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# FINANCIAL INSTRUMENTS FOR STIMULATING INVESTMENT IN GREEN HYDROGEN PRODUCTION PROJECTS: EU EXPERIENCE AND PERSPECTIVES FOR GEORGIA AND UKRAINE

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*Within the framework of the research, a comprehensive analysis of the transformation of the financial architecture for stimulating hydrogen energy is implemented, which allows for the formation of a holistic understanding of the mechanisms for transitioning to a climate-neutral economy. A thorough critical assessment of the evolution of state support instruments in the European Union is carried out, with particular focus placed on the paradigm shift from direct subsidization of capital expenditures (CAPEX) to the introduction of high-efficiency market models for stimulating operating activities (OPEX).*

*The functional role of the European Hydrogen Bank as a key institutional driver that ensures the de-risking of investment projects through a system of competitive auctions and fixed premiums is detailed. In the course of the study, a set of multi-vector barriers restricting capital inflow into the Georgian and Ukrainian energy sector is identified and systematized. The destructive impact of high costs of financial resources on project payback indicators is examined, and a critical dependence of investment activity on the availability of effective war risk insurance mechanisms in Ukraine is revealed. The necessity for the prompt implementation of a digital system for guarantees of origin of energy is substantiated as a fundamental condition for the full integration of Georgia and Ukraine into the EU hydrogen space and participation in cross-border renewable fuel trade schemes.*

*Significant attention in the work is devoted to the scientific substantiation of the strategic synergy between the states' agro-industrial potential and the latest technologies for hydrogen generation. The feasibility of forming integrated energy clusters based on the biogas capacities of sugar factories and organic waste processing enterprises is proven. It is established that the use of waste heat and digestate in closed cycles allows for a significant optimization of the levelized cost of hydrogen (LCOH), increasing the economic resilience of agricultural enterprises. Conceptual frameworks for the functioning of decentralized «energy hubs» are formulated, which are considered as a foundation for ensuring the energy autonomy of territorial communities and creating high-value-added products, such as «green» ammonia. It is confirmed that the combination of European financial instruments with national sectoral advantages is the most rational way to ensure sustainable energy development of the countries.*

**Key words:** green hydrogen, investments, financial instruments, European Hydrogen Bank, fixed premium, agro-industrial complex, biogas, energy synergy, decarbonization, sustainable development.

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# ФІНАНСОВІ ІНСТРУМЕНТИ СТИМУЛЮВАННЯ ІНВЕСТИЦІЙ У ПРОЄКТИ ВИРОБНИЦТВА «ЗЕЛЕНОГО» ВОДНЮ: ДОСВІД ЄС ТА ПЕРСПЕКТИВИ ДЛЯ ГРУЗІЇ ТА УКРАЇНИ

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*У межах проведеного дослідження виконано комплексний аналіз трансформації фінансової архітектури стимулювання водневої енергетики, що дало змогу сформувати цілісне уявлення про механізми переходу до кліматично нейтральної економіки. Здійснено ґрунтовну критичну оцінку еволюції інструментів державної підтримки у Європейському Союзі, де особливу увагу зосереджено на зміні парадигми від прямого субсидування капітальних витрат (CAPEX) до впровадження високоефективних ринкових моделей стимулювання операційної діяльності (OPEX). Деталізовано функціональну роль Європейського банку водню як ключового інституційного драйвера, що забезпечує мінімізацію інвестиційних проєктів через систему конкурентних аукціонів і фіксованих премій. Під час дослідження ідентифіковано й систематизовано сукупність багатовекторних бар'єрів, що обмежують приплив капіталу в грузинський та український енергетичний сектор. Розглянуто деструктивний вплив високої вартості фінансових ресурсів на показники окупності проєктів, а також виявлено критичну залежність інвестиційної активності від наявності дієвих механізмів страхування воєнних ризиків в Україні. Обґрунтовано необхідність оперативного впровадження цифрової системи гарантій походження енергії як базової умови для повноцінної інтеграції Грузії та України у водневий простір ЄС й участі у транскордонних схемах торгівлі відновлюваним паливом. Значне місце в роботі відведено науковому обґрунтуванню стратегічної синергії між агропромисловим потенціалом держав і новітніми технологіями водневої генерації. Доведено доцільність формування інтегрованих енергетичних кластерів на базі біогазових потужностей цукрових заводів, а також підприємств із перероблення органічних відходів. Установлено, що використання побічного тепла й дигестату в замкнених циклах дає змогу суттєво оптимізувати приведену вартість водню (LCOH), підвищуючи економічну стійкість аграрних підприємств. Сформульовано концептуальні засади функціонування децентралізованих «енергетичних хабів», які розглянуто як фундамент для забезпечення енергетичної автономності територіальних громад і створення продуктів із високою доданою вартістю, таких як «зелений» аміак. Підтверджено, що поєднання європейських фінансових інструментів із національними галузевими перевагами є найбільш раціональним шляхом забезпечення сталого енергетичного розвитку.*

