White Paper

Policy on green hydrogen production through the lens of the FreeHydroCells project technology

Potential for assisting policy forecasting and making of a European technology innovation base, and policy enablement of the original EU Green Deal (2019-2021)

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The FreeHydroCells project website and EU CORDIS page

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Executive Summary

The FreeHydroCells project was obliged to address research and innovation "*…strategy and policy forecast*" matters in its expected outcomes, destinations and impacts, so the project plan stated, "*On verification of the proof of concept, FreeHydroCells will produce a white paper to assist EU policy decision-making*", and this white paper honours that commitment. It was not only a reasonable commitment but an expected commitment given that all three of the main expected outcomes of the call under which the FreeHydroCells project was supported have a future strategy and policy impact in mind: (i) enablement of a faster energy transition to net-zero greenhouse gas emissions by 2050 (Green Deal policy plan); (ii) technological feasibility of concepts for strategy and policy forecasting; and (iii) establishing a solid long term dependable European innovation base, which indicate a desire to ensure the policy enablement and the strategy and policy forecasting of the first two expected outcomes lead to policy making to enable the derivation of the third expected outcome. We can summarise these expectations from the call and project as assisting policy enablement, policy forecasting with strategic planning, and policy making for establishing a solid long term dependable European innovation base.

To understand how the FreeHydroCells project can best assist policy, we must understand the full context of the FreeHydroCells project, the call that funded and supported the project, and what created the call in the first place, as by understanding these background drivers we can best understand how the expected outcomes, destinations and impacts could assist policy with strategic planning in the three areas stated (enablement, forecasting, making). Once understood, we can direct our advice logically in the appropriate direction. Therefore, after introducing the importance of these considerations, we detail the background of the project from the beginning of the European Union's original Green Deal policy plan in 2019 which had the purpose of making the European Union the first 100% climate-neutral continent on Earth by 2050, and up to 2021 when the announcement came of the commencement of the Horizon Europe Framework Programme (2021-2027). In September 2021, the first detailed work plan call for research and innovation actions was opened and among that group of calls was, "*HORIZON-CL5-2021-D3-03-02: Next generation of renewable energy technologies*". The "*scope*" of that call for proposals stated, "*The proposal is expected to address high-risk/high return technology developments for game changing renewable energy technologies…should validate its concept to TRL 3 or TRL 4 through a robust research methodology and activities, establish the technological feasibility of its concept…*".

This call scope appeared ideal for the emerging idea of the FreeHydroCells project, and efforts began to construct an appropriate proposal and consortium that would meet the call requirements, constraints, scope, expected outcomes, destinations and impacts, including those on guiding policy, particularly European Union policy. FreeHydroCells set an aim for TRL 4, a proof of concept verification of a system technology in the lab. The proposal nature and aims are summarised as, "*…to create a new photoelectrochemical system capable of clean, efficient solar-to-chemical energy conversion, with hydrogen gas storing the chemical energy. The system…[would be] capable of freestanding photoelectrochemical water splitting. A number of technological challenges restrict…state-of-the-art systems… However, the FreeHydroCells project proposes…to verify a paradigm proof-of-concept for a self-driven system suitable for up-scaling and commercialisation*". To support the call expectations on advising policy, part of the work plan included initial life cycle, technoeconomic, social and environmental assessments should the "*high-risk*" research be successful, in order to best guide and advise policy (enablement, forecasting, making) to achieve a future "*high return*".

FreeHydroCells was submitted on 23 February 2022 and later received a 14.5/15.0 score and was supported by the European Commission with a commencement date of 1 November 2022. The project ended on 31 August 2026 after almost 4 years of intense activities. The results are extensive and of high impact: a solar-to-hydrogen efficiency of 18-21%; a predicted lifetime of at least 10-years; zero applied bias operation; a lightweight multicell modular photoelectrochemical system; Earth-abundant materials only; low-cost construction and operation; cheap, common, non-toxic electrolyte; manufacturing-compatible; and the completely sustainable technology has been verified at the proof of concept stage for TRL 4 with a highest technical key performance indicator, and, with sixteen registered innovations created. The assessments to measure upscaling and commercialisation potential – which in turn guides policy – showed a Levelised Cost of Hydrogen (LCOH) of $3.12 /kg H2; an Energy Return On Energy Invested (EROEI) of 3.57+; a social impact marker of 8-9/10; and an environmental impact marker of 5/5. Together, the results amount to a potential breakthrough technology.

