Advancing Sustainable Transportation: Zero Emission Mobility Salzburg

Laurent Peters[1], Sven Dum[1], Hermann Riedl[2], Christian Kainz[2], Niusha Shakibi Nia[3], Nikolaus Fleischhacker[3], Johannes Mütterlein[4], Martin Sagmeister[5], Karl-Heinz Kopp[5], Iskandar Zeynalov[5], Sophie Parragh[6], Xenia Haslinger[6], Elisabeth Gaar[6], Thomas Prinz[7], Philipp Krisch[7], Christoph Müller[8], Sebastian Goers[8], Melanie Knöbl[8], Manuela Prieler[9], Jürgen Wulff-Gegenbaur[10], Hannes Macho[11] and Georg Kerbl[1]

Abstract:

The research and development (R&D) project Zero Emission Mobility Salzburg (ZEMoS) aims to contribute to the European and national energy & decarbonisation strategies focusing on mobility. one of the main challenges in this regard is the transition of the heavy-duty and public transport sector from diesel-powered vehicles to zero-emission vehicles, such as battery electric (BE) and fuel cell electric (FCE) vehicles. To achieve this goal, ZEMoS aims to implement two zero emission mobility (ZEM) model regions – one urban (Tennengau) and one alpine/touristic (Pinzgau) – for public bus transport and pilot projects for heavy-duty transport. The identification of the most cost-effective technology according to specific conditions and requirements within the model regions is part of this project. Based on which, the potential construction and implementation of the necessary infrastructure for the feasibility of ZEM solutions is considered. To assure the quality of the acquired data, a "living lab" will be set up and monitored and further developed based on required optimizations within a continuous improvement process (CIP).

Keywords: zero emission mobility, battery electric, fuel cell electric, green hydrogen infrastructure, sector coupling, model regions, sustainability.

[1] *Salzburg AG für Energie, Verkehr und Telekommunikation, Elisabethkai 52, 5020 Salzburg, Laurent.Peters@salzburg-ag.at, sven.dum@salzburg-ag.at, georg.kerbl@salzburg-ag.at*

[2] *Salzburger Verkehrsverbund Gesellschaft m.b.H., Schallmooser Hauptstraße 10, 5027 Salzburg, Hermann.Riedl@salzburgverkehr.at, Christian.kainz@salzburgverkehr.at*

[3] *FEN Research GmbH, Technikerstraße 1-3, 6020 Innsbruck, niusha.shakibinia@fen-research.org, nikolaus.fleischhacker@fen-research.org*

[4] *FEN Sustain Systems, Technikerstraße 1-3, 6020 Innsbruck, johannes.muetterlein@fen-systems.com*

[5] *HyCentA Research GmbH, Inffeldgasse 15, 8010 Graz, Sagmeister@hycenta.at, kopp@hycenta.at, zeynalov@hycenta.at*

[6] *Universität Linz, Institut für Produktions- und Logistikmanagement, Altenberger Straße 69, 4040 Linz, sophie.parragh@jku.at, xenia.haslinger@jku.at, elisabeth.gaar@jku.at*

[7] *Research Studios Austria Forschungsgesellschaft mbH, Leopoldskronstraße 30, 5020 Salzburg, thomas.prinz@researchstudio.at, philipp.krisch@researchstudio.at*

[8] *Energieinstitut an der Johannes Kepler Universität Linz, Altenberger Straße 69, 4040 Linz, goers@energieinstitut-linz.at, mueller@energieinstitutlinz.at, knoebl@energieinstitut-linz.at, goers@energieinstitut-linz.at*

[9] *WIVA P&G - Wasserstoffinitiative Vorzeigeregion Austria Power & Gas, Magazingasse 7, 4020 Linz, prieler@wiva.at*

[10] *Stadt Salzburg MA 7/03 Abfallservice - Recyclinghof – Wirtschaftshof, Siezenheimer Straße 20, 5024 Salzburg Juergen.wulffgegenbaur@stadtsalzburg.at*

[11] *ZEMKA - Zentrale Müllklärschlammverwertungsanlagen Gesellschaft m.b.H., Zell am See, 5700 ZELL AM SEE h.macho@zemka.at*

