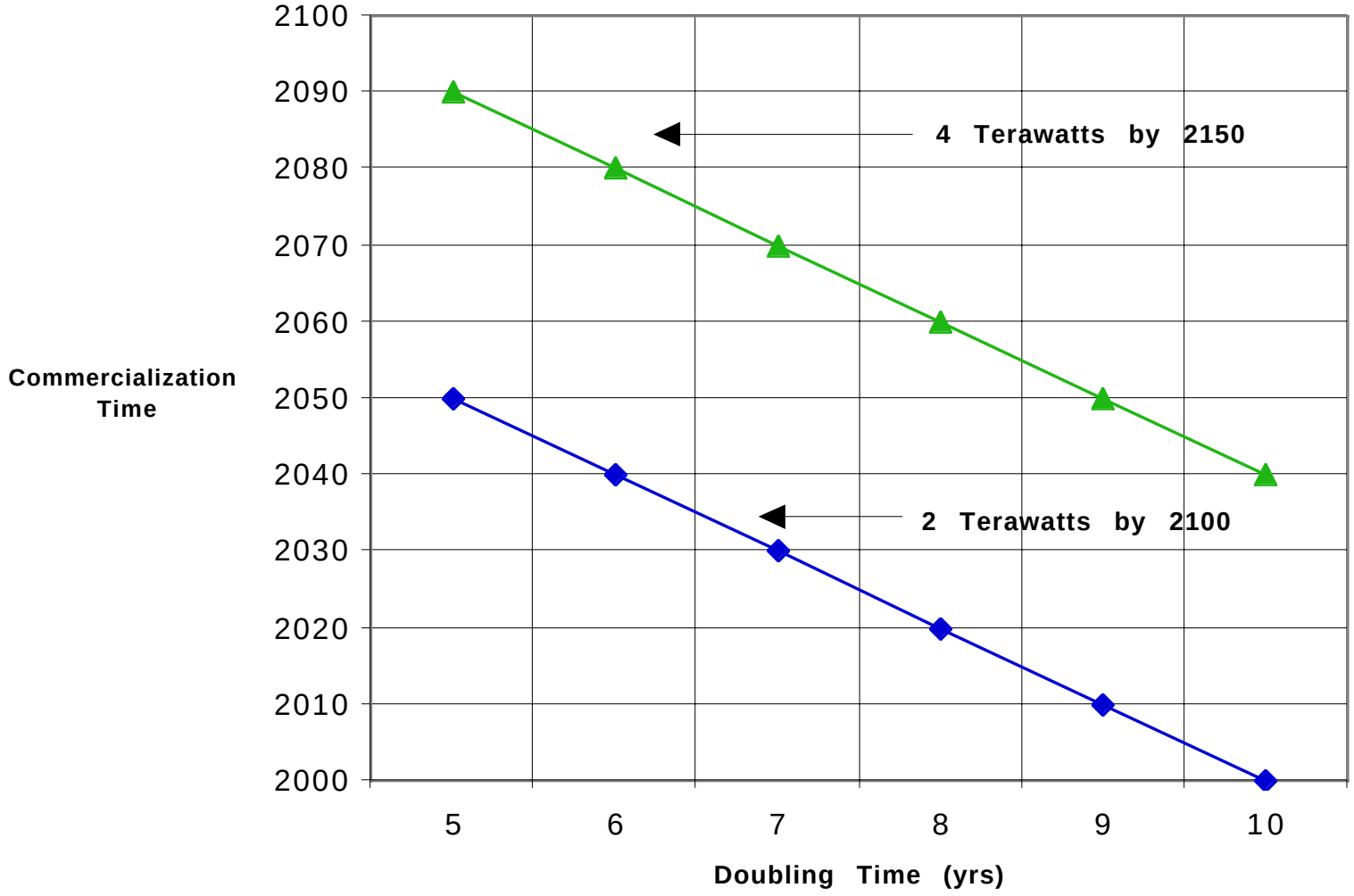
This is plotted in the following figure.

Commercial Fusion Beginning Versus Doubling Time to Meet the Two Terawatt Objectives by 2100



Unless we proceed expeditiously to prototype fusion reactors we will have to double fusion power production at an unrealistic rate if we choose to meet this objective.