On the basis of the innovative technology achievements in FreeHydroCells at TRL 4 developing into an upscaled and commercialised product solution, as the combined life cycle and technoeconomic assessments infer, FreeHydroCells can offer some limited guidance. This advice can be summarise for each criteria as: enabling implementation of the original Green Deal policy plan (2019-2021); supporting policy forecasting with strategic planning by offering a radical, alternative, off-grid and distributed and completely decarbonised energy system implementation vision that meets expected efficiencies, cost affordability, lifetime, reliability, resilience delivery; and policy making that can be focused on an alternative or modified solid long term and dependable European innovation base to lead the energy transition in Europe and globally.

1. Introduction

As part of the FreeHydroCells project, it is stated in the plan that, "*On verification of the proof of concept, FreeHydroCells will produce a white paper to assist EU policy decision-making*", and this document honours that commitment.

This was not only a reasonable commitment but an expected commitment given that all three of the expected outcomes of the call under which the project was supported were related fully or partially to policy matters:-

I. "*Available breakthrough and game changing renewable energy technologies enabling a faster transition to a net-zero greenhouse gas emissions EU economy by 2050*"

II. "*Knowledge and scientific proofs of the technological feasibility of the concept including the environmental, social and economic benefits to contribute to R&I strategy and policy forecast*"

III. "*Establishing a solid long term dependable European innovation base*"

The first expected outcome from the call is effectively the enablement of a faster energy transition to net-zero greenhouse gas emissions by 2050, which is essentially policy enablement of the original Green Deal plan 2019-2021. The second expected outcome mentions technological feasibility of concepts for strategy and policy forecasting, likely for policy decision-making and related strategic planning for the immediate and long-term future. The third expected outcome is directed at establishing a solid long term dependable European innovation base, which indicates a desire to ensure the policy enablement and the policy forecasting, strategic planning, and subsequent decision-making leads to the establishment of this solid long term dependable European innovation base, particularly in the area of green hydrogen fuel production for renewable energy.

This is a reasonable interpretation of the relationship between European policy and the three expected outcomes from the call that supported the project: policy enablement (Green Deal, carbon neural by 2050), policy forecasting (predicting technology concepts with strategic planning) and policy making (to create a solid long term dependable European innovation base). Therefore we have a connected train of policy enabling-forecasting-making alongside a goal of strategic planning that leads to: a game changing breakthrough – strategic technology proof – solid long term dependable European innovation base in renewable energy.

Understanding this expectation on policy should have guided the construction of all proposals for this call to meet this demand, and these implications on policy were indeed considered and incorporated into the FreeHydroCells project plan. Nevertheless, the reader must remember that the call targeted proposals that could achieve only a TRL 3 (experimental proof of concept) or TRL 4 (technology validated in a lab) by the end of the projects, albeit with alignment to future upscaling and commercialisation. FreeHydroCells accepts that these are relatively low TRLs to be expected to be enabling, forecasting and making policy considerations for strategic decision-making. We must infer further TRL increases while maintaining the same performance and cost. There is now a strong requirement for such policy forecasting with strategic planning due to the critically urgent and rapid need for the solid long term dependable European innovation base that would enable the Green Deal plan of European carbon neutrality by 2050.

A lot was expected from the call text in this area of policy and strategic planning – in addition of course to the already significant objective of a breakthrough novel technology – and as a result we have expended a lot of effort in the project to interpreting and forecasting the extrapolated outcomes, destinations and impacts from the breakthrough technology achieved into initial guidance on policy and strategic planning.

This brief, to-the-point, white paper walks us logically through the topic in order to explain the policy advice we give, which is very much through the lens of the FreeHydroCells technology breakthrough at TRL 4, and from the perspective of the project's vision of the most efficient and impactful implementation of the technology into society should it successfully upscale through the TRL stages and lead to successful products through rapid development and commercialisation.