1 Introduction

In line with European Union (EU) measures and goals towards climate neutrality, in 2021 the "Master Plan climate+energy 2030" was launched in the federal state of Salzburg as a transfer program of the "*Climate and energy strategy Salzburg 2050*"[12]. This Master Plan focuses on sustainable solutions by promoting the use of renewable energy sources in all sectors within its climate and energy strategy and the goal to reduce the annual carbon dioxide (CO2) emissions by over 40 % until 2030. Numerous measures and partnerships with companies in Salzburg are included in this Master Plan. Salzburg AG (S-AG)[13], a Green Tech company with many years of experience in the fields of energy, mobility, and communication, has introduced a comprehensive package of topics as part of its partnership. This package includes coordinated strategies for district heating and gas supply as well as more electricity from hydro, wind and solar power. Since a reduction of about 50 % of CO2 by 2030 in Salzburg must be carried out in mobility and/or traffic sector, alternative drive solutions as BE and FCE concepts are further promoted within this package.

The R&D project ZEMoS (FFG Nr. FO999900979) initiated in April 2023 under the coordination of S-AG in close alignment with the goals outlined in the strategical Master Plan of the federal state of Salzburg. With its focus on the mobility sector, ZEMoS is a pioneering project contributing to the necessary transition from conventional diesel vehicles to emission-free alternatives. The goals outlined in this project within fostering sustainable mobility applications in the region are not only limited to the identification of suitable technologies but also address the challenging task of developing the required infrastructure. Consortium partners of this project, in addition to S-AG, are Salzburger Verkehrsverbund GmbH (SVG), Energieinstitut an der Johannes Kepler Universität Linz (EI), Institute of Production and Logistics Management, Johannes Kepler University Linz (JKU-PLM), Research Studios Austria Forschungs-GmbH / Research Studio iSpcae (iSpace), FEN Research GmbH (FENR), FEN Sustain Systems GmbH (FEN Systems), Verein WIVA P&G (WIVA), HyCentA Research GmbH (HyCentA), Zentrale Müllklärschlammverwertungsanlagen GmbH (ZEMKA) and Magistrat der Stadt Salzburg (Stadt Salzburg).

The holistic concept of ZEMoS and planned industrial research and experimental development activities by the end of March 2027 are further described in this paper and the first preliminary results are reported.

12 *https://www.salzburg.gv.at/themen/umwelt/salzburg2050*

13 *https://www.salzburg-ag.at/*

2 State of the Art

In order to reach the EU climate goals, it is necessary to replace the diesel operating heavy-duty vehicles by low- and zero-emission vehicles. In this regard, the employment of BE and/or fuel cell electric FCE buses are considered as complementary technologies. Despite being highly efficient, the BE-buses have limitations in terms of charging time, range (specially in winter because of low temperatures and corresponding heating demands) and the disadvantage of “power on demand”. On the contrary, the refuelling time of FCE-buses is short, and they can be used at low temperatures for heavy load transportations over long distances. It is noteworthy that both e-buses (FCE- and BE-buses) are currently still in the phase of first small series production and prototyping process, resulting in higher prices for them in comparison to conventional buses.

In 2020, the share of newly registered BE and hydrogen FCE-buses in the EU (excluding Bulgaria, Malta and Lithuania) was at 6.1 % which showed an increase of 18.4 % compared to 2019. In the EU plus UK, Norway, and Switzerland over 1500 e-buses (includes hybrid electric, FCE, trolley, and BE technologies) have been sold in 2020. Austria lags behind in this respect with only 175 e-buses or a share of new registrations of e-buses (including FCE-buses) of only 1.6 %[14] in 2020[15]. Preparations for the roll-out of FCE buses in Austria have officially started in 2021 in the framework of the national cooperative R&D HyBus Implementation project[16][17] with the aim to implement the European “Clean Vehicle Directive” 2009/33/EC[18]. The large-scale demonstration of first 700-bar FCE buses (Hyundai) initiated in Vienna (urban case) and Graz (regional case) to accelerate their implementation and to establish the required know-how. Furthermore, the suitability of a Hyundai ElecCity hydrogen bus in alpine terrain was recently investigated through test drives made available by Graz Linien.[19]

Regarding electric heavy-duty trucks, FCE-trucks have some major benefits in comparison to BE-trucks. Heavy duty vehicles have limitations regarding the maximum allowed gross vehicle weight (GVW). Since batteries add considerably to weight of the vehicle, BE-trucks have less payload capacity in comparison to FCE-trucks. Besides higher ranges and fast refuelling compared to charging and in future lower TCO are further decisive advantages of FCE-trucks.