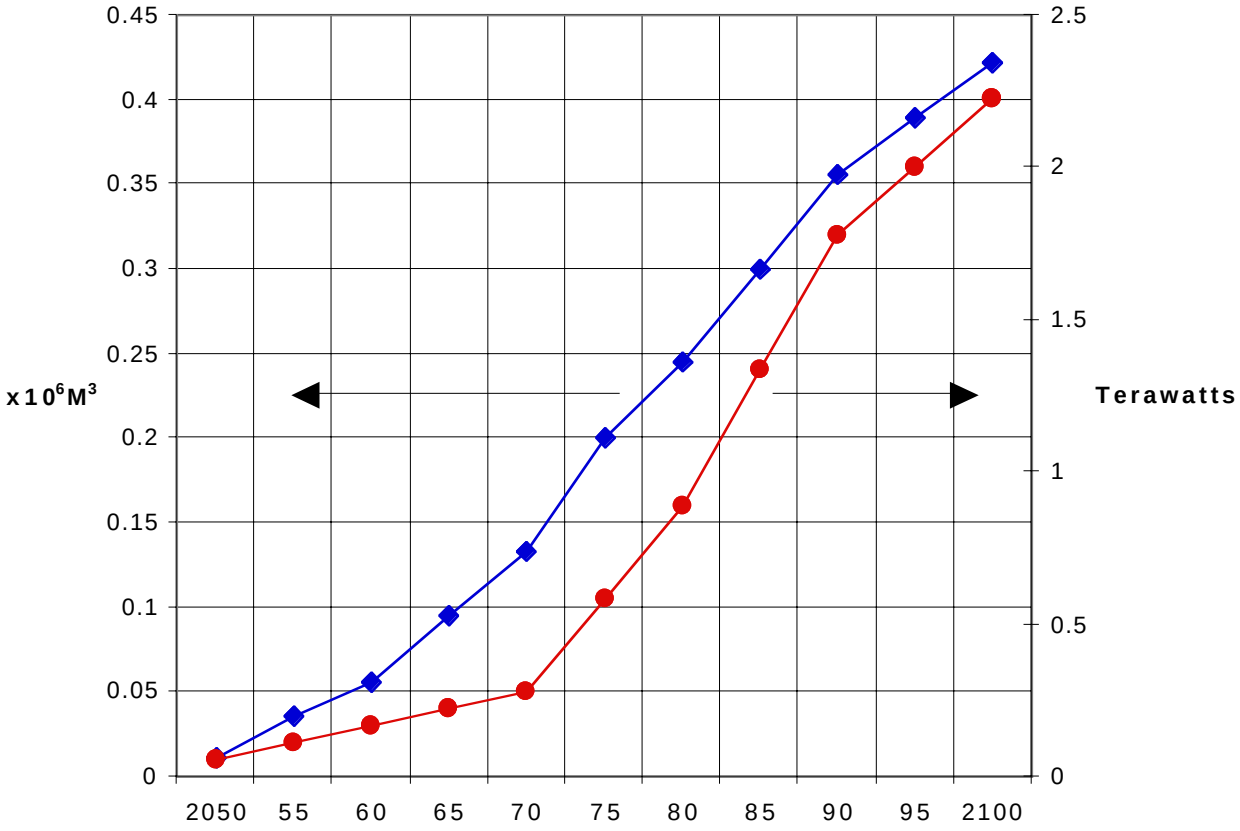
If fusion cannot achieve the goals for the period 2050-2100 implied by the last figure, it could still “get into the game” during the period 2100-2150 by producing, for example, 4 terawatts by 2150. The implications are shown on the following figure:



Waste From Fusion is Manageable

Assuming the world fusion program can meet the commercialization milestones, we can estimate the waste production from fusion and the critical resource requirements.

