

Article

Not peer-reviewed version

Understanding and Developing Cold Nuclear Fusion Energy Technology with 4G Model of Strong and Weak Interactions

[U. V. S. Seshavatharam](#)^{*}, T. Gunavardhana Naidu, S. Lakshminarayana

Posted Date: 14 April 2026

doi: 10.20944/preprints202604.0895.v1

Keywords: cold nuclear fusion; nuclear binding energy; 4G model of final unification; strong and electroweak mass formula; to review and replace the coulombic term; energy liberation of 1 MeV



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

Understanding and Developing Cold Nuclear Fusion Energy Technology with 4G Model of Strong and Weak Interactions

U. V. S. Seshavatharam ^{1,2,*}, T. Gunavardhana Naidu ³ and S. Lakshminarayana ⁴

¹ Honorary faculty, I-SERVE, Survey no-42, Hitech city, Hyderabad-500084, Telangana, India

² Quality Assurance Dept, Casting, DIP Division, Electrosteel Castings Ltd., Srikalahasthi-517641, AP, India

³ Dept. of Physics, Aditya Institute of Technology and Management, Tekkali-532201, AP, India

⁴ Dept. of Nuclear Physics, Andhra University, Visakhapatnam-530003, AP, India

* Correspondence: seshavatharam.uvs@gmail.com

Abstract

Considering the uniqueness and simplicity of our 4G model of strong and electroweak nuclear binding energy formula, the traditional Coulombic repulsion concept in nuclear binding scheme can be reconsidered or replaced by a fundamental electroweak interaction framework. Close to stable mass numbers, for medium and heavy atomic nuclides, A and Z being the mass number and proton number, approximate formula for nuclear binding energy is, $BE = \{A - 0.0016[(A^2 + Z^2)/2] - A^{(1/3)} - 0.5\} 10.1$ MeV where the factor 0.0016 can be considered as the nuclear electroweak stability coefficient. Approximate stable mass number associated with any proton number Z can be understood with, $A_s = 2Z + 0.0016(2Z)^2$. Building on this foundation, the potential mechanism of cold nuclear fusion—assumed to be governed by strong and weak interactions, can be more effectively explored. Continued research may enable the development of clean, green and safe cold nuclear energy technologies capable of generating approximately 1 MeV of energy per fusion event. For experimental purposes, stable isotopes of light to medium-heavy elements with atomic numbers ranging from $Z=1$ to 30 can be targeted. Material selection point of view, it is expected that, cold nuclear material, should have the ability of absorbing hydrogen atoms or neutrons. Upon absorbing the hydrogen atom, nuclide experiences isotopic or isobaric conversion, increase in nuclear binding energy and increase in nucleons' kinetic energy. Higher the difference of nuclear binding energy, lower the expected thermal energy and vice versa. In our recent papers, we have taken Iron and Magnesium as the cold nuclear fuels. It needs further study.

Keywords: cold nuclear fusion; nuclear binding energy; 4G model of final unification; strong and electroweak mass formula; to review and replace the coulombic term; energy liberation of 1 MeV

1. Introduction

Nuclear binding energy, a cornerstone concept in nuclear physics, explains the stability and reaction energetics of atomic nuclei. The well-established semi-empirical mass formula (SEMF), or liquid-drop model, quantifies binding energy with terms representing volume, surface, Coulomb repulsion between protons, asymmetry (neutron-proton imbalance), and pairing effects [1–9]. Based on our 4G model of final unification, in this work, we are introducing a nuclear electroweak stability coefficient to refine the nuclear binding energy formulation. This approach challenges the classical view of Coulombic repulsion, presenting nuclear stability as an outcome of unified strong and electroweak interactions. Such reinterpretation provides a constructive foundation for understanding and advancing cold nuclear fusion theories and technologies [10–16].

2. Theoretical Framework

While Coulombic repulsion is a long-accepted pillar explaining proton-proton repulsion within nuclei, it remains classical and separate from weak/intermediate boson-mediated electroweak forces. The physical justification for separating pure electrostatics from weak-force contributions at nuclear scales is limited. The 4G model [17–21] seeks to unify these effects, embedding charge repulsion effects into a combined electroweak term [22–27] having a very simple form. Our 4G model [17–21] introduces a simplified binding energy formula,

$$(BE)_{A_s} \cong \left[A_s - A_s^{1/3} - 0.0016 \left(\frac{Z^2 + A_s^2}{2} \right) \right] 10.1 \text{ MeV} \quad (1)$$

where, $(BE)_{A_s}$ is the nuclear binding energy close to stable mass numbers. A_s is stable mass number, Z is the proton number and 10.1 MeV is common energy coefficient connected with our 4G model.

Here, $0.0016 \left[\frac{Z^2 + A_s^2}{2} \right]$ is the proposed electroweak term and refers to the number of free nucleons having no involvement in nuclear binding energy scheme. These free nucleons will not participate in the nuclear binding energy scheme. Thus, each free nucleon takes 10.1 MeV from the volume energy. Considering the ingoing and outcoming of single free nucleon within the nuclear binding energy scheme, an average of 5 MeV can be considered as an inherent electroweak energy. In this electroweak term, Coulombic energy part can be expressed as, $0.0016 \left[\frac{Z^2}{2} \right] \times 10.1 \text{ MeV} \cong 0.0008 Z^2 \times 10.1 \text{ MeV}$

. Magnitude point of view, it is far less than the traditional, Coulombic term, $\left[\frac{Z^2}{A^{1/3}} \right] \times 0.71 \text{ MeV}$.

Specifically, this coefficient 0.0016 can be precisely interpreted as the ratio between the rest mass of the proton m_p , 938 MeV/c² and our 4G model of electroweak-scale fermion, $M_{wf} = 585 \text{ GeV}/c^2$. This mass ratio, $(m_p/M_{wf}) = 0.0016$ reflects an intrinsic hierarchical disparity between the relatively low mass scale of nucleons bound by the strong force and the much higher mass scale characteristic of electroweak physics. It is very interesting to note that with reference to weak interaction, our assumed charged 585 GeV fermion is very similar to the modern estimates of dark matter related neutral supersymmetric fermion, Higgsino [28–30] of rest mass (1.1 to 1.2) TeV/c². Notably, this mass scale aligns with current galactic halo dark matter estimates [31] of (500 to 800) GeV, further bridged by the 1.17 electron-related scaling factor [32–35]. Readers are encouraged to refer our recent papers for further information [36,37].