In Austria, first heavy-duty FCET logistic fleet is being implemented in the framework of the “MPREIS Hydrogen”[20] project in Tyrol. In the first quarter of 2022 green hydrogen was produced for the first time in the region of Tyrol. In the secod quarter of 2022, a first prototype

[14] *Deloitte. H2-Mobility Austria Studie 2022: 2.000 H2-LKW auf Österreichs Straßen bis 2030; 2022.*

[15] *AustriaTech GmbH. Mobilitätsdaten in Österreich / Zahlen, Daten und Fakten.*

[16] *https://www.hybus.eu/*

[17] *https://www.klimafonds.gv.at/themen/mobilitaetswende/serviceseiten/zem/hybus-implementation-implementierung-der-ersten-drei-wasserstoff-busse-oesterreichs-in-den-realbetrieb/*

[18] *https://www.eumonitor.eu/9353000/1/j4nvk6yhcbpeywk_j9vvik7m1c3gyxp/vl04czyb9kzs*

[19] *Fleischhacker, N., Shakibi Nia, N., Coll, M., Perwög, E., Schreiner, H., Burger, A., Stamatakis, E., & Fleischhacker, E. (2023). Establishment of Austria’s First Regional Green Hydrogen Economy: WIVA P&G HyWest. Energies, 16(9), 3619.*

[20] *https://www.mpreis.at/wasserstoff/projekt*

from Hyzon Motors[21] (tractor model 4 x 2) was made available by JuVe Automotion[22], through a framework agreement with MPREIS.[19] At the same time, a hydrogen refuelling station (HRS) operating at 350 bar, including pre-cooling, for heavy-duty vehicles was commissioned at MPREIS premises in Völs, Tyrol. This HRS was further used to validate the safety functions and the refuelling protocol for the hydrogen storage system (HSS) of FCET.[19] This truck was further employed for the training of local service technicians and drivers of MPREIS, organized and carried out by FEN Sustain Systems GmbH[23]. In January 2023, Austria's first hydrogen semi-trailer truck (tractor plus trailer) was handed over to MPREIS for comissioning[24]. Regarding quality assurance and optimization processes, a close collaboration took place between MPREIS/JuVe and Hyzon for their follow-up implementation in the next production series of FCETs[19]. Other main elements of the developed green hydrogen economy within "MPREIS Hydrogen" are a 3 MW pressurized alkaline electrolyser (AEL) system with a capacity of 1.3 tons of hydrogen production per day (implemented in the framework of the European project "Demo4Grid"[25]), three hydrogen storage vessels at 30 bar with the capacity to store a hald a day of full production and the possibility of regulation at different pressures, and two multi element gas containers (MEGCs, 20-foot hydrogen storage containers).

The "MPREIS Hydrogen" project is one of the three ongoing complementary implementation projects within the WIVA P&G HyWest[26][27], initiated since 2018. This project is the result of the developed "Tyrol 2050 energy autonomous" strategy, ongoing since 2014[28].

Other national projects focusing on the long-term green energy supply are namely "Renewable Gasfield"[29] and "H2Real"[30]. The green hydrogen production from wind power or photovoltaics (PV) in Renewable Gasfield is further used in the methanation process and mobility as well. In the H2Real project a hydrogen valley as the key for hydrogen technology and application in the eastern Austria is under development. The overview of other national R&D projects within the scope of the energy model region is depicted in Figure 1.

In Salzburg, currently the necessary infrastructure in the case of hydrogen buses and trucks is still unavailable. It was recently reported that fossil-based production of 1 kg of hydrogen results in 10 kg of CO2 emissions[31]. Furthermore, given the advantage of green hydrogen production via electorlysis and its storage on site, as described above within current cases in Austria, this concept is considered in the ZEMoS project.