**Ключові слова:** зелений водень, інвестиції, фінансові інструменти, Європейський банк водню, фіксована премія, агропромисловий комплекс, біогаз, енергетична синергія, декарбонізація, сталий розвиток.

**Табл.: 3. Літ.: 15.**

**Formulation of the problem.** The global energy transition and the commitment to achieving climate neutrality by 2050, as outlined in the European Green Deal, have posed a challenge to the international community to undertake a radical transformation of energy systems [1]. In this context, «green» hydrogen, produced through water electrolysis using renewable energy sources (hereinafter – RES), is considered a critically important energy carrier for the decarbonization of

sectors where emissions are difficult to reduce (such as metallurgy, the chemical industry, and heavy transport).

For Georgia and Ukraine, the development of hydrogen energy is not only an environmental priority but also an instrument of energy security. However, the high capital intensity of projects (CAPEX) and the significant cost of production compared to fossil fuels create investment risks associated with the high cost of commissioning such facilities. The European Union has already implemented a number of powerful financial instruments to mitigate these risks, the experience of which is essential for the formation of Ukraine's public policy.

**Analysis of recent research and publications.** The contemporary global energy paradigm is undergoing fundamental transformations, in which hydrogen is regarded as a key vector for the decarbonization of industry and transport. For Georgia and Ukraine, which possess significant natural capital, the development of hydrogen technologies is not only an environmental commitment within the framework of the European Green Deal, but also a strategic instrument for the strengthening national energy independence.

The effective implementation of hydrogen projects requires a comprehensive approach, beginning with the analysis of the resource base. The research by S. Kudria demonstrates that the resource potential of wind energy in Ukraine is sufficient for the development of large-scale wind–hydrogen complexes capable of ensuring sustainable production of this energy carrier [2, p. 162]. However, the transition to a hydrogen economy faces serious financial barriers. As noted by S. Tuskar, the successful attraction of investments for the phased reduction of carbon emissions, particularly in heavy industry, critically depends on the development of effective financing mechanisms and government support [3, p. 55].

Global experience, summarized in the works of B. Lebrouhi, indicates that the development of hydrogen infrastructure has a pronounced geopolitical dimension, where technological leadership is determined by the scale of investments in research and development (R&D) and the expansion of electrolysis capacities [4, p. 7028]. At the same time, the institutional environment plays a regulatory role. E. Pereira and others emphasize that legal challenges and the lack of unified international standards remain significant risks for long-term investment [5, p. 65].

A special place within the structure of renewable energy is occupied by the bioenergy sector. Studies on the kinetics of biochemical processes conducted by K. Pilarski demonstrate the possibility of optimizing energy production from agricultural biomass, which, in synergy with hydrogen technologies, creates conditions for the development of a circular economy [6]. The management of such projects in Eastern European countries, according to V. Lutska and others, should be based on the principles of sustainable development of organic agriculture and integrated management [7, p. 272].

The implementation of these opportunities in Ukraine in the context of post-war recovery requires a stable foundation in the areas of resource provision and legal regulation. H.M. Kaletnik emphasizes that transparent regulation of land circulation is a fundamental prerequisite for the placement of "green" generation facilities [8, p. 560]. Ultimately, the strategic success of the sector will depend on the quality of

marketing management and the ability of the enterprises to effectively utilize their bioeconomic potential [9, p. 655].