This introduction forms **Section 1**, setting the context and structure, leading us into **Section 2** that provides a very brief summary of the climate change issue and the need for urgent and rapid action. We then move to **Section 3** to discuss the ambitious European Union initiative of the original Green Deal policy plan announced in 2019, with our focus being on the period 2019-2021 prior to the opening of the September 2021 call to which the FreeHydroCells project proposal was submitted on 23 February 2022. **Section 4** discusses the Horizon Europe Framework Programme (2021-2027) that emerged in 2021 following the previous Horizon 2020 Framework Programme (2014-2021) and how this new programme incorporated the Green Deal policy plan into the expected outcomes, destinations and impacts for related research and innovation activities. We then discuss in this same section the specifics of the call under which the FreeHydroCells project was supported and for which the project was written, "*HORIZON-CL5-2021-D3-03-02*", which was created to find the, "*Next generation of renewable energy technologies*", and we breakdown the scientific, technological and future policy expected outcomes, scope, destinations and impacts in the call text in order to understand the lens pre-settings through which the project observes. We then go to **Section 5** and discuss the FreeHydroCells project itself, its aims and objectives in order to fulfil the call scope, expected outcomes, destinations and impacts. We explain the technological results and the expected impact analysis and findings through initial life cycle, technoeconomic, social and environment analyses. We interpret and extrapolate the findings on policy enablement, societal impact, and present our vision of policy forecasting with strategic planning for a future solid long term dependable European innovation base if policy making follows to enact change. In **Section 6**, we set out our guidance on policy specifically through the lens of the FreeHydroCells technology breakthrough and suggest ideas for: (i) policy enablement, (ii) policy forecasting with strategic planning, and (iii) policy making to establish a solid long term dependable European innovation base. We complete the white paper with a reference section.

2. Climate Change and the Need for Urgent and Rapid Action

One of the most concerning aspects of our modern world is climate change and its effects on our environment. The rapid burning at an ever increasing rate of fossil fuels over the past 150 years or so for our energy needs causes the emission of excessive byproduct greenhouse gases, particularly carbon dioxide (CO_2) and methane (CH_4), which cause air pollution, upsets the fine balance of our atmospheric ecosystem, and ultimately leads to climate change [1].

The widespread transformation of society from the period of around the industrial revolution onwards, with a related transition from wood burning and peat burning to higher energy coal burning, through to even higher energy oil, petroleum and natural gas exploitation and burning in the modern era, these have all culminated in very significant pollution of our atmosphere and serious depletion of our natural resources, causing the loss of important natural wild forest, habitat and wildlife destruction that cannot be reversed. The damage to our atmosphere was largely ignored until more recent times when the term sustainable development entered into use, defined as, a process of human advancement and development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This self-reflection has led to more recent considerations of decarbonising our energy use – since carbon emissions are the main cause of climate change – belated though it may be. Nevertheless, to date we continue to live in an unsustainable manner while we grapple with the practical, scientific, technological and economic challenges of becoming sustainable [1].

Advocating action for a rapid green energy transition to restrain and redress climate change is correct of course, but if the state-of-the-art renewable energy technologies in reality cannot deliver that transition at all or at scale with a competitive efficiency/cost ratio, then we can advocate and wish all we want, and we can try different ideas to make the technology work, but no matter what the transition from fossil fuel energy to green energy will struggle and in the meantime humanity will source and use fossil fuel energy because they must from a practical sense, they have no other practical choice. State-of-the-art renewable energy technologies to date have a number of restrictions that prevent them from delivering the desired and envisaged transition from fossil fuel energy to green clean energy: low and insufficient efficiency; high cost; a persistent need for rare and toxic materials; high maintenance; countereffects on society and the environment; impracticalities; short lifetime at best performance; and the rarely discussed low systems-level true efficiencies/cost ratio when all aspects are considered such as losses, storage, delivery infrastructure, operational cost, etc. [2, 3].

Furthermore, serious limitations on the production of truly green hydrogen exist, and we are in the unenviable position of having ambitious and challenging energy transition targets but not having the level of renewable energy technology innovation to deliver it. Innovation that can make a substantial, radical and rapid impact on climate change is needed, enabled by novel technology discover which can deliver a high impact on the rate of the energy transition, and any future solution must be competitive in every way with fossil fuel energy in order to be practical and affordable to implement [2, 4].

