LiWall Fusion: no alternative, no other option

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1. Introduction.

Putting aside politics and propaganda, it is clear that the present approach to fusion does not lead to "harvesting" fusion energy. Moreover it cannot even resolve the plasma physics part of the problem. Exhausted at the level of TFTR and JET, which showed fusion power but did not reach the promised $Q_{DT} = 1$, it resulted in stagnation of the program, which is now gradually falling into degradation. ITER, which is presented as a last step before putting fusion power to the grid, could very well be the last magnetic fusion experiment. Developed without having a single essential plasma physics problem solved, it cannot fulfill the claims of the fusion proponents. More likely, it will completely discredit fusion as a valuable physics idea.

Neither plasma physics and fusion technology nor "the lack" of funding are responsible for the present situation. In 1998, the new approach to fusion, called Lithium Wall Fusion (LiWF), emerged. The idea is very simple: *(a) fueling the plasma core with NBI, and (b) pumping out particles leaving plasma using flowing lithium, thus preventing cooling down the plasma.* Now fully conceptually developed, it implements the original basic idea of magnetic fusion, i.e., the plasma insulation from the wall.

This white paper outlines the sharp contrast between LiWF and the existing approach, referenced here by the sign of "5 Bigs", which include: (1) "Bigger size" (to fight unpredictable turbulent energy losses), (2) "Stronger B_{tor}" (up to the cost and structural strength limits), (3) "Larger I_{plasma}" (with no way to prevent disruptions), (4) "Higher heating power" (dumped to anomalous electrons and to divertor plates), (5) "Exa scale HPC" (with "salt-water" numerical models for plasma dynamics).

Eight of key issues of the plasma physics relevant to fusion power are commented below.

2. Energy confinement.

Good energy confinement is the key to magnetic fusion. Tokamaks became the leader just because of their highest confinement among other plasma devices.

The biggest, root-level mistake, costing tens of $B and decades of wasted research time, of the current program is the misrepresentation of the confinement problem as a "core transport" problem. Yes, it would be remarkably good if the turbulent thermal conduction coefficients were orders of magnitude smaller. No such luck, TFTR and JET proved this.

The non-sense of regarding confinement is that is accepts as a religious dogma that the edge plasma temperature is low. For regimes this is true because the plasma edge is cooled down by recycles neutrals from the wall. After this, the thermal conduction (always turbulent) becomes the key player. It leaves nothing else except reliance on wasteful "5 Bigs", which create more problems than they solve.

In fact, the key factor in confinement is the plasma edge conditions, rather than core transport. For magnetically confined plasma it is much more efficient to prevent the plasma edge cooling by pumping out plasma particles, rather than to rely on enhanced heating power in the presence of unrestricted turbulence.

LiWF introduces the diffusion based confinement regime, where the losses of energy are determined by particle losses, while thermal conduction (including anomalous electrons) plays no role. The core fueling and pumping boundary conditions create high plasma temperature ($\simeq E^{NBI}/5$) all over the core. In a burning plasma device, the entire plasma volume (rather than 1/4 of it as in) will produce fusion power.

LiWF reinstalls the original idea of magnetic fusion (lasted till the 1970s). In the LiWF regime the plasma does not see the walls and, thus, is insulated from them. The energy confinement, described by ion-neoclassical diffusion (better than in by orders of magnitude), becomes not only possible but natural for tokamaks. Contrary to this, , named as "fusion energy science program", ignores the basic physics idea of fusion and has little in common with its development.

3. Plasma edge.

In its H- and I-modes (essentially the same), subdivides the plasma on core and pedestal zones, with the second one presented as a marvelous "edge transport barrier" (ETB) for electrons. Not having found in three decades any answer to a natural question, what is the reason for having two separated zones, has cooked a "turbulence suppression by sheared rotation" as explanation of reduced energy transport in ETB.

Instead, LiWF gave understanding and a rigorous definition of the plasma edge. It determined the edge temperature as the ratio of the heating power to the particle flux from the edge to the wall.

This understanding is consistent with clean DIII-D experiments on Quiescent H-mode and RMP. In particular, it shows that the “edge transport barrier” of was a non-sense from the beginning: the temperature pedestal is located outside the confinement zone.

Surprised by the presence of unshakable temperature pedestal and ignoring the full picture of edge, the “certified experts” of have cooked the theory of “screening effect due to rotation” in order to rescue the ETB.

Full of cooking, presented to the outside physics community as a great science, the approach has little in common not only with fusion energy but also with fusion physics science.

4. Fueling.

The fueling concept of is a caricature on common sense: (a) tritium from the pellet injections is going right to the plasma center (instead to being thrown away by the first big ELM or by paced mini-ELMs), (b) helium ash from the center is flowing in the opposit direction to the plasma edge, (c) tungsten ions sputtered from the divertor plates ignore the physics of the thermal force and remain locked at the plasma edge. This non-sense is one of the pillars of the $20 B device being built by .

The LiWF resolves this fueling problem, unresolvable for , in a natural way: with excellent confinement 60-120 keV NBI can provide core fueling and maintain the regime in existing and burning plasma devices.

5. Power extraction.

While expecting cooperation of the plasma with science fantasies, the program expects also a miracle from material development. The divertor plates should withstand not only the α-particle power, but also ELMs and a huge axillary heating power, which fights (and enhances) the core turbulence. In reality, the situation is very simple - there is no power extraction solution for the approach.

Good materials are indeed a great thing, being important far beyond the scope of magnetic fusion.

For fusion, LiWF suggests the only realistic solution: enhanced confinement and associated new ELM-free regimes with significantly reduced energy flux to the divertor plates, combined with material development.