Clearly writing, our assumed charged electroweak fermion mass seems to be equal to half of the currently believed neutral Higgsino mass. This mass approximation highlights and quantifies the separation of scales between the nucleon masses (~GeV scale) and the exotic electroweak fermions (~TeV scale), reinforcing the conceptual foundation of our 4G model in explaining nuclear binding energy through connections across these mass scales with various applications [38–40]. Furthermore, an alternative but equivalent interpretation identifies this coefficient as the ratio of the geometric mean of charged (π^\pm) and neutral (π^0) pion masses (~137.26 MeV/c²) to the geometric mean of the weak boson masses (~85.61 GeV/c²). This finely tuned ratio provides a physically meaningful bridge between the strongly interacting regime, governed by mesons like pions, and the electroweak sector represented by massive gauge bosons W^\pm and Z^0 .

$$\frac{m_p}{M_{wf}} \cong \frac{938.272 \text{ MeV}}{584725 \text{ MeV}} \cong 0.001605 \cong \left(\frac{\sqrt{(m_\pi c^2)^0 (m_\pi c^2)^\pm}}{\sqrt{(m_w c^2)^\pm (m_z c^2)^0}} \right) \cong 0.0016032 \cong \beta \dots (\text{say}) \quad (2)$$

Based on this electroweak coefficient $\beta \cong 0.001605$ and $2 \times Z$, nuclear stability associated with neutron-proton pairing [41,42] and the required excess neutron number can be understood with the simple relation.

$$A_s \cong 2Z + \beta (2Z)^2 \cong 2Z + 0.00642Z^2$$

$$\rightarrow \frac{A_s - 2Z}{(2Z)^2} \cong \frac{A_s - 2Z}{4Z^2} \cong \beta \cong 0.0016 \quad (3)$$

Here it is very important to note that, this expression is independent of the currently believed nuclear binding energy formulae and their energy coefficients. For example, considering $Z=21$ and 92 ,

$$\text{for } Z=21, \frac{45 - (2 \times 21)}{4(21)^2} \cong 0.0017 \quad \text{and for } Z=92, \frac{238 - (2 \times 92)}{4(92)^2} \cong 0.0016;$$

In terms of actual stable mass numbers, corresponding proton number can be addressed with,

$$Z \cong \frac{A_s}{1 + \sqrt{1 + 0.0064 A_s}} \cong \frac{A_s}{2 + 0.0153 A_s^{2/3}} \quad (4)$$

$$\text{where } \frac{a_c}{2a_{asy}} \cong \frac{0.71 \text{ MeV}}{2 \times 23.21 \text{ MeV}} \cong \frac{0.6615 \text{ MeV}}{2 \times 21.6091 \text{ MeV}} \cong 0.0153$$

Following these relations, one can work on understanding and estimating the stable super heavy atomic nuclides.

3. Predictions and Validation Based on 4G Model of Final Unification

In Table 1, for $Z=6$ to $Z=117$, our 4G model relation (1) has been tested against experimental binding energies for a range of nuclei near to stable mass numbers.

Table 1. Experimental and estimated binding energies of atomic nuclides.

Nuclide	Z	A	Experimental BE (MeV)	4G Model BE (MeV)	% Error
Carbon-12	6	12	92.16	91.57	0.64%
Magnesium-24	12	24	198.26	202.40	-2.1%
Iron-56	26	56	492.25	491.11	0.23%
Tin-116	50	116	988.68	988.37	0.03%
Lead-208	82	208	1636.45	1632.00	0.27%
Uranium-238	92	238	1801.69	1810.1	-0.47%
Tennessee-294	117	294	2085.04	2088.18	-0.15%

Based on a few number of inputs, there is an impressive match between the models' predictions and experimental data for nuclei ranging from light atomic nuclides to superheavy atomic nuclides.

4. Asymmetry Term in the 4G Model of Nuclear Binding Energy

From the well-established SEMF it is also very that, nuclei with proton-to-neutron ratio deviating from their stable configurations have a reduction in total binding energy. This can be understood by considering an asymmetry correction term, proportional to the squared difference between the actual mass number A and the stable mass number A_s scaled by its inverse A_s as,

$$A_{asy} \cong \frac{(A_s - A)^2}{A_s} \times 10.1 \text{ MeV} \quad (5)$$

Thus, the corrected binding energy formula can be approximated with,

$$(BE)_{A,Z} \cong \left[A - A^{1/3} - 0.0008(Z^2 + A^2) - \frac{(A_s - A)^2}{A_s} - 0.5 \right] 10.1 \text{ MeV} \quad (6)$$

See Table 2 for the estimated binding energy of isotopes of Z=1 and Z=2 having asymmetry correction.

Table 2. Isotopic binding energy of Z=1 and 2.

Isotope	Corrected BE (MeV)	Experimental BE (MeV)	Difference (MeV)
Z=1, A=2	2.399	2.2246	-0.175
Z=1, A=3	5.552	8.4818	+2.929
Z=2, A=3	8.053	7.7180	-0.335
Z=2, A=4	19.154	28.2957	+9.142
Z=2, A=5	25.420	27.4093	+1.988
Z=2, A=6	26.774	29.2692	+2.495

Considering the wide range of atomic nuclides and accuracy point of view, we are working on

fine tuning the terms $\frac{(Z^2 + A^2)}{2}$ and $\frac{(A_s - A)^2}{A_s}$ with $I \cong \left(\frac{N - Z}{A} \right)$.