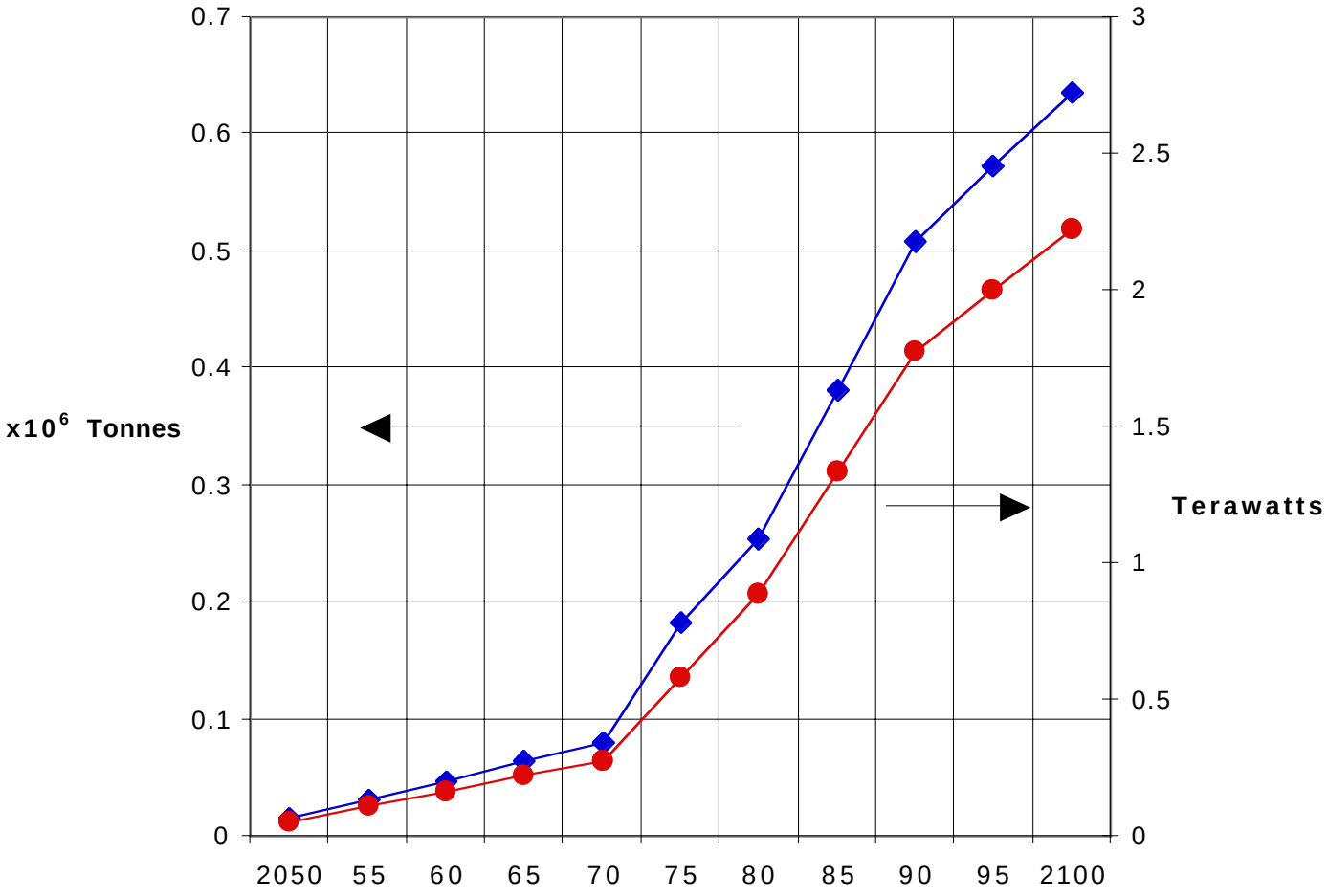
The total (world) Class C fusion waste produced in units of millions of metric tonnes can be estimated as follows based on the ARIES RS design for the portfolio scenario.



As a measure of the significance of this level of waste production, the present U. S. licensed shallow burial waste repositories have a remaining capacity in the million cubic meter range. The waste disposal for an aggressive fusion scenario should not present a significant problem.

Fusion Resource Needs Will Not be Prohibitive

The critical resource requirements for the representative fusion scenario can be estimated based on the ARIES RS design studies. For example, the vanadium required is estimated to be as follows:



These estimates can be measured against the present world production rate of 50 kt/yr of vanadium with a reserve of roughly 30 Mt.

Conclusions

- Clearly fusion will not make a significant contribution to world energy production during the period 2000-2050.

- It will be very difficult for fusion to meet the initial commercialization, and following doubling time conditions, to provide the needed non-carbon dioxide emitting power during the period 2050-2100.

- It is more likely that fusion will begin “shouldering a meaningful load” during the period 2100-2150.

- Potential fusion implementation scenarios should result in manageable resource or waste disposal problems.

Future Studies

- We need to assess the implications for atmospheric concentrations of carbon dioxide of delaying the serious commercialization of fusion until the twenty-second century.

- We need to examine the regional implications of the world implementation scenarios.