6. Stationary plasma regimes.

In program the vision of stationary plasma is simply absent. One part of the problem, i.e., the current drive, is typically addressed by reference to stellarators, which are incompatible with LiWF and irrelevant to fusion in many other aspects. In fact, the real part of the problem is in stationary long term plasma-wall interactions. There were attempts to address it by relying on plasma edge radiation (including CPS with lithium). Shortly, enhanced edge radiation is nothing else than the gambling with plasma disruptions. The presence of tungsten divertor and ignorance of the thermal force, $\propto Z^2$, is the peak of the non-sense in the approach to the stationary regimes.

The only practical approach to stationary plasma is provided by LiWF: (a) elimination of ELMs and plasma interaction with the side walls, (b) undamageable liquid lithium surface of divertor plates, (c) hour-long inductive burning plasma regime, (d) (high temperature)+(low density) for efficient current drive.

A stationary flowing liquid lithium (FLiLi) system with a minuscule flow rate $\simeq 2$ cm^3/s has now been invented for pumping 10^{22} particles/s, using a slow 0.1 mm thick lithium layer driven by gravity, with $\simeq 0.5$ liter of expected Li inventory exposed to the plasma.

7. Stability and safety.

In fusion all natural tendencies of the tokamak plasma are bad for stability: (a) peaked temperature leads to sawtooth oscillations with unpredictable extent of affected zone, (b) in turn, they trigger NTMs, (c) H-mode automatically leads to ELMs, (d) the plasma edge density is high and prone to high-density disruptions.

Predictive understanding of above instabilities in is absent. The top of the non-sense in the stability area is the “salt-water” boundary condition for the plasma velocity to the wall, $V_{normal} = 0$ in multi-$M numerical codes.

In LiWF, the situation with stability is simple and predictable: (a) no sawteeth and NTM triggering, (b) no ELMs, (c) no density limit, (d) the entire plasma is stationary and externally controlled, and (e) the expected plasma is well relevant to the ideal MHD model (which is in the hands).

Regarding Li safety, the required free surface inventory of FLiLi does not exceed the Low Fire or Detonation Limits of hydrogen, potentially released by accidential interactions with water.

8. Burning plasma.
Having unresolvable problems of fueling and stationary regimes, the program has no burning plasma concept. Instead, it replaces the physics of the burning plasma by propaganda of fusion power promised even from the ocean water.

LiWF envisions innovative burning plasma regimes at high temperature ($T_i \simeq 25$ keV), low density ($n_{20} \simeq 0.5$) with core fueling by 120 keV NBI, and most of the energy from α-particles irradiated by synchrotron radiation of electrons, leading to a familiar hot ion regime $T_e < T_i$, which is good for fusion.

9. Demo concept.
The reasonable definition of DEMO mission is the demonstration of the possibility of electricity production exceeding its consumption level, i.e., $Q^{eng}_{DT} > 1$. There is no chance to design DEMO within approach. Now, this became evident not only to public, but even to the -establishment, which dropped DEMO from the budget requests and replaced it by the another propaganda object - FNSF for material testing.

LiWF burning regimes provide the physics and practical basis for DEMO (in the publication called Fusion-Fission Research Facility, FFRF): $P_{DT} = 100$ MW, EAST plasma configuration scaled to $R/a = 4/1$, $I_{pl} = 5$ MA, $B_{tor} = 4 - 6$ T (e.g., using ITER superconductor), $P_{NBI} = 5/120$ MW/keV, ($T_i \simeq 25$ keV), low density ($n_{20} \simeq 0.5$), hour-long inductive regime, not relying on unreliable “high-tech”. The blanket space in LiWF DEMO is 1 m thick and can accommodate both fusion and fission nuclear components.

Regarding FNSF mission, at the APS-2006 DPP meeting, the 3 step program for Reactor Development Facility, based on ST as the only choice, was presented in details with NSTX as an initiating step. Instead, the leaders of soon ruined NSTX and moved to its upgrade with the same meaningless approach.

10. Summary.
In its 50 year long tokamak history, US and international fusion programs have created the most of the necessary plasma physics and technology. But in application to fusion energy they were converted into the approach, which substituted the science with observations and short living interpretations, often erroneous. As a result, the progress was stagnated, while the scientific level of is under rapid degradation.

Instead, LiWF opens a way for resolving plasma physics issues of fusion energy. It does require the development of a new, FLiLi technology, while otherwise it relies on already existing means.

With LiWF, 13.5 years ago we recovered the vision of the 1970s on the path to fusion energy and then developed it to the level of self-consistent fusion concept based on the best understanding of fusion. During these years there were no single failure in our predictions of experiments, which remained distant from LiWF but some, at least, partially relevant. Using only Li conditioning, CDX-U and NSTX demonstrated significantly enhanced confinement and flattening of temperature profile, FTU exceeded the Greenwald limit by more than factor 1.3, NSTX demonstrated the predicted ELM stabilization, DIII-D with RMP has confirmed our understanding of the plasma edge. Even for ITER, the top project of , we gave a critical understanding of disruptions, consistent with physics and measurements.

Implementation of LiWF is consistent with both options of funding, mentioned in the charge. At the same time, any level of funding cannot prevent the bankruptcy of . The case with is lethal and cannot be cured by expected another attempt of FESAC to hide its unstoppable scientific degradation.

My request to FESAC (and DoE) is simple and minimal:

Let , which discredited fusion, die in its own bed, while giving a chance to still clean, but unprotected from the dead-end ideas Chinese program to make a step to new regimes and to progress in fusion.