5. Pairing Term, the Advanced Electroweak Term and the Revised 4G Model of Nuclear Binding Energy formula

Considering the light atomic nuclides, we see the possibility of including the simple pairing energy as follows. It may help in exploring the nuclear binding energy scheme further [1–9]. For $Z > 1$,

$$(BE)_{A,Z} \cong \left[A - A^{1/3} - \left\{ (c_{ew})_Z \times 0.0016 \left(\left[Z^2 + 0.5 \left(\frac{Z}{N} \right)^5 Z^2 \right] + [N^2 - (NI)^2] \right) \right\} - \left((1 - I^2) \frac{(A_s - A)^2}{A_s} \right) + \frac{(-1)^Z + (-1)^N}{2\sqrt{A}} - 0.5 \right] 10.1 \text{ MeV} \quad (7)$$

$$\cong \left[A - A^{1/3} - \left\{ (c_{ew})_Z \times 0.0016 \left(\left[1 + 0.5 \left(\frac{Z}{N} \right)^5 \right] Z^2 + [N^2 - (NI)^2] \right) \right\} - \left((1 - I^2) \frac{(A_s - A)^2}{A_s} \right) + \frac{(-1)^Z + (-1)^N}{2\sqrt{A}} - 0.5 \right] 10.1 \text{ MeV}$$

$$\left. \begin{array}{l} (c_{ew})_Z \cong \text{Electroweak coefficient of 'Z'.} \\ \approx 2 \text{ for } Z=(1 \text{ to } 11) \\ \approx 1.5 \text{ for } Z=(12 \text{ to } 17) \\ \approx 1.25 \text{ for } Z=(18 \text{ to } 21) \\ \approx \left[\left(1 + \sqrt{\frac{156-Z}{156}} \right)^{1/3} - \frac{1}{2\sqrt{Z}} \right] \text{ for } Z > 21 \end{array} \right\}$$

where, $156 \approx \frac{1}{4 \times 0.0016} \cong 156.25$

For medium, heavy and super heavy atomic nuclides, this formula seems to work well. As the proton number is increasing, electroweak coefficient of Z starts decreasing from (2x0.0016) to (0.0016). We are working on finetuning the proposed electroweak coefficients of Z in a unified approach for a better understanding and accuracy as described here. It can be given a chance based on the simplicity of relation (9). Thus, the electroweak term can be rewritten as,

$$A_{free} \cong \left\{ \frac{1}{2} + \left[(c_{ew})_Z \times 0.0016 \left(Z^2 \left(1 + 0.5 \left(\frac{Z}{N} \right)^5 \right) + N^2 (1 - I^2) \right) \right] \right\} \quad (8)$$

Here, the factor $\frac{1}{2}$ can be viewed as the residual and inherent part of the electroweak energy associated with incoming and outgoing free nucleon from the binding energy scheme. Finally, the advanced strong and electroweak mass formula including the pairing energy term can be written as,

$$(BE)_{A,Z} \cong \left[A - A_{radius} - A_{free} - A_{asy} + A_{pair} \right] 10.1 \text{ MeV} \quad (9)$$

$$\text{here, } A_{radius} \cong A^{1/3}; \quad A_{asy} \cong \left((1 - I^2) \frac{(A_s - A)^2}{A_s} \right); \quad A_{pair} \cong \frac{(-1)^Z + (-1)^N}{2\sqrt{A}};$$

For Helium-4 like tightly bound atomic nuclides having no free nucleons, this residual electroweak energy of 5 MeV seems to be unnecessary. Clearly writing, factor $\frac{1}{2}$ of the electroweak term can be ignored. Proceeding further, an error of ± 5 MeV can be considered as a correction or uncertainty in the estimated nuclear binding energy. It needs further study.

6. Understanding Cold Nuclear Fusion

In general, Low energy nuclear reactions (LENR) associated with liberation of energy can be called as Cold fusion reactions (CFR) assumed to be associated Cold fusion (CF). Now-a-days, CF is gaining lot of scientific interest in view of its expected clean and green energy at controllable temperatures. NASA cold fusion experiments [10,11], Russian E-cat experiments [13], Andrea Rossi's industrial E-cat patents and developments [14] and Japanese experiments [15] show reproducible fusion reactions and excess heat linked with low temperature nuclear reactions. This accelerating progress in experimental techniques and reactor designs associated with cold fusion technology potentially offers a hopeful alternative to fossil fuels. It may also be noted that, cold fusion experiments indicate that, there is no generation of harmful waste and not involved with high temperatures. Thus, cold nuclear fusion technology seems to be safer and environmentally friendly. Even though current situation is limited to experimental phase and developing stage, increasing international collaboration and better reproducibility are encouraging cold fusion research toward next level with a great positive hope in view of practical applications like global energy needs and power for space exploration. The growing body of validated evidence and patents underline a hopeful future for cold nuclear fusion in the clean energy landscape [12,16] with sustainable development.

a) Nuclear Absorption and Composition Changes

In a controllable and safe thermal bath, under certain operating conditions, base atomic nuclide (BAN) absorbs hydrogen atoms or neutrons. As a consequence, its nucleon composition changes, mass number A and proton number Z are modified depending on the interaction:

- (1) **Isotopic Conversion:** Adding neutrons increases A while Z remains constant.
- (2) **Isobaric or Isotonic Changes:** Proton absorption or nuclear transmutation also modifies Z alongside A .

Such changes alter nuclear binding energy and nucleon kinetic energy due to shifts in nuclear stability and internal nuclear force balance.

b) Binding Energy and Kinetic Energy Shifts

The model also predicts that the difference in nuclear binding energies between initial and absorbed states determines the energy balance during the reaction, governing reaction feasibility and thermal yield. Considering the concept of 'maximum binding energy per nucleon', it can be understood as follows. Absorption of hydrogen gives 8.8 MeV to the base atomic nuclide. This energy helps in increasing the binding energy of the converted atomic nuclide. Considering the increase in kinetic energy as zero, liberated thermal energy can be expressed as [43–47],

$$E_{th} \cong k [8.8 - (B_2 - B_1)] \text{ MeV} \quad (10)$$

where B_1 and B_2 represent the binding energies of base and converted atomic nuclides and k is a process dependent coefficient of the order of (0.9 to 1.0). Based on this concept, atomic nuclides can be selected as cold nuclear fuels. If $(B_2 - B_1)$ is greater than 8.8 MeV, triggering of cold nuclear fusion seems to be doubtful.

c) Role of the Electroweak Interaction in Cold Nuclear Fusion

Based on our 4G model, it is clear that, coulombic interaction energy barrier is on lower side. Quantitatively, from relation (8), one can infer the following relation.

$$\left\{ (c_{ew})_Z \times 0.0016 \times Z^2 \left(1 + 0.5 \left(\frac{Z}{N} \right)^5 \right) \times 10.1 \text{ MeV} \right\} < \left[Z^2 / A^{1/3} \right] \times 0.71 \text{ MeV}, \quad (11)$$

Thus,

- (1) Cold fusion reactions can be initiated with low energy triggering.
- (2) Neutron-proton decay reactions can be allowed in a significant way.
- (3) Light atomic stable nuclides having the ability to absorb hydrogen atoms can be identified.

d) Iron and Magnesium

Following the traditional nuclear stability conditions associated with neutron-proton pairing [41,42] and our proposed stability relations, Iron and Magnesium like elements can be selected for cold nuclear fusion.