---

[21] *https://www.hyzonmotors.com/*

[22] *https://juvemotion.at/*

[23] *https://www.fen-systems.com/wasserstoffausbildung-und-fahrzeugtraining-fur-die-mechaniker-fur-ersten-wasserstoff-trucks-von-mpreis/*

[24] https://www.youtube.com/watch?v=m9-5WU2_4pA

[25] *https://www.demo4grid.eu/*

[26] *https://www.hywest.at/*

[27] *https://www.wiva.at/project/hywest/?lang=en*

[28] *https://www.tirol2050.at/*

[29] *https://www.wiva.at/project/renewable-gasfield/?lang=en*

[30] *https://www.wiva.at/project/h2real/?lang=en*

[31] *Chouhan K, Sinha S, Kumar S. International Journal of Hydrogen Energy 2021, 46(53), 26809–24.*

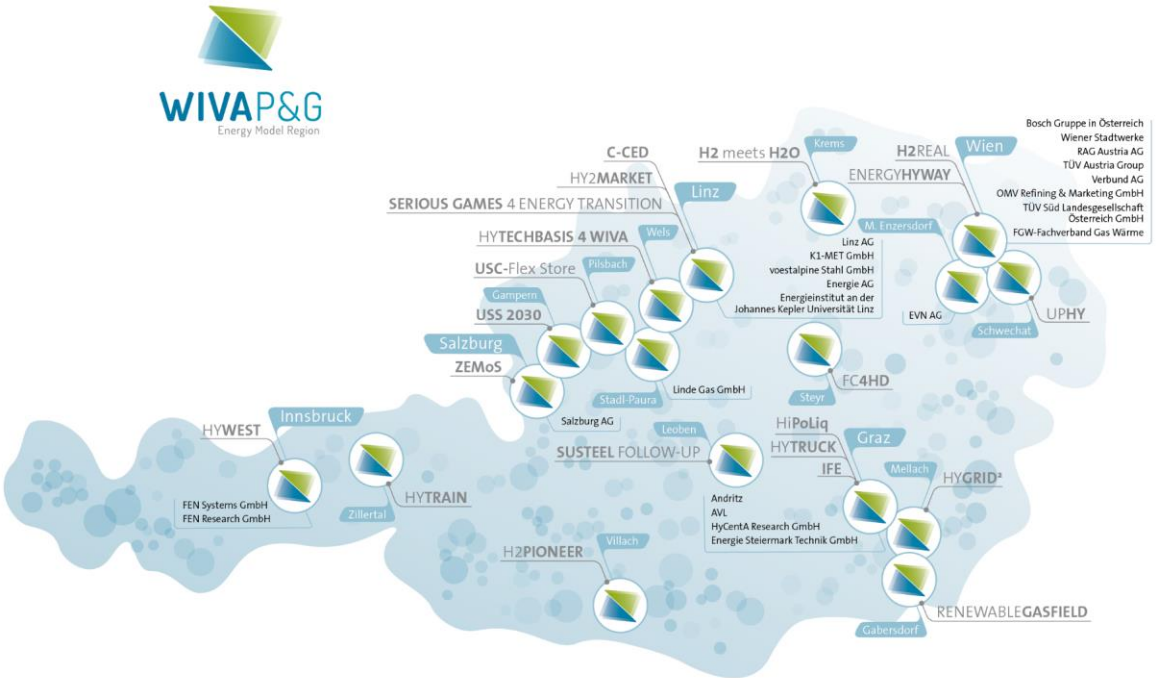

Figure 1 Geographical overview of national R&D projects within the WIVA P&G Energy Model Region[32].

The comparison of different electrolysis technologies is provided in Table 1. PEMEL is advantageous regarding dynamic operation, hydrogen quality, maintenance effort as well as required space but still comes with higher capital expenditures (CAPEX). This technology provides system efficiencies up to 65 % (based on the lower heating value), which means that a minimum of 35 % of the supplied energy is transformed into thermal energy. The overall system efficiency can therefore be improved by using the waste heat. This will additionally result in a reduced levelized cost of hydrogen (LCOH) production and will generate additional revenues.

