# SUSTAINABLE FUSION/ FISSION DEPLOYMENT SCENARIOS ON THE LONG TERM FOR PROPER ADDRESSING OF CLIMATE CHANGE

E.F. MORALES RODRÍGUEZ

Centro de Altos Estudios Estratégicos (CALEN, Ministry of Defense)

Montevideo, Uruguay

Email: Enrique.Morales@miem.gub.uy

Email contact of corresponding author: Enrique.Morales@miem.gub.uy

As widely known, climate change is the current worst global environmental menace in the medium term, unless it is properly mitigated (1). At the same time, according to WHO, more than 4 million premature deaths due to air pollution at outdoors are to be regretted every year. On the other hand, if Sustainable Development Goals (SDG) are met –as should be pursued by everyone- global population could grow until it peaks to around 8,500 million people, as of 2050 and energy –especially power- per capita consumption is likely to reach historical maximums (around 7000 kW\*h/person), even if great efficiency improvements are attained (1).

Obviously, the only way to get simultaneously SDGs, climate and air pollution control, is to have firm power sources enough to properly meet skyrocketing demand, along a deep reduction in release to atmosphere of combustion emissions, to the so-called *Net Zero*. Probably, most of the way to this point by 2050 will be a drastic drop of fossil fuels share in global primary energy mix, from their current 83% to around 30% or much less, depending on the feasibility of afforestation and global Carbon Capture and Storage/Use (CCS/ U) deployment.

Nuclear power (fission reactors, including all its types and fuels) and renewables (including all its branches, dispatchable or not) have been repeatedly mentioned as key power sources in this energy transition, so-urgently required. We, by ourselves, have published a paper that aimed to draw sustainable approaches of global shares for both kinds of sources, consistent with a change in global mean temperature of 1.5 ºC, the upmost goal of 2015 Paris Climate Agreement (2). Besides their role in reduction of emissions, all low-carbon sources mentioned above, were assessed in that paper, related to their other environmental and agricultural/ forestry impacts, depletion of mineral resources, required deployment of critical infrastructure and others. Assessments were made for power consumption required by high Human Development (similar to SDGs) and for both 1.5 ºC scenarios considered by IPCC: High Overshot, very likely overshot of 0.1 – 0.4 ºC before temperature stabilizes; Low Overshot, likely overshot of 0.1 ºC before stabilization. A set of power generation/shares of total figures from that paper (2), that could be attainable by 2050 and close to 1.5 ºC emissions restrictions, is given in Table 1.

***This paper showcases author´s personal views and does not necessarily reflect CALEN institutional opinions or doctrine.-***

TABLE 1. NUCLEAR AND RENEWABLE SHARES ATTAINABLE BY 2050

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1.5 ºC scenario | Nuclear power (TW\*h/yr) | All-renewables power (TW\*h/yr)  | Nuclear share (%) | Renewable share (%) |
| Low Overshot | 19,100 | 25,700 | 32 | 43 |
| High Overshot | 22,300 | 30,000 | 32 | 43 |

Even if this energy portfolio could be “attainable”, our paper highlighted that it also poses huge challenges for nuclear industry as a whole, uranium mining, energy planners, nuclear regulators. Depletion of currently proven and probable low-cost uranium reserves before 2090, the urgent need to wide and quickly expand world uranium enrichment capacity, were mentioned as some very hard challenges to face at. Shift to thorium cycle, use of fast/breeder reactors, plutonium reprocessing and reuse, could fit each to diverse national circumstances and were pointed “*at least to some extent*” as resources; obviously, massive use of these options is also very challenging.

Power from nuclear fusion, due to the characteristics of physical processes on which it would be based, is the promise of plenty energy for Humanity, for probably much more than the latter could last on Earth, as about 1% of world seawater could supply deuterium to power societies for 109 years, returning 99,6% of that raw water as such. It would also be “clean” energy in the sense that it would render little radioactive or toxic residues (except minor amounts of manageable, medium-lived tritium or activated items), would not impact on land use or afforestation. Ignition accidents will be hindered by design. Once technology is available for world-wide use, there would be less strategic restrictions to access it for developing countries, than there are today for nuclear energy, which requires continuous supplies of sophisticated items as nuclear fuel, enriched uranium, etc.