- (1) **Iron (Fe) and Magnesium (Mg):** Close to the stability line predicted by $2Z + 0.0016(2Z)^2$, stable isotopes of Fe and Mg can be identified in line with relation (11).
- (2) **Hydrogen and Neutron Absorption:** Interesting point to be noted is that, stable isotopes of Fe and Mg can be 'bombarded with' or can be 'fused with' hydrogen atoms or neutrons in a safe mode. If the expected cold nuclear electroweak reactions are workable, thermal energy can be released.

e) To Clear the skepticism on Cold Nuclear Fusion

- (1) The 4G model offers a theoretical basis linking nuclear structure shifts and low-energy nuclear reactions observed in cold fusion experiments.
- (2) It predicts a scalable approach for selecting nuclear fuels and reaction conditions with optimized energy yield and reduced thermal input.

- (3) Understanding electroweak contributions to nuclear stability could lead to improved cold fusion reactor designs, cleaner nuclear energy production, and new pathways for isotope generation.
- (4) Once the idea of relinquishing the traditional Coulombic interactions comes into picture, it helps in reviewing the basics of nuclear binding energy scheme in terms of strong and weak interactions. Proceeding further, interaction of hydrogen with stable atomic nuclides, can also be analysed in terms of strong and weak interactions. Thus, with further analysis on the probability calculations associated with hydrogen and stable atomic nuclides, it seems possible to study and review the cold nuclear fusion scheme. This approach will certainly help in addressing the skepticism in the broader fusion research community.

7. On the Non-Essentiality of Megakelvin Temperatures for Isotopic Transformation

a) The Thermonuclear Fallacy

The common scientific insistence on a 10^6 K environment is rooted in the Coulomb Barrier—the electrostatic repulsion between two positively charged nuclei. In a vacuum or plasma state, high kinetic energy (heat) is the only way to force nuclei close enough for the Strong Nuclear Force to take over. However, this “Thermal Force” requirement is specific to Hot Fusion and does not account for established alternative pathways in nature and laboratory physics.

b) Natural Low-Temperature Precedents

Nature frequently produces isotopes in ‘cold’ environments less than 10^4 K through mechanisms that bypass the Coulomb barrier entirely:

- **Cosmic Ray Spallation:** High-energy protons strike atmospheric nuclei (Nitrogen/Oxygen) at ambient temperatures, fragmenting them into isotopes of Lithium, Beryllium, and Boron [48].
- **Natural Neutron Capture:** In Earth’s crust, spontaneous fission of heavy elements releases neutrons. These neutrons, having no charge, penetrate surrounding nuclei at room temperature to create new isotopes (e.g., Pu-239 found in Uranium ores) [49].
- **Geological Radioactive Decay:** Isobaric shifts occur constantly within the Earth’s mantle (e.g., Potassium (K-40) to Argon (Ar-40) driven by internal nuclear instability rather than external thermal excitation.

c) The Solid-State Advantage: Lattice-Assisted Nuclear Reactions (LANR)

In a laboratory setting involving a metallic lattice (such as **Iron-56**), the environment differs fundamentally from a gaseous plasma. Two primary factors lower the ‘effective’ temperature requirement:

- **Electron Screening:** Within a dense metallic lattice, the sea of conduction electrons [50] acts as a shield. This ‘screens’ the positive charge of the incoming hydrogen nucleus, significantly reducing the repulsion force and allowing for closer approach at much lower energies (1000°C).
- **Coherent Matter Interactions:** In the solid state, nuclear interactions can be distributed across the lattice. This allows for momentum and energy transfers that are impossible in a vacuum, potentially enabling ‘tunneling’ through the Coulomb barrier at thermal energies.

d) Neutron-Equivalent Pathways

If the experimental setup facilitates a mechanism where a proton and electron behave as a ‘virtual neutron’ or undergo local **electron capture**, the Coulomb barrier becomes irrelevant. Since a neutron carries no charge, it requires zero kinetic energy to enter an Iron-56 (Fe-56) nucleus [51–54]. Therefore, if the process is capture-based rather than collision-based, the 10^6 K requirement is physically inapplicable.

e) Important Note Points

The requirement for million-degree temperatures is a limitation of kinetic fusion, not a law of nuclear transformation. By utilizing the high-density environment of an Iron lattice at 1000°C, we

move from the regime of ‘High-Energy Physics’ to ‘Low-Energy Nuclear Chemistry’ where the governing factor is the local electromagnetic environment rather than bulk thermal velocity.

The Role of the 1000°C Thermal Threshold: In this approach, the maintenance of a 1000°C background environment is not intended to provide thermonuclear kinetic energy. Instead, it serves as a critical metallurgical transition point. At this temperature (~1273 K), the iron core undergoes two vital transformations:

Phase Transition & Lattice Softening: Iron enters the Austenite (Gamma-phase), characterized by a Face-Centered Cubic (FCC) structure. This state exhibits increased lattice vibrations and higher permeability, effectively “softening” the core to allow deep penetration of hydrogen atoms into the nuclear active zones.

Hydrogen Activation: Thermal energy at 1000°C ensures that hydrogen atoms are sufficiently excited to maximize their interaction frequency with the screened potential of the iron lattice.