In the context of sustainable rural development, the circular model of resource utilization becomes particularly important. As noted by I. Honcharuk, the bioenergy utilization of solid household waste is not only an environmental necessity but also a strategic direction for ensuring the energy autonomy of communities [10, p. 28]. The authors emphasize that the integration of such systems into local infrastructure creates a reliable basis for the further conversion of biogas into clean energy carriers, particularly green hydrogen [10, p. 35].

Alongside municipal waste, the agro-industrial complex – particularly the processing industry – acts as a powerful driver of the hydrogen economy in Ukraine. Research by Ya.V. Hontaruk demonstrates the high efficiency of biogas and digestate production at sugar plants. This makes it possible to simultaneously address issues of energy and food security, as "the use of by-products of sugar production for biofuel generation minimizes energy costs and enhances the competitiveness of the sector" [11, p. 202].

An important aspect of the development of hydrogen production in the Black Sea region is the experience of Georgia, which demonstrates significant potential in the context of international cooperation. Studies by H. Tatishvili emphasize that strategic partnership between Georgia and Azerbaijan in the field of green hydrogen may serve as a foundation for the creation of a new energy corridor connecting the Caspian region with the European market [12]. This confirms Georgia's role as a key transit and production hub integrated into global decarbonization value chains.

The resource base for the implementation of such ambitious plans must be supported by fundamental hydrological and geological research. In particular, the stability of the hydrogen cycle in the region and the potential use of water resources for electrolysis require detailed investigation. The works of L. Holko and H. Melikadze on the analysis of stable isotopes of oxygen and hydrogen in atmospheric precipitation and river waters in Georgia provide the necessary scientific foundation for modeling hydropower potential, which is critical for the stable supply of electrolysis capacities [14].

Moreover, the development of hydrogen technologies is closely intertwined with the study of natural gas sources and the ecological condition of marine ecosystems. Research by M. Anderson and others on methane seeps on the shelf of South Georgia, although oceanographic in nature, highlights the importance of understanding complex biochemical and geological structures when planning large-scale energy infrastructure in coastal zones [13, p. 255]. This underscores the need to take into account ecological vulnerability and biodiversity when implementing new energy instruments.

Despite numerous studies, the issues of financial incentives for investments in hydrogen projects in Georgia and the conditions of high military risk and limited budgetary financing in Ukraine remain insufficiently resolved. Most research focus on the technical and economic parameters of electrolysis or the general benefits of decarbonization, while practical mechanisms for adapting EU financial instruments (such as the «Fixed Premium» or European Hydrogen Bank auctions) to the specifics of the Georgian and Ukrainian agro-industrial sectors of the economy and territorial

communities require further scientific justification.

**Formulation of the goals of the article**. The article aims to provide a comprehensive study of the European experience in applying financial instruments to stimulate investments in «green» hydrogen production projects, and to justify promising mechanisms for their adaptation in Georgia and Ukraine to ensure the sustainable development of territorial communities and the agro-industrial sector of the economy in modern conditions. The implementation of these goals involves a comparative analysis of existing instruments for financial support of hydrogen initiatives in the EU, in particular the mechanisms of the European Hydrogen Bank and the system of fixed bonuses, as well as the identification of key economic, legal, and security barriers that hinder the inflow of investments into hydrogen energy in Georgia and Ukraine. Special attention is paid to the scientific justification of the synergy between the agro-industrial potential, in particular through biogas production at sugar factories and processing of organic waste, and «green» hydrogen generation technologies as a strategic factor in increasing the investment attractiveness and energy independence of both states.

**Presentation of the main research materials**. The systemic transformation of the energy sector of the European Union within the framework of implementing the Formulation of the goals of the article «Hydrogen Strategy for a Climate-Neutral Europe» is based on transitioning from selective subsidization of capital expenditures to the introduction of highly effective market instruments to stimulate operational activities. The leading mechanism in this architecture is the EHB, which introduced the instrument of a fixed premium per unit of verified «green» hydrogen through a system of competitive auctions. This financial instrument allows for the level of the existing price gap (green premium) between renewable and fossil hydrogen, ensuring the de-risking of investment projects and guaranteeing the stability of cash flows over a ten-year planning horizon, which is a critical condition for attracting bank financing and reducing the cost of the capital [15].