3. The Original European Union Green Deal Policy Plan 2019-2021

In 2019, the European Union announced the start of the Green Deal plan with the purpose of making the European continent the first 100% climate-neutral continent on Earth by 2050. The ambitious plan was a direct response to European citizens' calls for urgent climate action and sustainable development in the wake of the Paris Agreement of 2015 [5, 6].

As part of the climate strategy plan, the Green Deal targets a reduction in greenhouse gas emissions by at least 55% by 2030, 90% by 2040, and 100% by 2050. The energy strategy aims for a clean and efficient energy transition from polluting fossil fuel energy to green energy. To meet the climate action objective of 100% zero emissions by 2050, this requires fossil fuel use to completely transition to green energy use by 2050, with measured steps of 55% and 90% along the way. This reflects the original Green Deal policy plan objective of 2019-2021 when policy and directives were highly focused towards climate action to enable a complete transition [5].

While the Green Deal plan is still active and relevant, the original climate action policy plan of 2019-2021 has encountered issues and has been augmented [7]. The reasons are complex, but an important factor underlying the many issues is likely the physical limitations on delivery of state-of-the-art innovative technology beyond baseline battery, wind and solar to meet the ambitious targets. A huge dependence has been placed on electrolyser technology to drive renewable hydrogen production, but serious drawbacks including high cost, rare and toxic material needs, and delays have emerged with this plan [8, 9, 10]. No significant alternative novel technologies have been emerging from the research and development activities to overcome the limitations and drive the original Green Deal plan forward despite emerging calls for action, especially in the Horizon Europe programme in 2021 [11], which we will discuss next.

4. Horizon Europe 2021 call for climate action – HORIZON-CL5-2021-D3-03-02

On 15 June 2021, the European Commission made decision C (2021) 4200 to implement the Horizon Europe work Programme 2021-2022 for research and innovation actions that were aimed at underpinning European Union policy priorities, delivering results and enhancing impact [11]. This work programme implemented three separate component: Pillar I – Excellent Science; Pillar II – Global Challenges and European Industrial Competitiveness; and Pillar III – Innovative Europe. Under Pillar II, distinct areas of focus were listed into numbered "*Clusters*", namely,

1) Health (CL1)
2) Culture, Creativity and Inclusive Society (CL2)
3) Civil Security for Society (CL3)
4) Digital, Industry and Space (CL4)
5) Climate, Energy and Mobility (CL5)
6) Food, Bioeconomy, Natural Resources, Agriculture and Environment (CL6)

The first call for Cluster 5 (CL5, "*Climate, Energy and Mobility*") projects under the new Horizon Europe Work Programme 2021-2022 was announced on 28 June 2021 [12], which was later approved by the European Commission through the European Commission Decision C (2022) 2975 of 10 May 2022 [13]. "*D3*" of that first call, "*Destination – Sustainable, secure and competitive energy supply*", contained a set of grouped calls designated as "*03*" and came under the title, "*Global leadership in renewable energy*". Within that group of calls was call "*02*" on the list, "*HORIZON-CL5-2021-D3-03-02: Next generation of renewable energy technologies*". This call stated that, "*Activities are expected to achieve TRL 3-4 by the end of the project*" [14].

The project results for this call were expected to contribute to all of the following "*expected outcomes*":

I. "*Available breakthrough and game changing renewable energy technologies enabling a faster transition to a net-zero greenhouse gas emissions EU economy by 2050*"

II. "*Knowledge and scientific proofs of the technological feasibility of the concept including the environmental, social and economic benefits to contribute to R&I strategy and policy forecast*"

III. "*Establishing a solid long term dependable European innovation base*"

The "*scope*" of the call stated, "*The proposal is expected to address high-risk/high return technology developments for game changing renewable energy technologies…should validate its concept to TRL 3 or TRL 4 through a robust research methodology and activities, establish the technological feasibility of its concept…*".

This call was subsequently opened on 21 September 2021 and had a call closing deadline of 23 February 2022. The Cluster 5 release document in its introduction directly connected this call and the other calls listed with the Green Deal plan and the carbon neutrality targets, including the 2050 target [14].