- **The Binding Energy Rebalancing Mechanism:** The transition from Iron-56 to Iron-57 is governed by an internal rebalancing of nuclear binding energy (BE). We propose the following energy exchange:
- **Input Potential (Input BE):** Approximately 8.8 MeV (representing the peak BE per nucleon for the incoming hydrogen-derived nucleon).
- **Final State (Output BE):** Approximately 7.96 MeV (representing the specific binding energy of the added nucleon in Fe-57).
- **Net Energy Release:** $8.8 \text{ MeV} - 7.96 \text{ MeV} = 0.84 \text{ MeV}$

Self-Sustained Operation and ‘Atomic Spark Plugs’: A primary doubt in cold nuclear synthesis is the absence of million-degree temperatures. We resolve this by demonstrating that the energy release is a **consequence**, not a **requirement**, of the reaction.

Once the initial 1000°C threshold is reached and the first captures occur, the release of 0.84 MeV per reaction acts as a localized “atomic spark plug”. This energy is transferred to the surrounding nucleons as kinetic energy, which is then thermalized through the lattice. Because 0.84 MeV is orders of magnitude greater than the ambient thermal energy (~0.1 eV, a very low reaction density is sufficient to maintain the 1000°C core temperature. This creates a self-sustaining feedback loop where the reaction provides the heat necessary to keep the lattice “soft” for further hydrogen absorption.

Conclusion on Background Requirements: We conclude that the 10^6 K requirement is a limitation of kinetic-collision fusion in gaseous plasmas. By utilizing a solid-state catalytic medium (Iron), we replace bulk thermal velocity with lattice-mediated capture. In this framework, 1000°C is a functional necessity for material permeability, while the internal binding energy differential provides the motive force for sustainable energy production.

8. Strategic Pilot Plant Implementation: Isotopic Energy Scavenging in High-Neutron Flux Environments

a) The “Neutron Scavenger” Model

The most efficient path for validating the 4G model involves integrating the proposed Iron core into environments where free neutrons are already abundant, such as the peripheral zones of existing fission reactors. In this scenario, the requirement for hydrogen excitation is bypassed because neutrons, carrying no electrostatic charge, penetrate the Fe-56 nuclei without encountering a Coulomb barrier. This transforms the equipment from a standalone generator into an “Active Isotopic Scavenger” that captures “waste” neutrons to produce secondary thermal energy.

b) Objectives of the Pilot Project

A pilot plant installation within a nuclear power facility serves two primary strategic purposes:

- **Empirical Validation:** By exposing calibrated Iron-56 samples to a known neutron flux, we can perform real-time monitoring of the Fe-56 to Fe-57 transition. This provides a laboratory-grade environment to study the transition dynamics under controlled conditions.

- **Calorimetric Calibration:** Measuring the precise temperature differential of the coolant as it passes through the Iron-56 test-bed allows for the direct measurement of liberated energy. This data is essential for verifying if the measured thermal output matches our predicted 0.84 MeV per capture.

c) Refinement of Energy Calculations

Data gathered from the pilot project will allow for a “bottom-up” revision of the 4G model’s energy density formulas. By correlating the rate of isotopic transformation with total thermal output, we can refine the electroweak stability coefficient (0.0016) and the associated asymmetry terms. This empirical baseline will transform our theoretical energy calculations into a verified engineering standard, necessary for the design of independent power units.

d) Implications for “New Installation” Infrastructure

Success in the pilot phase establishes the feasibility of a new class of power infrastructure. These “New Installations” can be designed as:

- **Hybrid Reactors:** Combining a primary neutron source with a high-volume Iron-56 secondary energy ring to maximize total thermal efficiency.
- **Modular Isotopic Batteries:** Compact, safe units that can be installed in existing industrial zones to provide decentralized heat and power without the complexities of high-pressure plasma or radioactive fuel management.

Thus, transitioning from theoretical modelling to a pilot project in a high-neutron environment represents the logical bridge between physics and commercial power generation. This approach mitigates the risks associated with standalone cold fusion experiments and utilizes established nuclear infrastructure to prove that stable, abundant materials like Iron can be harnessed as a viable “Cold Fuel” for the future.

9. Industrial Case Study: Anomalous Energy Release in Molten Iron-Water Interactions

a) The Incident Narrative

To understand the potential for low-temperature nuclear transitions, we look to an observed industrial anomaly in a foundry environment. During a mechanical breakdown, approximately 3 tons of liquid iron at 1500°C was accidentally discharged onto a floor area containing a localized pond of collected water. Positioned within this area was a steel bin with a mass of 100 kg.

Upon the interaction of the molten metal with the water, a high-order explosion occurred. The force was sufficient to propel the 100 kg steel bin vertically to a height of 20 meters, where it possessed enough kinetic energy to breach the industrial roof sheeting before coming to rest on the structural steel channels.

b) Energy Density Analysis: Steam vs. Nuclear Transition

Standard industrial safety models attribute such events to “steam explosions”, where water undergoes a rapid phase transition. However, from the perspective of the 4G model, we examine if the energy density required for such a mechanical feat exceeds the limits of a purely thermal-hydraulic event:

- **Mechanical Work:** Lifting 100 kg to a height of 20 meters requires a minimum potential energy of 19,600 Joules. However, the energy required to shatter an asbestos roof and overcome aerodynamic drag at high velocity implies a peak force significantly higher than that produced by expanding steam in an open, unconfined environment.
- **The Fusion Hypothesis:** In this scenario, the molten iron (at 1500°C) provides the “softened” lattice state and high thermal excitation discussed in our model. The water provides a dense source of hydrogen. We hypothesize that the sudden, high-pressure contact between the molten iron lattice and the hydrogen atoms may have triggered a localized, “runaway” isotopic transition (Fe-56 to Fe-57).

c) Molten Metal as a Catalytic Medium

This incident provides a real-world parallel to our proposed reactor conditions. The 1500°C temperature of the liquid iron exceeds our 1000°C “softening” threshold, creating an ideal environment for hydrogen penetration. The resulting explosion may be interpreted as a macroscopic validation of the 0.84 MeV energy release per capture. If even a microscopic fraction of the iron atoms underwent isotopic transformation during the splash, the liberated nuclear energy would far exceed the energy of a chemical steam expansion.

d) **Conclusion for Pilot Design**

This foundry incident serves as a “natural experiment” in high-temperature metal-hydrogen interactions. It reinforces the logic that:

1. High Background Temperatures (1500°C) facilitate rapid nuclear-scale interactions.
2. The resulting energy release is mechanical and thermal, capable of performing massive work.
3. Experimental Safety: Future pilot projects must account for this “threshold effect” to ensure that the 0.84 MeV release per nucleon is harvested steadily rather than in a singular, explosive event.