Table 1 Overview of actual key parameters of different electrolyser technologies[33][34][35]

	AEL	AEMEL	PEMEL	SOEC
System Efficiency [%][a)]	Up to 65	Up to 68	Up to 65	Up to 82
Current Densities [A/cm²]	0.2 – 0.6	0.5 – 2	1 – 3	0.3 – 1
Operating temperature [°C]	60 – 95	40 – 80	50 – 80	700 – 1000
Operating Pressure [bar]	Atm. – 32	30 – 35	Atm. – 40[b)]	1 – 3
Module size [kW]	5 – 6 000	Up to 5	5 – 2 500	-
System size [MW]	Up to 100	-	Up to 100	Up to 0.15
Lifetime [h]	60 000 – 90 000	> 2000	30 000 – 90 000	< 20 000
CAPEX costs [€/kW]	500 – 1200	-	800 – 1800	1200 – 2000

a) based on H_u = 3 kWh/Nm³ H_2; b) demonstration up to 700 bar

For an integration into a district heat system, technological pathways may be considered which would require further comprehensive techno economical assessments by means of plant

[32] *https://www.wiva.at/activities/?lang=en*

[33] *The International Renewable Energy Agency. Green hydrogen cost reduction, 2020.*

[34] *International Energy Agency. The Future of Hydrogen: Seizing today's opportunities, 2019.*

[35] *Christensen A. Assessment of Hydrogen Production Costs from Electrolysis: United States and Europe; 2020.*

simulations. Such studies regarding commercially available systems as well as their durability, operational behaviour and demonstration in large scale operation are still missing[36].Economic and socio-technical analyses are important tools to identify market relevant influencing factors. In order to be able to identify various decision-relevant factors and corresponding correlations regarding the transition to FCE and BE-mobility, a targeted analysis and evaluation is required.

The industrial research and experimental development topics under investigation in the ZEMoS project deal with technology readiness levels (TRLs) above 5 and aim to investigate the open questions described in this section based on the real-world data.

3 Methodology

The ZEMoS project outlines a strategic framework that aims for the gradual substitution of diesel-powered public transport and heavy-duty vehicles in operation all year round. Based on the considered technology-open approach in this project, both BE and FCE vehicles are examined.

3.1 ZEMoS Model Regions

ZEMoS aims to develop two ZEM model regions – one urban (Tennengau) and one alpine/tourist (Pinzgau) – for public bus transport and pilot projects for the transfer of heavy-duty transport (see Figure 2). ZEMoS will be set up as a “living lab”, meaning that the acquired real-case data will be reevaluated periodically. This ensures that the developed models will be continuously improved and therefore, the evaluated results will be continuously plausibilised. ZEMoS will be further developed as part of a continuous improvement process (CIP).

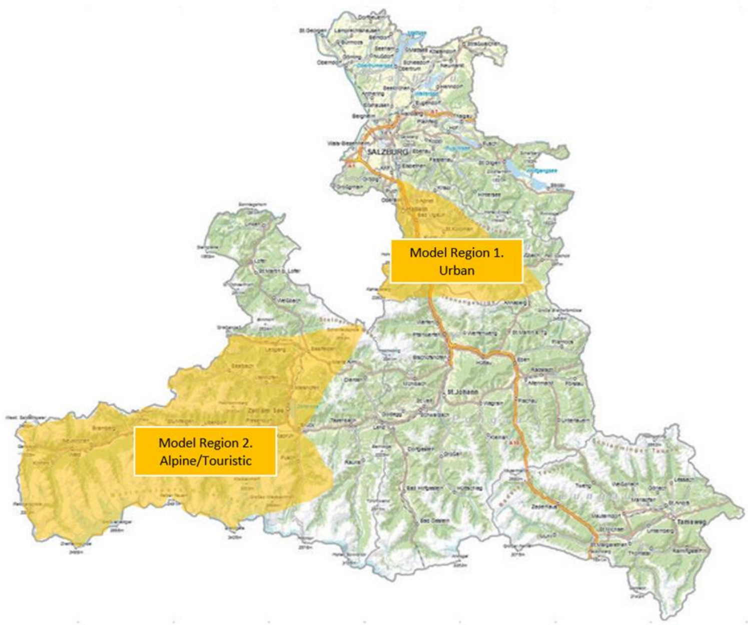

Figure 2 Map of ZEMoS model regions: Urban model region 1 (Tennengau), Alpin/Tourist model region 2 (Pinzgau).