However, the integration of Georgia and Ukraine into the European hydrogen space and the attraction of relevant investment resources are currently constrained by a set of determined barriers, among which economic factors are dominant, particularly the high weighted-average cost of capital and the lack of established domestic demand. These obstacles are exacerbated by the institutional and legal incompleteness of the mechanisms for certifying guarantees of origin of energy and critical security risks in Ukraine. This necessitates the development of specialized blended financing instruments with the participation of international financial institutions as well as political and military threat insurance agencies.

In order to prevent fragmentation of the internal energy market, the European Union has introduced an innovative model “Auctions-as-a-Service”, which allows member states to integrate national budgets into a single IT platform and use EHB selection criteria. The use of this approach ensures that high-tech projects that did not receive funding under the pan-European quota due to high competition can be supported at the national level without the need to develop separate complex regulatory frameworks.

This ensures transparency of the investment process and uniform verification standards for all market participants (Table 1).

*Table 1*

**Comparative characteristics of financial instruments for stimulating hydrogen projects in the EU**

| *Instrument* | Object of stimulation | Period of action | Main advantage for the investor | Leveled risks |
|---|---|---|---|---|
| Fixed Premium | Operating activity(OPEX) | 10 years | Direct increase in the marginality of each kg of product | Risk of high cost compared to gray hydrogen |
| CCfD (contracts for difference) | Difference between market and base price | 10–15 years | Stabilization of cash flows regardless of market conditions | Volatility of energy prices and $CO_2$ quotas |
| Auctions-as-a-Service | National budgets via the EHB platform | According to the auction round | Simplified access to financing according to common EU standards | Administrative barriers and regulatory desynchronization |
| Investment grants (Innovation Fund) | Capital expenditures (CAPEX) | One-time (construction stage) | Reduction of the initial financial burden and LCOH | Technological risks of the 'first-of-a-kind' (FOAK) projects |

*Source: systematized by the authors based on [15-16]*

The objective prerequisite for overcoming the risks specified in Table 1 and increasing the investment attractiveness of projects is the implementation of strategic synergy between the powerful agro-industrial potential of Georgia and Ukraine and the latest hydrogen technologies.

A comprehensive combination of these instruments within a single state strategy will allow the formation of a stable financial architecture capable of attracting international capital under the guarantees of mixed financing and insurance of military risks, which is a basic prerequisite for the large-scale deployment of hydrogen infrastructure in Georgia and Ukraine. The comparative analysis (Table 2) indicates a significant differentiation in mechanisms for stimulating the development of «green» hydrogen production, depending on the project implementation phase and the specifics of the market risks being addressed.

*Table 2*

**A Comparative Assessment of instruments for Developing Hydrogen Infrastructure in Georgia and Ukraine**

| Instrument | Adaptability | Prerequisites | Expected effect |
|---|---|---|---|
| in Georgia | | | |
| Regional Partnership (Green Corridor) | High | Conclusion of intergovernmental agreements with Azerbaijan and EU gas transmission system operators | Establishment of the Caspian-Black Sea Hub; attracting investment in transit infrastructure. |
| Hydropower Subsidies | High | Monitoring of the isotopic composition and stability of river runoff that are used to supply electrolysers. | Stable production of “green” hydrogen at a low cost (LCOH). |
| MFI Blending (EBRD/ADB) | Average | Harmonization of environmental standards for coastal zones and the continental shelf. | Lower cost of the capital for large-scale infrastructure projects. |
| in Ukraine | | | |
| Fixed Premium | High | Availability of donor capital (Pillar II Ukraine Facility). | Reducing the payback period (DPP) of projects by 3–5 years. |
| Auctions-as-a-Service | High | Harmonization of the legislation with EU Delegated Acts and the implementation of Guarantees of Origin. | Barrier-free access to the EU market; verification of Ukrainian hydrogen in accordance with RFNBO standards. |
| CCfD (Contracts for Difference) | Average | The launch of the national emissions of trading system (ETS) and stable domestic demand. | Deep decarbonization of metallurgical and chemical plants (green steel/fertilizers). |
| Innovation Fund (grants) | Average | High technology readiness level (TRL 7–9) and safety assurances for the sites. | The creation of “energy islands» and agro-hydrogen clusters based on sugar refineries. |