10. Integration of NASA Research (Pines et al. & Steinetz et al.)

The hypothesis that a metallic lattice can facilitate nuclear transitions at energies far below the thermonuclear threshold is strongly supported by recent high-level experimental data [10,11]. Specifically, Pines et al. (2020) and Steinetz et al. (2020) have demonstrated that deuterated metals (such as Erbium or Titanium), when subjected to external excitation, can trigger nuclear fusion reactions within the lattice.

- **Lattice-Confined Fusion (LCF):** NASA’s research describes a process where the electron screening provided by the metal lattice (similar to the “softened” Iron lattice at 1000°C) allows for a significantly higher probability of nuclear interaction.
- **Relevance to the Foundry Incident:** While the NASA experiments utilized bremsstrahlung-irradiation, the physical principle is the same: the metal lattice acts as a “catalytic cage” that overcomes the Coulomb barrier. In our 1500°C molten iron incident, the thermal energy and high atomic density of the liquid iron provide the “excitation” necessary to achieve a similar lattice-confined effect, leading to the explosive liberation of 0.84 MeV per capture.
- **Validation of the 4G Model:** These references confirm that “Cold” or “Lattice-Assisted” reactions are a real physical phenomenon. Our 4G model provides the underlying mathematical framework—using the electroweak stability coefficient (0.0016)—to explain why these reactions occur at low temperatures and how to predict the resulting isotopic stability.

11. High-Level Scientific Validation: Lattice-Enhanced Fusion Rates

a) **The Nature (2025) Breakthrough**

The recent findings by Chen et al. (2025), published in Nature [55], demonstrate that electrochemical loading in metal targets can enhance deuterium fusion rates by several orders of magnitude. This research confirms that the solid-state environment of a metal lattice is not a passive container but an active catalyst that facilitates nuclear interactions at low energies.

b) **Correlation with the 4G Model and Iron Lattice**

While the ‘Nature’ study focuses on electrochemical loading, it supports the core pillars of our approach:

- **Electron Screening & Enhanced Rates:** The study confirms that the “environment” around the nucleus (the lattice) is what drives the fusion boost. This aligns with our proposal that a 1000°C “softened” Iron lattice provides the necessary screening and permeability for isotopic transformation.
- **Predictive Framework:** The Nature paper provides the empirical “boost” data; our 4G model provides the underlying stability math. By applying the electroweak stability coefficient (0.0016), we can predict which metal targets (like Iron and Magnesium) will yield the most stable energy output (0.84 MeV).

c) From Laboratory “Boosts” to Industrial “Explosions”

The Nature paper proves that fusion rates can be “boosted” in a lab. Our Industrial Case Study (the 3-ton foundry spillage) suggests that under extreme conditions—such as 1500°C molten iron meeting a dense hydrogen source—this “boost” becomes a massive energy release. The 2025 Nature findings provide the scientific mechanism that explains why those foundry incidents are not mere steam events, but high-density nuclear transitions.

12. Conclusions

The 4G model of strong and electroweak interactions provides a robust, unified framework for understanding nuclear stability and binding energy. By replacing the multi-parameter Liquid Drop Model with a single electroweak stability coefficient (0.0016), we demonstrate that nuclear transformation is not solely a consequence of high-velocity kinetic collisions, but rather a predictable outcome of isotopic rebalancing.

Our proposed approach to cold nuclear fusion offers a disruptive alternative to current high-temperature fusion strategies in several key ways:

1. **Abundance and Stability:** By utilizing abundant and stable materials such as Iron-56 and Magnesium-24, we eliminate the need for rare or radioactive fuels like Tritium. The end products are stable isotopes (Iron-57), ensuring a clean energy cycle with zero radioactive waste.
2. **Operational Simplicity:** The transition from the gaseous plasma regime 10^6 K to a solid-state lattice regime 1000 degree C allows for the use of existing industrial metallurgy and turbine infrastructure. At 1000 degree C, the iron lattice reaches a “softened” state that facilitates hydrogen or neutron absorption, significantly reducing the complexity of reactor engineering.
3. **Self-Sustaining Energy Yield:** The calculated energy release of approximately 0.84 MeV per capture event provides a localized thermal source. This “atomic spark plug” effect maintains the required lattice temperature, allowing for self-sustained operation without continuous external power input.
4. **Strategic Pilot Implementation:** We propose that the fastest path to commercial validation is the integration of this equipment into existing nuclear power plants. In these high-neutron flux environments, the process is further simplified as free neutrons can be directly scavenged to produce secondary thermal energy. This pilot phase will allow for the empirical refinement of our energy calculations and the 4G binding energy formula.

The 4G model transitions nuclear energy from the extreme conditions of gaseous plasmas to the manageable regime of solid-state chemistry. Supported by recent experimental breakthroughs in lattice-enhanced fusion (Nature, 2025) and high-level aerospace research (NASA, 2020), our model demonstrates that abundant materials like Iron-56 can serve as a viable cold fuel. By utilizing existing nuclear infrastructure for pilot studies, we can harvest the 0.84 MeV energy release predicted by our unified binding energy formula, paving the way for safe, abundant, and decentralized power generation.

Ultimately, the 4G model suggests that the global energy crisis can be solved through Low-Energy Nuclear Transformation. By shifting focus toward the “sweet spot” of the binding energy curve, we can build new, modular power installations that are safe, abundant, and easily integrated into the modern power grid.

Data Availability Statement: The data that support the findings of this study are openly available.

Acknowledgments: Author Seshavatharam is indebted to Padma Shri M. Nagaphani Sarma, Chairman, Shri K.V. Krishna Murthy, founder Chairman, Institute of Scientific Research in Vedas (I-SERVE), Hyderabad, India and Shri K.V.R.S. Murthy, former scientist IICT (CSIR), Govt. of India, Director, Research and Development, I-SERVE, for their valuable guidance and great support in developing this subject. Authors are very much thankful to the conference committee for awarding “Best Oral Presentation” in the 2nd International Conference on Emerging Materials for Technological Applications (Integrating Artificial Intelligence and Data

Science), held on 10-12 December 2025 at Aditya Institute of Technology and Management, (AITAM), Tekkali, A.P. India.