Commercial nuclear fusion is awaited from long ago, some 60 years. Currently, 96 facilities worldwide –and more incoming, including large, aimed as self-sustainable, international ITER- are achieving great technological milestones that bring the so-desired controlled, commercial fusion reactor, closer and closer.

DEMO fusion reactors are expected to be operating by 2040s in Europe and Far East (3) and next step would be deployment of first fusion commercial power plants, for which no clear calendar is available. Some reports expect first fusion power integrated to grids by 2070s and sharing 20% of total world power in 2100 (3). We took this forecast as a base scenario and considered also two other (optimistic/ pessimistic) scenarios for our analysis of future sustainable climate and social scenarios. In an optimistic assumption, commercial fusion power could come just in 2060 and supply 20% of global power consumption in 2080. The bad scenario sees no fusion power in grids until 2100, and a fusion share of 20% just by 2130. We have made a preliminary assessment of how one or another scenario can impact on mitigating climate change and warranting global energy security and access, using energy portfolios proposed in (2) and keeping in mind other findings of (2), that anticipated challenges for uranium low cost reserves even if “*nuclear-fussion becomes wide-comercially available before 2100*“. For this assessment, we assumed –as a hard case- a 1.5 ºC High-Overshot scenario where world power demand finally peaks in 2060 at 75,000 TW\*h/yr and remains almost stable until 2100. It is worth to remark that such absolute power demand differs from (3) projections, even if we took (3) fusion share prospects as base case. Power generation from each source detailed in (2) by 2050, remains in its absolute figures (scarce thermal-fossil abated, fitted with CCS/ U, could be added to fill some gaps) for every scenario until it is –if possible- replaced by fusion power. For nuclear power, as advised by (2), we supposed that from 2040s on, 15% of global nuclear generation comes from advanced cycles (fast breeder, fast, thorium) that require only minor amounts of raw mined uranium; remaining would be usual light water reactors (LWR). Based on global capabilities reasonably achievable, an example of possible respective shares of these advanced cycles within mentioned 15% nuclear could be as seen in Fig. 1, with Thorium delivering 1,000 TW\*h/yr and Fast Breeder Reactors 1,500 TW\*h/yr.

*FIG 1. Example shares of advanced cycles within nuclear power.*

We assumed that from 2070, besides arrival of fusion, advanced nuclear could expand more, and reach some 40% of nuclear power. At this time, it could be assumed that much power from fast reactors is also flexible power (4), so, it is not to be replaced by fusion but moreover, it replaces part of other flexible power sources, as fusion becomes first baseload power source.

Future fusion power is likely to be produced by large, baseload plants. These units are to replace –in our scenarios, they will come when power demand has already peaked- other baseload power stations as coal- CCS/ U, conventional nuclear, biomass and some hydropower stations that are operating when commercial fusion comes. Small Modular Reactors (SMR) for local power in remote locations or industrial/ district heating/ transport (maritime, railway) powering uses, probably would not be replaced by fusion at a first stance and even less if they are flexible (4). Other flexible sources, as natural gas and most hydropower stations that remain in use, are not likely to be immediately replaced by fusion power plants. Share of intermittent sources, due to their nature, would be unavoidably linked to shares of flexible power (typically gas) stations and/or power storage effectively in use.

Abated thermal-CCS/U power stations, are supposed to be scarce by 2060, as said, therefore their replacement would not be a priority and we did not consider it for our assessment. Replacement of other stations by fusion power, however, would ease the challenges detailed in (2) for sources as conventional nuclear fission, some hydropower and biomass. For the assessment of scenarios, we supposed that any new gigawatt-hour (GW\*h) of fusion power, replaces a before-existing mix comprised of 0.73 GW\*h nuclear (LWRs, the oldest replaced first), 0.20 GW\*h biomass and 0.07 GW\*h hydro; these figures results from low carbon generation shown in Table 1, according to portfolios detailed in (2), excluding intermittent sources and accounting for just 20% hydro as baseload. It must be highlighted that even in the most optimistic scenario for fusion, some nuclear power will remain in grids by 2100 and by that date, it will be mainly advanced; abovementioned non-electrical nuclear applications are likely also to remain in use to some extent, although they were not assessed here. Flexible fast reactors, may indeed remain in service for a long time, during which they could burn actinides from LWRs shutted down, in order to reduce long-term radiotoxic inventory legacy.