*Source: the author’s perspective*

The table below outlines the key financial instruments for promoting hydrogen energy, distinguishing between the approaches for Georgia and Ukraine based on their respective national economic characteristics and resource potential. For Georgia, the priority identified instruments are regional partnerships and hydropower subsidies, which, through the conclusion of intergovernmental agreements with Azerbaijan and EU gas transmission system operators, enable the formation of a powerful Caspian-Black Sea energy hub with low energy production costs. The use of blended finance mechanisms from international financial institutions (EBRD, ADB) enables Georgia to reduce the cost of capital for large-scale infrastructure projects, on condition that environmental standards for coastal zones are harmonized. In the context of Ukraine, the main focus is on operational support instruments, such as fixed premiums and the «Auctions as a Service» model, which, within the framework of the Ukraine Facility program [16], allow for a reduction in project payback periods by 3–5 years and guarantee barrier-free access for domestic hydrogen to the EU market. Contracts for Difference (CCfD) mechanisms and Innovation Fund grants are aimed at the deep decarbonization of Ukrainian industrial giants and the creation of autonomous energy clusters based on the agro-industrial sector, which requires adequate technological readiness and the implementation of an emissions trading system.

The overall architecture of these instruments reflects a shift from direct subsidies for capital expenditures to market-based incentive mechanisms, where the success of project implementation critically depends on legal harmonization with EU regulations and the implementation of risk insurance systems.

The process of developing of a hydrogen ecosystem in Georgia and Ukraine requires a clear identification of the constraints that are currently undermining the countries' natural competitive advantages. We have systematized the critical barriers and strategic opportunities for the development of hydrogen energy, highlighting specific challenges and potential synergies for Ukraine and Georgia within the framework of European integration (Table 3).

*Table 3*

**A Systematic Analysis of the Barriers and Synergy Mechanisms in the Hydrogen Energy Sectors of Georgia and Ukraine**

| Category of factors | Breakdown of factors and constraints | Impact on financial and economic indicators | Optimization mechanisms and synergy |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| The Unique Characteristics of Georgia | | | |
| Geopolitical barriers | The complexity of cross-border regulation with Azerbaijan; limited capacity of the gas transmission system. | Risk of low capacity utilization; dependence on transit tariffs. | Establishment of the "Green Corridor" (Azerbaijan–Georgia–EU); joint investment projects with SOCAR/MFO. |
| Resource barriers | Seasonal fluctuations in hydropower generation; a shortage of fresh water in certain regions for electrolysis. | Fluctuations in electricity prices; rising water treatment costs. | The use of small hydroelectric power plants as stabilizers; the construction of plants near the ports for the export of ammonia. |
| Technological synergy | The potential for producing nitrogen fertilizers (green ammonia) to meet the region's needs. | Increased profitability driven by high-value-added products. | Establishment of the Black Sea Ammonia Cluster; transition of port logistics to hydrogen. |
| Institutional capacity | A liberalized energy market; high confidence from international financial institutions (EBRD). | Access to cheaper capital; rapid attraction of foreign direct investment (FDI). | Adaptation of European financial frameworks through joint funds with international development banks. |

*Continuation of Table 1*

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| The Specifics of Ukraine | | | |
| Economic barriers | High WACC due to war-related risks; a limited domestic capital market; and a government budget deficit. | An increase in LCOH; a significant decrease in IRR; an extension of the payback period (DPP) to more than 10 years. | Use of the Pillar II Ukraine Facility; securing grants from the Innovation Fund; preferential loans from the EIB. |
| Safety barriers | The threat of physical destruction of facilities; disruptions in the gas transmission system; a shortage of skilled personnel. | Lack of standard insurance coverage; risk of total loss of CAPEX. | Insurance programs from MIGA and DFC; development of decentralized "energy islands." |
| Agro-energy synergy | A large biomass base; the presence of a well-developed network of sugar mills and agricultural holdings. | Reduction in operating expenses through the use of on-site biogas and heat; revenue from digestate. | Transforming agricultural enterprises into energy hubs (biomethane and hydrogen for agricultural transportation needs). |
| Legal barriers | Slow implementation of regulations regarding RFNBO; lack of a registry of guarantees of origin. | Regulatory barriers to exporting to the EU; inability to participate in European Hydrogen Bank auctions. | Adoption of the "Auctions-as-a-Service" model; launch of a national certification system based on EU standards. |