Conflicts of Interest: Authors declare no conflict of interest in this paper or subject.

References

1. Bethe H. A, Thomas-Fermi Theory of Nuclei. *Phys. Rev.*, 167(4) (1968) 879-907.
2. Myers W. D. and Swiatecki W. J. Nuclear Properties According to the Thomas-Fermi Model. *LBL-36557 Rev. UC-413*, 1995.
3. Myers W. D. and Swiatecki W. J, Table of nuclear masses according to the 1994 Thomas-Fermi model. United States: N. p., 1994. Web.
4. P.R. Chowdhury, C. Samanta, D.N. Basu, Modified Bethe– Weizsacker mass formula with isotonic shift and new driplines. *Mod. Phys. Lett. A* 20 (2005) 1605–1618.
5. G. Royer, On the coefficients of the liquid drop model mass formulae and nuclear radii. *Nuclear Physics A*, 807(3–4) (2008) 105-118.
6. Djelloul Benzaid, Salaheddine Bentriddi, Abdelkader Kerraci, Naima Amrani, Bethe–Weizsacker semiempirical mass formula coefficients 2019 update based on AME2016. *NUCL. SCI. TECH.* 31 (2020) 9.
7. Gao, Z.P., Wang, YJ., Lü, HL. et al., Machine learning the nuclear mass. *NUCL. SCI. TECH.* 32 (2021) 109.
8. Peng Guo, et. al. (DRHBc Mass Table Collaboration), Nuclear mass table in deformed relativistic Hartree-Bogoliubov theory in continuum, II: Even-Z nuclei. *Atomic Data and Nuclear Data Tables* 158 (2024) 101661.
9. Cht. Mavrodiev S, Deliyergiyev M.A, Modification of the nuclear landscape in the inverse problem framework using the generalized Bethe-Weizsäcker mass formula. *Int. J. Mod. Phys. E* 27 (2018) 1850015.
10. V. Pines et al., Nuclear fusion reactions in deuterated metals. *Phys. Rev. C* 101(4) (2020) 044609.
11. M. Steinetz Bruce, et al., Novel nuclear reactions observed in bremsstrahlung-irradiated deuterated metals. *Phys. Rev. C.* 101(4) (2020) 044610.
12. L.O. Freire, D.A. Andrade, Preliminary survey on cold fusion: it's not pathological science and may require revision of nuclear theory. *J. Electroanal. Chem.* 903 (2021) 115871.
13. A.G. Parkhomov, K.A. Alabin, S.N. Andreev et al., Nickel-hydrogen reactors: heat release, isotopic and elemental composition of fuel. *RENSIT* 9(1) (2017) 74–93.
14. G. Levi et al., Indication of anomalous heat energy production in a reactor device (2013). arXiv:1305.3913
15. Y. Iwamura, T. Itoh, J. Kasagi, S. Murakami, M. Saito, Excess energy generation using a nano-sized multilayer metal composite and hydrogen gas. *J. Condensed Matter Nucl. Sci.* 33 (2020) 1–13.
16. E. Storms, Introduction to the main experimental findings of the LENR field. *Curr. Sci.* 108 (2015) 535–539.
17. Seshavatharam U. V. S, Gunavardhana Naidu T and Lakshminarayana S, Nuclear evidences for confirming the physical existence of 585 GeV weak fermion and galactic observations of TeV radiation. *International Journal of Advanced Astronomy.* 13(1) (2025) 1-17.
18. Seshavatharam U. V. S and Lakshminarayana S, 4G model of final unification – A brief report. *Journal of Physics: Conference Series* 2197 (2022) 012029.
19. Seshavatharam U.V.S and Lakshminarayana S. A very brief review on strong and electroweak mass formula pertaining to 4G model of final unification. *Proceedings of the DAE Symp. on Nucl. Phys.* 67 (2023) 1173.
20. Seshavatharam U.V.S. and Lakshminarayana S, Understanding the Origins of Quark Charges, Quantum of Magnetic Flux, Planck's Radiation Constant and Celestial Magnetic Moments with the 4G Model of Nuclear Charge. *Current Physics*, 1, e090524229812 (2024) 122-147.
21. Seshavatharam U.V.S. and Lakshminarayana S, Exploring condensed matter physics with refined electroweak term of the strong and electroweak mass formula. *World Scientific News.*193(2) (2024) 105-13.
22. C. Grojean, Higgs Physics. *Proceedings of the 2015 CERN–Latin-American School of High-Energy Physics*, 143-157, 2016, CERN-2016-005 (CERN, Geneva, 2016)
23. Ahmed Abokhalil, The Higgs Mechanism and Higgs Boson: Unveiling the Symmetry of the Universe. arXiv:2306.01019v2 [hep-ph]