[36] *Moradi Nafchi F, Baniasadi E, Afshari E, Javani N. International Journal of Hydrogen Energy 2018, 43(11), 5820–31.*

3.1.1 Urban Model Region – Tennengau

Tennengau, as the urban model region (Figure 2), is a key focus area for ZEMoS. The project envisions the development and implementation of innovative, holistic, large-scale zero-emission bus concepts for public transport. An optimization model will be created to determine the most suitable zero-emission drive technology for each specific bus line. Additionally, pilot projects for garbage trucks and heavy-duty trucks shall be initiated as well.

3.1.2 Alpine/Tourist Model Region – Pinzgau

Pinzgau, known for its alpine and tourist characteristics, poses unique challenges and opportunities. ZEMoS aims to extend its impact to heavy-duty transport, initiating FCE projects for heavy-duty trucks. The partial decarbonization of public transport at the ski world championship foressen in Saalbach in 2025 is pursued as well by provision of ZEM buses for this event. This region will also be a testing ground for the establishment of a green hydrogen infrastructure.

The focus on public transport and heavy-duty traffic, predominantly diesel-operated, represents a crucial and challenging shift. ZEMoS adresses the diverse weather conditions, topography, and seasonal variations, especially in alpine terrain, adding an innovative perspective to zero-emission mobility in challenging environments. The first results regarding feasibility assessment of FCE and BE buses are described in 4.2.

3.2 ZEMoS Concept

The R&D national projects to date have established the groundwork for technical maturity regarding green hydrogen production and infrastructural know-how (see State of the Art). The further obtained knowledge and achieved optimizations in the ZEMoS model regions, depicted in Figure 3 and Figure 4Figure 4, provide the basis for nationwide deployment, which represents a pioneering role in this regard.

ZEMoS introduces a paradigm shift in the planning basis, moving from traditional demand-centric approaches to a focus on infrastructure considerations. This involves addressing issues such as charging station accessibility, HRS placement, and charging times. The project pioneer’s new geographic information systems (GIS) based methods and spatial databases to effectively plan locations based on accessibility and demand. By integrating infrastructure location and fleet composition decisions in its planning process, ZEMoS aims at the development of a mixed-integer linear program with the goal to optimize these intertwined decisions simultaneously. The model is tested on real-world data from Tennengau and Pinzgau, showcasing a commitment to practical application.

The complex technological challenges of hydrogen production by electrolysis will be investigated by implementing a digital twin of the concepted hydrogen infrastructure, including degradation models and economical optimisationof operating strategies. The optimization processes further include the sector coupling issues, such as process heat extraction during different operation strategies with a concepted large scale heat pump and the provision of balancing energy to the power grid. Alternative hydrogen compression technologies are planned to be further explored within the digital twin, recognizing the limitations of traditional compressors. The advantages, disadvantages, and research need for piston, diaphragm, electrochemical, and metal hydride compressors are planned to be meticulously examined.

Furthermore, the supply strategy of green hydrogen, produced by the electrolyser situated in the urban model region, and the decentralized HRS situated in the alpine model region is considered through hydrogen logistics between both model regions (see Figure 3 and Figure 4Figure 4). In addition to the technical aspects, ZEMoS emphasises socio-technical analyses aiming to understand acceptance among the population, particularly in the model regions of Salzburg. Willingness-to-pay analyses refer to both the local population and tourists, taking into account possible differences in attitudes.