Needs of natural resources to properly power global society in the long term, are summarized in Tables 2,3,4, for each of the scenarios reviewed of fusion power replacing mentioned sources of (2) forecast.

TABLE 2. POWER NEEDS/ IMPACTS BY 2100 IN FUSION BASE CASE SCENARIO

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Fusion Power by 2100(TW\*h/yr) | Uranium for nuclear power (million ton U, accumulated) | Land area for biomass power (million Ha)  | Land area flooded by hydrpower (million Ha) | Crops land area seized by power needs (million Ha) |
| 15,000 | 10.1 | -no needed- | 168 | 168 |

TABLE 3. POWER NEEDS/ IMPACTS BY 2100 IN FUSION OPTIMISTIC SCENARIO

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Fusion Power (TW\*h/yr) | Uranium for nuclear power (million ton U, accumulated) | Land area for biomass power (million Ha)  | Land area flooded by hydropower (million Ha) | Crops/ forest land area seized by power needs (million Ha) |
| 15,000 (2080) | 6.7 | -no needed- | 168 | 168 |
| 22,000 (2090) | 7.5 | -no needed- | 154 | 154 |
| 30,000 (2100) | 8.8 | -no needed- | 137 | 137 |

TABLE 4. POWER NEEDS/ IMPACTS BY 2100 IN FUSION BAD SCENARIO

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Fusion Power by 2100(TW\*h/yr) | Uranium for nuclear power (million ton U, accumulated) | Land area for biomass power (million Ha)  | Land area flooded by hydropower (million Ha) | Crops land area seized by power needs (million Ha) |
| 3,000 | 13.2 | 98 | 194 | 292 |

From above data, we highlight the following remarks:

* Early deployment of fusion, coupled with a smoothly deployed and probably achievable shift to advanced fission cycles, may limit global use of uranium in the long term, just to somewhat plus than currently proven reserves (some 8 million tons U) and clearly within reasonable assured resources (12.8 million tons U) (5).
	+ - * Thorium reserves would be more than enough, although global infrastructure available from 2050s on for reprocessing or fuel fabrication must be assessed.
* This early deployment, also may recover some 130 - 160 million Ha (otherwise flooded or used for energy crops) to help in the feeding of 23 million persons and have more forest that will help to smooth the temperature overshot.
* Sustainability of climate, energy security and land use in the event of no fusion until 2100, would be strongly dependent on availability of a huge capacity of thermal power fitted with CCS/ U (very unlikely to attain) or massive use of advanced nuclear fission.

It was mentioned in (2), that relying in 32% nuclear power (LWR) by 2050, besides uranium reserves issues, would be challenging due to the uranium enrichment capacity required. Abovementioned use of fast reactors by 2050 would require some 10 - 30 million SWU/year of high (20% 235U) enrichment capacity, depending on reactor type, to our estimation, and such capacity is currently, technically available, even should some retrofitting be required. If amounts of low enriched uranium and plutonium are stockpiled from the 2020s on, using existing enrichment and reprocessing capacities, these issues could be relieved, as LWR-fission would see a sharp drop from 2060, when it starts to be replaced by fusion in the fusion optimistic case, and nuclear power gradually turns fully to advanced nuclear, as the latter are the remaining nuclear units, besides expanding themselves. Additional reprocessing capacities (including plutonium from breeders and advanced ones that will recycle minor actinides) installed from 2040s, could close the gap. It is not to be forgotten the strong pressure on safeguards and security that these stockpiles would put.

For the transition phase until fusion surges as baseload source, deployment of advanced fission cycles by countries with great expertise in the nuclear field, could be achievable and would let developing countries rely, at first stage, mainly on LWRs, for which large operational experience and criteria for regulation purposes is widely available (6), so energy-turn in these countries would be eased.

On the long term, nuclear fusion is the promise for sustainable power. During 21st Century, its deployment as early as operationally possible, synergized with nuclear power (taking advantage of its current and future facilities, that transition to advanced near the end of the Century) would allow addressing urgent environmental and societal matters in an achievable way.

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