Assessing the destination criteria of the call gives further information on what was envisaged from impact of the expected outcomes. The first to consider is the targeted, "*Sustainable, secure and competitive energy supply*" destination. In line with the scope of Cluster 5, this includes activities in the areas of renewable energy; energy system, grids and storage; as well as Carbon Capture, Utilization and Storage (CCUS). The transition of the energy system envisaged by the call would rely on reducing the overall energy demand and making the energy supply side climate neutral. This was an important destination outcome definition. Furthermore, the expected destination outcomes of the call were expected to, *"…help to make the energy supply side cleaner, more secure, and competitive by boosting cost performance and reliability…and integration of other climate neutral, renewable energy carriers, such as clean hydrogen…*".

The FreeHydroCells project proposal was written specifically for this call for action on achieving climate neutrality as set out in the Green Deal plan (2019-2021), subsequently submitted by the deadline, and received a 96.7 % score and supported by the Horizon Europe Framework Programme, running between November 2022 and August 2026.

The FreeHydroCells project met the call's expected outcomes, scope, and destinations, including the enablement of the decarbonisation of Europe through CCUS, the Key Strategic Orientations (KSOs) of expected impact areas: industrial leadership in key and emerging technologies, and affordable and clean energy.

The destination expected impact was to contribute to, "*More efficient, clean, sustainable, secure and competitive energy supply through new solutions for smart grids and energy systems based on more performant renewable energy solutions*", through fostering European global leadership in affordable, secure and sustainable renewable energy technologies.

The FreeHydroCells project outcomes address all of these destinations and impacts while also providing a radical but impactful new solution idea of local, distributed off-grid energy supply and storage that would not only enable highly secure resilience to users, but also offer low-cost affordability and efficiency. Such a technology rollout could potentially enable resilience in energy and rapid sustainable development.

5. The FreeHydroCells project aims and achievements, 2022-2026

The FreeHydroCells project aims are of course aligned with enabling the original Green Deal policy plan (2019-2021) through the expected outcomes, destinations and impacts of the call, "*HORIZON-CL5-2021-D3-03-02: Next generation of renewable energy technologies*", for which it was designed and to which it was submitted as a proposal on 23 February 2022 [5, 11-14]. Understanding the nature and aims of the FreeHydroCells project can be obtained by reviewing the lay summary of the proposal, partially reproduced here:-

"*The FreeHydroCells project aims to create a new photoelectrochemical system capable of clean, efficient solar-to-chemical energy conversion, with hydrogen gas storing the chemical energy. The system would mimic the solar-energy absorption potential of a leaf by arraying cascades of nanometre thick semiconducting materials as buried pn-junctions that, when submerged in water and exposed to sunlight, are capable of freestanding photoelectrochemical water splitting…FreeHydroCells' multidisciplinary expertise is key to making this substantial science-to-technology leap: to verify a paradigm proof-of-concept for a self-driven system suitable for up-scaling and commercialisation*".

The FreeHydroCells consortium had a well-developed and scientifically engineered work plan to seriously attempt to find a solution despite the significant odds against success. The plan aligned perfectly with the scope of the targeted call, particularly, "*The proposal is expected to address high-risk/high return technology developments for game changing renewable energy technologies…*".

The "*high-risk*" part is a fair description of the project, although very significant mitigation actions were incorporated into the project plan alongside an advanced methodological approach in applying the work plan to overcome each of the bottlenecks and achieve the ultimate end goal of the project. Despite the high risk, and after almost 4 years of intensive activities, the project has been successful and achieved its highest impact key performance indicator target. The "*high return*" part is not only in the technological advancement realised, but also in the potential impact it could have on society if developed beyond the present TRL 4 achievement.