*Source: the author's perspective*

For Georgia, geopolitical and resource aspects are priorities, in particular the implementation of the Green Corridor project for energy transit from the Caspian region to the EU and the use of significant hydropower potential. Unlike Ukraine, Georgia has a more liberalized energy market and a higher level of trust from international investors, which allows it to attract foreign direct investment to create the Black Sea Ammonia Cluster and export products with high added value.

At the same time, for Ukraine, the key determinant remains the security factor, which requires the introduction of specialized instruments for insurance of military risks through international institutions (MIGA, DFC) and the development of decentralized «energy islands» to ensure the survivability of the infrastructure. The economic landscape of Ukraine is characterized by a high cost of capital (WACC), which is proposed to be leveled using mixed financing within the framework of the Ukraine Facility program and grant support from the Innovation Fund. The study places special emphasis on agro-energy synergy, where the transformation of sugar factories into biogas-hydrogen hubs allows for significant optimization of the LCOH indicator through the use of waste heat and digestate.

A common challenge for the both countries remains the legal incompleteness of the certification system and guarantees of origin, which, without the implementation of the "Auctions-as-a-Service" model, limits their participation in the auctions of the European Hydrogen Bank. Thus, the successful realization of the hydrogen potential of the both countries depends on the ability to integrate national sectoral advantages – the agricultural potential of Ukraine and the transit potential of Georgia – into a common financial and regulatory architecture with the EU.

Therefore, the successful implementation of hydrogen projects in Georgia and Ukraine directly depends on the adaptation of the European experience of market incentives to the specific conditions of national economies. The analysis had confirmed that the transition from direct subsidization of capital expenditures to the stimulation of operational activities through the mechanisms of the European Hydrogen Bank provides the necessary return on investment and stability of cash flows in the long term.

Overcoming the identified economic, legal and security barriers is possible only through the formation of a sustainable financial architecture that combines mixed financing instruments with military threat insurance programs for Ukraine and the development of cross-border corridors for Georgia. The most promising vector for increasing investment attractiveness is the implementation of synergy between hydrogen technologies and the potential of the agricultural and hydropower industries, which allows minimizing the cost of energy and ensuring sustainable development of regions within the framework of global decarbonization.

**Conclusions.** The conducted research allows us to state that in the context of the global energy transition, the formation of the effective financial architecture to stimulate hydrogen projects is a key prerequisite for the development of the energy sector of the Georgian economy, as well as energy independence and post-war reconstruction of Ukraine. The conducted comparative analysis of the existing financial support instruments in the European Union indicates the feasibility of the transition from traditional investment grants to market mechanisms for stimulating operational activities, where the EHB with a system of fixed premiums and auctions plays a central role. It was established that the implementation of the "Auctions as a Service» model is the most adaptive way to integrate Georgian and Ukrainian producers into the European ecosystem, since it provides uniform verification standards and lowers the threshold for market entry for developers from these countries.

It is scientifically proven that overcoming the high cost of capital and leveling specific risks requires the introduction of the specialized de-risking tools, in particular, insurance of military threats for Ukrainian assets and the development of cross-border energy corridors for Georgian infrastructure. It is proven that the most promising vector for increasing investment attractiveness is the implementation of strategic synergy between the agro-industrial potential of the states and technologies for generating «green» hydrogen, which allows creating decentralized energy hubs based on biogas capacities. The use of waste heat and digestate in closed cycles of agricultural enterprises provides a significant reduction in the present value of hydrogen, contributing to the formation of products with high added value and energy autonomy of communities. As a result, the successful integration of both countries into the EU hydrogen space critically depends on the prompt implementation of the system of guarantees of origin and the harmonization of national legislation with European standards.

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**INVESTMENT POLICY IN UKRAINE'S AGRICULTURE: STRATEGIC DIRECTIONS FOR POST-WAR RECOVERY**

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