24. Seshavatharam U.V.S and Lakshminarayana S, On the Role of Nuclear Binding Energy in Understanding Cold Nuclear Fusion. *Mapana Journal of Sciences*, 20(3), (2021) 29-42.
25. Seshavatharam U.V.S and Lakshminarayana S, On the Combined Role of Strong and Electroweak Interactions in Understanding Nuclear Binding Energy Scheme. *Mapana Journal of Sciences*. 20(1) (2021) 1-18.
26. Ghahramany N, Gharaati, S., & Ghanaatian, M, New approach to nuclear binding energy in integrated nuclear model. *Journal of Theoretical and Applied Physics*, 6(1) (2012) 3.
27. Seshavatharam U. V. S and Lakshminarayana S., H. K. Cherop and K. M. Khanna, Three Unified Nuclear Binding Energy Formulae. *World Scientific News*, 163, (2022) 30-77.
28. Antonio Delgado and Mariano Quirós, Higgsino dark matter in the MSSM. *Phys. Rev. D* 103, (2021) 015024.
29. Stephen P. Martin, Curtain lowers on directly detectable higgsino dark matter. *Phys. Rev. D* 111 (2025) 075004.
30. Fukuda, H., Li, Q., Moroi, T. et al., Non-thermal production of Higgsino dark matter by late-decaying scalar fields. *J. High Energ. Phys.* 2025 (2025) 91.
31. Tomonori Totani. 20 GeV halo-like excess of the Galactic diffuse emission and implications for dark matter annihilation. *JCAP*, 11 (2025) 080.
32. Yosui Akaike and Shoji Toriia for the CALET collaboration Waseda Research Institute for Science and Engineering, Waseda University, The cosmic-ray electron and positron spectrum measured with CALET on the International Space Station. 38th International Cosmic Ray Conference (ICRC2023) 26 July - 3 August, 2023 Nagoya, Japan.
33. Satyendra Thoudam. Origin of the break in the cosmic-ray electron plus positron spectrum at ~ 1 TeV. arXiv:2409.05509v2 [astro-ph.HE] for this version) 2024.
34. Yu-Chen Ding, Nan Li, Chun-Cheng Wei, Yue-Liang Wu, and Yu-Feng Zhou. Implications of a possible TeV break in the cosmic-ray electron and positron flux. *Phys. Rev. D* 103 (2021)115010.
35. F. Aharonian F, Ait Benkhali, J. Aschersleben, H. Ashkar, M. Backes, V. Barbosa Martins, R. Batzofin, Y. Becherini, D. Berge et al. (H.E.S.S. Collaboration). High-Statistics Measurement of the Cosmic-Ray Electron Spectrum with H.E.S.S. *Phys. Rev. Lett.* 133 (2024) 221001.
36. Seshavatharam U. V. S, Gunavardhana Naidu T and Lakshminarayana S. 4G Model of Heavy Electroweak Charged 585 GeV Fermions as the Supposed Microscopic Origin of the 1.17 TeV All-Electron Spectral Break. *International Journal of Advance Research and Innovative Ideas in Education*. 11(6) (2025) 2116-2140.
37. Seshavatharam U.V.S, Gunavardhana, T. N. and Lakshminarayana, S. Advancing String Theory with 4G Model of Final Unification. *J. Phys.: Theor. Appl.* 9(2) (2025) 158-197.
38. Seshavatharam U. V. S.; Lakshminarayana S, Revised Electroweak and Asymmetry Terms of the Strong and Electroweak Mass Formula Associated with 4G Model of Final Unification. Preprints 2025050425, 2025.
39. Seshavatharam, U. V. S. and S. Lakshminarayana. A Unified 6-Term Formula for Nuclear Binding Energy with a Single Set of Energy Coefficients for $Z = 1-140$. *International Journal of Advance Research and Innovative Ideas in Education*.2(6), (2025) 1716-1731.
40. Seshavatharam U.V.S, Gunavardhana, T. N. and Lakshminarayana S, Avogadro's Number: History, Scientific Role, State-of-the-Art, and Frontier Computational Perspectives. Preprints 2025, 2025080338.
41. S. Frauendorf, A.O. Macchiavelli, Overview of neutron-proton pairing, *Progress in Particle and Nuclear Physics*, 8, (2014) 24-90.
42. F. Simkovic, Ch.C. Moustakidis, L. Paceaescu and Amand Faessler, Proton-neutron pairing in the deformed BCS approach. *Phys. Rev. C* 68 (2023) 054319.
43. Seshavatharam U.V.S and Lakshminarayana S, Exploring the Possibility of Running an Electric Locomotive with Cold Nuclear Fusion by Considering Iron-56 or Magnesium-24 as Nuclear Fuels. *New Energy Exploitation and Application*. 4(1) (2025) 161-174.
44. Seshavatharam U.V.S and Lakshminarayana S, To Develop an Eco-Friendly Cold Nuclear Thermal Power Plant by Considering Iron-56 as a Fuel. In: Zhao, J., Kadam, S., Yu, Z., Li, X. (eds) *IGEC Transactions, Volume 1: Energy Conversion and Management*. IAGE 2023. Springer Proceedings in Energy. Springer, Cham. 2024.

45. Seshavatharam U.V.S and Lakshminarayana S, Small scale production of gold with tungsten like heavy and cheap metals via cold nuclear fusion associated with safe and secured hydration, *Materials Today: Proceedings*. 57, Part 2, (2022) 603-606.
46. Seshavatharam U. V. S and Lakshminarayana S, Energy, environmental and medical applications of cold nuclear fusion of hydrogen with powder and liquid forms of metals. *Innov. Sci. Tech.* 1(3) (2022) 43–50.
47. Seshavatharam U.V.S and Lakshminarayana, S, Nickel- the ultimate substitute of coal, oil and Uranium, *International journal of Sustainable and green energy* 4 (15) (2015) 1-6.
48. R. C., Arnold, J. R., & Lal, D. Cosmic-ray record in solar system matter. *Science*, 219(4581), (1983) 127-135.
49. Clayton, D. D. *Principles of Stellar Evolution and Nucleosynthesis*. University of Chicago Press. (1983) (Chapters on the s-process and neutron cross-sections).
50. Assenbaum, H. J., Langanke, K., & Rolfs, C. Effects of electron screening on low-energy fusion cross sections. *Zeitschrift für Physik A Atoms and Nuclei*, 327(4), (1987) 461-468.
51. Shurtleff R and Derrin, E. The iron cone and the binding energy of nuclei. *American Journal of Physics*, 57(4), (1989) 352-355.
52. Huss, G. R., & Lewis, R. S. Presolar diamond, SiC, and graphite in primitive chondrites: Abundances as a function of primordial metamorphism. *Geochimica et Cosmochimica Acta*, 59(1), (1995) 115-160.
53. Widom, A., and Larsen, L. Absorption of nuclear specific heat capacity in heavy water. *European Physical Journal C*, 46(1), (2006) 107-110.
54. Hagelstein, P.L. A unified model for anomalies in metal deuterides. in *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science*. 2002. Tsinghua Univ., Beijing, China: Tsinghua Univ. Press.
55. Chen, K. Y., et al. Electrochemical loading enhances deuterium fusion rates in a metal target. *Nature*, 644, (2025) 640–645.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.