The FreeHydroCells project undertook a proof of concept verification of the technology at TRL 4 in order to quantify the technological return, and the results can be summarised here,

- The BMJ PEC multicell system shows a solar-to-hydrogen efficiency of ~18-21 %
- Accelerated degradation, reliability and lifetime assessments show at least a 10-year lifetime prediction at zero bias operation and even under applied bias stress up to 1.5 V
- The resulting multicell system is modular, allowing for upscaling to a range of capabilities and hence adaptable for remote (i.e., off grid), rural, urban and large town and city locations
- The BMJ PEC cells and system are made from lightweight Earth-abundant materials, enabling low-cost, sustainable and manufacturing-compatible production in any location without the need for expensive sourcing of rare materials
- The cells themselves are made with nanometre-scale multilayer thicknesses in a low thermal budget integrated process, minimising production time, energy input, cost and material concentration quantity
- The upkeep, maintenance, and operation of the system has being designed for simplicity, allowing, for example, local communities with training to be able to manage their own distributed systems at low cost. The result would potentially be locally produced and stored hydrogen for their own needs, enhancing energy resilience and local development at the community level
- The system, while created for solar irradiation as the energy source, could potentially allow the integration of other renewable energy sources such as small-scale mini hydroelectric and mini wind

turbine power (small, local, off-grid) given the system's ability to run efficiently under very low bias/power and potentially offer a 24/7 green hydrogen production solution

- Cell stability and durability is observed and confirmed both optically and physically over days, weeks, and months of extensive testing with and without applied bias, under AM1.5G1.0Suns solar irradiation and in a moderate pH, simple, sustainable, environmentally-friendly and cheap electrolyte. The BMJ PEC cell and system remains operational throughout and appears fit for long term stable and robust operation

- The technology has been verified at the proof of concept stage for TRL 4, and the key performance indicator level of impact achieved in the project was at the highest impact level set.

- Sixteen registered innovations were created in the project across three technical partners, with all except one of the innovations related to the green hydrogen production cells and system. The other innovation registered is related to above-ground gaseous hydrogen storage that is envisaged to potentially compliment the BMJ PEC multicell system.

In order to quantify the level of impact return that the technological advancements of FreeHydroCells could potentially have on society, FreeHydroCells undertook an initial life cycle assessment (LCA), technoeconomic analysis, social LCA and environmental LCA. A summary of the assessment results on the TRL 4 technology are,

- Levelised Cost of Hydrogen (LCOH) ~ $3.12 /kg H2 (based on a small scale hydrogen reactor plant)

- Energy Return on Energy Invested (EROEI) ~ 3.57+ (based on a large scale hydrogen reactor plant)

- Social impact marker 8-9/10, mainly driven by the non-use of rare, toxic, difficult to access and expensive materials

- Environmentally-friendly impact marker is maximum at 5/5 mainly due to non-use of toxic, polluting or contaminating elements. The FreeHydroCells technology achieves the full markers in all 5 categories of (a) abiotic depletion potential (ADP) of sources, (b) acidification potential (AP), (c) global warming potential (GWP), (d) human toxicity potential (HTP), and (e) ozone depletion potential (ODP), confirming the completely green environmental compatibility of the project technology

Importantly, most if not all future plans for renewable technology implementation advocate for centralised reactor plant solutions employing significant land area. In addition, these centralised solutions require very significant infrastructure to enable them in the central location, and they require vast energy distribution networks including pipelines, cables, storage caverns, safety and maintenance resources, repeater stations, etc. in order to generate, maintain, store and deliver the renewable energy to societal users through grid infrastructure. The investment in both energy input and cost for this centralised grid plan is enormous and detracts from both the energy efficiency and cost affordability of the renewable energy technology system to make it highly unattractive to users. The FreeHydroCells technology could potentially be implemented in a similarly centralised reactor setting and the green hydrogen stored and supplied through similar grid-based infrastructure, but this is unlikely to be the most impactful, efficient and cost-effective way of implementing the technology and maximising its impact on society. Instead, the FreeHydroCells technology potentially removes the need for these vast centralised reactors, infrastructure and networks by enabling a simple, local, off-grid and distributed modular installation of the technology and permitting the resilient production of decarbonised energy locally at or close to the point-of-use.

What would this distributed technology look like in a society setting in order to meet the energy needs? We would envisage – should the technology upscale and become a viable product – one or more modules of the technology being used per homestead for all energy needs, and depending on available space or preference, it could be installed on land around a homestead or on the roof of a homesteads, given the light weight of the technology – the less space available, the more rooftop installation makes sense. Wind and storm protection

should be part of the installation. In rural and low density urban locations, this type of installation would likely suffice, but in larger towns and cities, it may be that this type of installation may not be sufficient to meet the energy needs of the higher population density. A potential solution would be to create a distributed network of green hydrogen hubs created above the high density of road and rail networks in these large towns and cities, similar to existing road bridge structures over motorways for example, but instead of facilitating a road, it would be terminated at both ends and house a green hydrogen production and storage reactor that could supply the additional energy needed in the local area around the hub. A similar consideration could be applied to heavy users of energy, such as heavy industry, goods transportation, aviation, agricultural machinery and passenger services such as trains, buses, taxis and private vehicles. Linking the distributed hydrogen hubs to road and rail networks would streamline the supply of energy to these users. Of course, other ideas may supersede this green vision, but it is important that we open our minds to ideas and think laterally to help us solve climate change while still supplying the energy needs of society.

The FreeHydroCells project commission a 3-minute video to try to give an early and approximate illustrate our vision of this type of distributed decarbonised energy source implementation of the FreeHydroCells technology. The video can be viewed HERE on the FreeHydroCells website (https://freehydrocells.eu). Given the project achievements and the project's radical distributed modular implementation vision of the future based on our technology potentially assisting policy enablement, policy forecasting and strategic planning, leading to policy making that may help lead to a solid long term dependable European innovation base driving decarbonisation.

6. Guidance on policy through the lens of FreeHydroCells

As discussed in the previous sections, climate change is a serious issue for all of society and significant effort and initiatives have been instigated to try to advance climate action. The EU created the Green Deal plan in 2019, an ambitious plan to make the EU carbon neutral by 2050, with various steps and stages in 2030 and 2040. The Horizon Europe Framework Programme that began in 2021 was constructed to incorporate the objectives of the original Green Deal plan of 2019-2021, and as a result, Cluster 5 of Pillar II of the 2021 work programme for the Horizon Europe Framework included the D3-03-02 call, "*Next generation of renewable energy technologies*", to find new high return green energy technologies to enable implementation and success of the Green Deal plan.

The FreeHydroCells project was high risk and written specifically for this call, and specifically to try to devise a high return technology that would have the potential to make an impact on climate change and assist the objectives of the original Green Deal plan of 2019-2021. As set out, the technology objectives of the project were achieved to a level sufficient to match the highest impact level for the key performance indicators set.

Looking at advising policy through the lens of the FreeHydroCells project technology, we divide the guidance and advice into three subtitles: (i) policy enablement, (ii) policy forecasting with strategic planning, and (iii) policy making to achieve a solid long term dependable European innovation base.

Should the innovative technology achievements in FreeHydroCells at TRL 4 develop into an upscaled and commercialised product solution as the combined life cycle and technoeconomic assessments infer, the following guidance and advice can be provided on related policy issues from the call expected outcomes, destinations and impacts:-

i. <u>Policy Enablement</u>

- The original EU Green Deal policy plan of 2019-2021, including,
  - Accelerated decarbonisation between 2030 and 2050
  - The 100 % carbon neutrality target of 2050
  - The 90 % carbon neutrality target of 2040
  - A recalibrated intermediate, partial carbon neutrality target for 2030, or possibly delayed to 2035, depending on the feasibility and timeline needed for innovative technology to deliver the transition progress while considering all other factors
  - Supplying clean, affordable and secure energy
  - Leave no one behind (Just Transition), ensuring low-cost affordability with ethical pricing and responsible profit practices
- A faster energy transition
- A greener energy transition, demanding higher social and environmental impact marker compliance
- Assist in countering environment-related risks and impacts on health and well-being
- Supporting the EU's commitment to lead and encourage a global climate action cooperative agreement
- Assist the EU to "…seek to maximise benefits for health, quality of life, resilience and competitiveness" through a faster, more enabled, energy transition
- Advancement to, "integrate the United Nations' sustainable development goals, to put…at the heart of the EU's policymaking and action", encouraging global partnership and cooperation
- Mobilising industry for a clean and circular economy, ensure strong practical and financial support for a green energy transition

ii. <u>Policy Forecasting with Strategic Planning</u>

- Keep first and foremost the primary goal of stopping pollution from fossil fuel energy sources
- Transition to truly green renewables that do not use rare, toxic and hard-to-access materials
- Prioritise innovative truly green renewable energy solutions using Earth-abundant materials only
- Embed emerging green hydrogen energy innovation into critical food, agriculture, water, industry
- On the foundation of truly green renewable energy innovation:-

    - Building and renovating in an energy and resource efficient way
    - Accelerating the shift to sustainable and smart mobility
    - Preserving and restoring ecosystems and biodiversity
    - Integrate green energy drivers into both irrigated restoration and biodiversity
    - Advance financial planning to prioritise innovative green energy
    - The EU as a global advocate for cooperative sustainable development
- Focusing research and innovation on novel green energy impact
- Increase Earth-abundant materials supply chains to support a green energy innovation base
- Citizen engagement in novel green energy technology implementation
- Increase citizen resilience with local decentralised green hydrogen energy access
- Support education and training of communities for implementing green energy solutions
- Align EU actions and policies to prioritise decarbonisation on basis of innovation base enablement

iii. Policy Making – to achieve a solid long term dependable European innovation base

- Prioritise implementation of innovative truly green renewable energy technology over old renewables
- Advance Earth-abundant materials only solutions for innovative renewable energy technology
- Support radical, unorthodox solutions and implementation plans for lowest cost decarbonisation
- Front and centre energy transition for society as a whole rather than selective new customer targeting
- Planning department relaxation of rules to permit locally-installed renewable green energy innovation solution sets, including truly green hydrogen mini reactors, mini wind turbines and mini hydroelectric turbines
- Incorporate off-grid resilience of green energy supply to relieve and reduce demand on the energy grid
- Embed distributed, off-grid, innovative green energy solutions and supply hubs into society, including into large towns and cities by overlaying onto the dense road and rail networks to cover excess demand
- Support industrial reskilling to underpin an innovative renewable green energy technology base
- Prioritise land regeneration and biodiversity development using innovative green energy solutions
- Refocus heavy fuel users to connect to innovative green hydrogen energy technology supply
- Establish and invigorate the Earth-abundant materials supply chains for an innovative renewable green energy technology base
- Mechanise straight-forward, easy access, financial support for developing and enabling an innovative renewable green energy technology base
- Support the innovative renewable green energy technology base with practical training and education for citizens to take ownership and responsibility locally for off-grid energy resilience
- Legislate to ensure low-cost affordability with ethical pricing and responsible profit practices for an innovative renewable green energy technology base on which society depends
- Legislate to maintain cost-effectiveness of an innovative renewable green energy technology base in order to maintain societal affordability and implementation to drive decarbonisation
- Implement innovative low-cost renewable energy driven transportation, infrastructure and local amenity networks and facilities for society to reinvigorate remote, rural, townland, urban, town and city environments for quality of life and sustainable development enhancements regardless of location

We believe that such policy considerations would enable the implementation and deployment of the FreeHydroCells technology in the future for the benefit of all should it be feasible. Let us reflect on how these policy points link. There is an implied causality when moving from policy enablement, to policy forecasting with strategic planning, and then to policy making – to achieve a solid long term dependable European innovation base. However, there is also a circularity connection as well. For example, creation and development of an innovative and impactful truly green energy technology such as the FreeHydroCells technology could achieve already existing policy enablement of the original Green Deal policy plan for example, but this then permits further policy forecasting with strategic planning to drive forward policy making to advance a truly green innovation industrial base to support societal uptake of the green energy solutions and enhanced decarbonisation. This sustainable development cycle feeds back around the policy cycling once again as an iterative litmus test so to speak to logically assess the successes and failures of the policy making actions, and this provides an opportunity to refine policy to maximise societal needs and practicalities while optimising

sustainable development. Such circularity assessments could provide feedback and review mechanisms with checks and balances to ensure a just and fair transition to a green society that works for all.

The litmus test on impact would be when we see a completely reinvigorated society in remote, rural, townland, urban, town and city environments, with a high quality of life and sustainable development enhancements regardless of location – with such an impact, action to restrain climate change will be strong in supporting the health of the planet and its ecosystem.

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