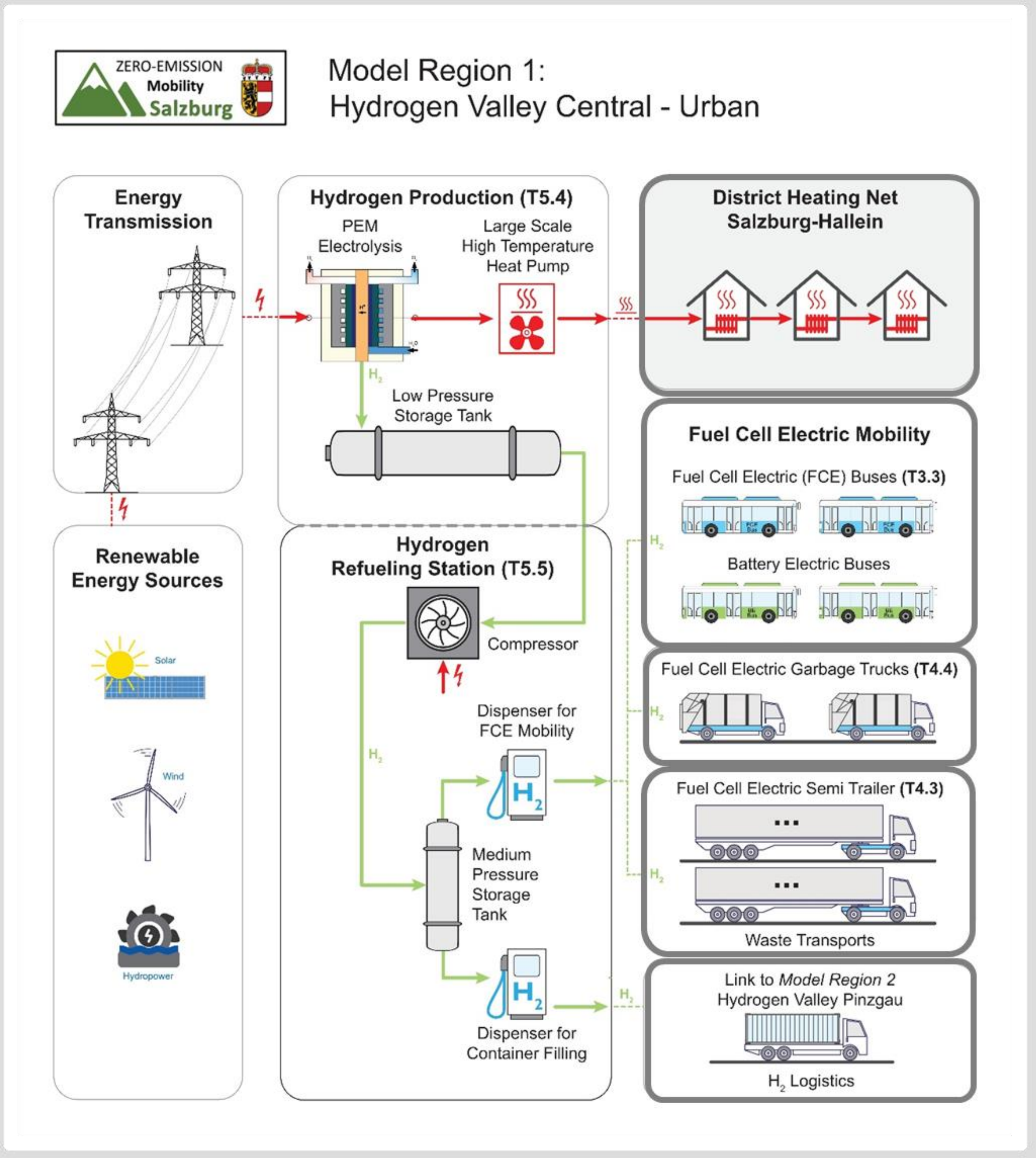

Figure 3 ZEMoS Concept Model Region 1

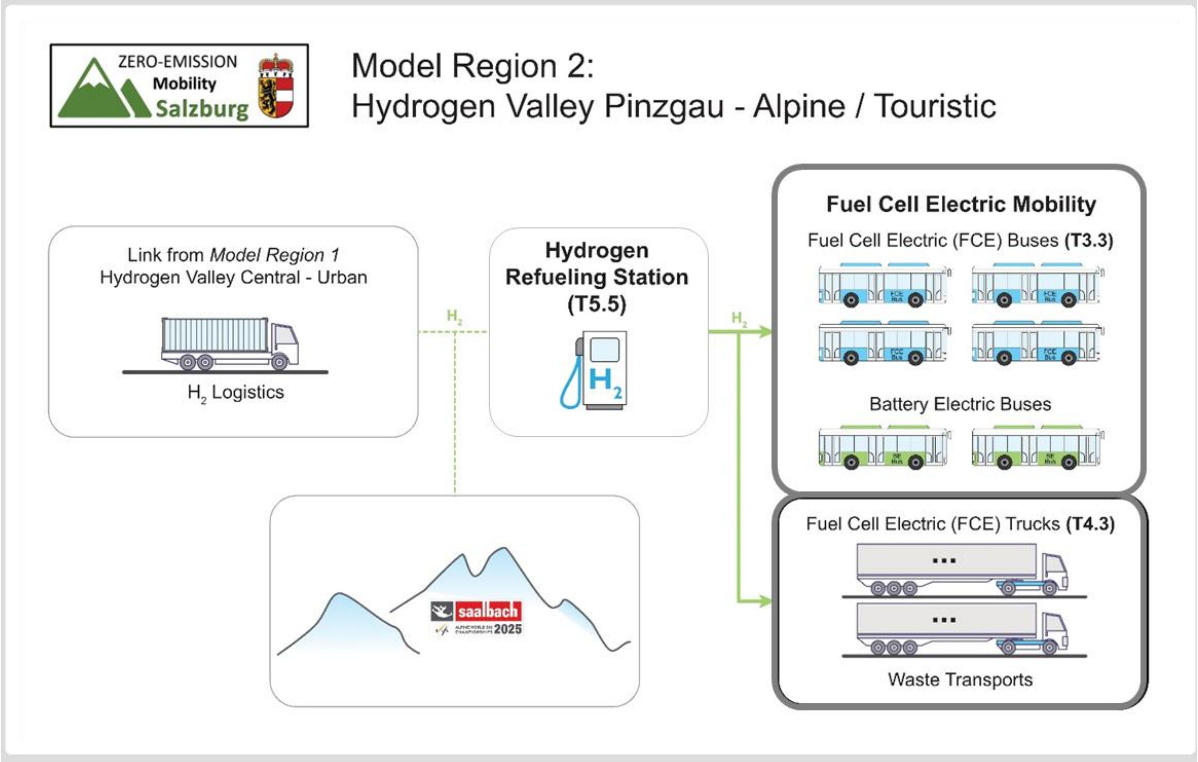

Figure 4 ZEMoS Concept Model Region 2

4 Preliminary Results

4.1 Changes to the initial concept

Regarding the initial conceived concept, some changes were made due to unforseen events. For instance, the current unavailability of a refueling infrastructure and uncertainty concerning the green hydrogen price were identified as the main factors inhibiting investment decisions in FCEVs (buses, garbage trucks and trucks). Furthermore, the expected CAPEX for FCEV was budgeted before the increase in prices due to the inflation period, resulting in a gap in the funding volume. This funding-gap in combinantion with the aforementioned arguments was decisive for a negative investment decision in particular for FCE buses and garbage trucks and complicated the investment decisions for FCE trucks.

The initial project intended the implementation of 32 e-buses (FCE and/or BE). In preparation for the EBIN-funding program[37], a first simplified computational preliminary study for the determination of the most cost-effective propulsion technology (BE or FCE) was carried out. The results of this study were used to plan the implementation of 5 FCE buses and 16 BE buses. The initially planned 32 e-buses were reduced to 21 e-buses due to the higher CAPEX. Eventually, no bus operator was able to invest in FCE buses for the reasons mentioned above, despite available funding.

[37] *https://www.ffg.at/EBIN*

Due to the same reason, the initially intended implementation of 4 FCE garbage trucks had to be postponed to 2025 and beyond. The initially foreseen 4 FCE longhaul trucks by ZEMKA in the alpine model region could not be implemented due to economical factors, although funding was available. An attempt is therefore being made to integrate 2 new partners into the project for the implementation of these 4 FCE longhaul trucks in the urban model region.

Consequently, only BE buses and BE garbage trucks will be available in both model regions. For this reason, ZEMoS is primarily focusing on the development of the urban model region, with a particular emphasis on FCE trucks. The development of the hydrogen side of the alpine model region is postponed by the time FCEVs have been made available in this region.

4.2 Feasibility Assessment

Addressing the critical aspect of feasibility, ZEMoS undertakes a comprehensive approach to assess the viability of ZEM solutions. The project's primary objective is to formulate an inclusive roadmap for transitioning to ZEM, accounting for the diverse geographical and operational landscapes of Salzburg.

The foundation of this assessment lies in detailed data collection, encompassing spatial typologies, demographic data, bus routes with timetables, and specifics concerning hydrogen and charging infrastructure in the Pinzgau and Tennengau regions. A collaborative effort with SVG enhances existing spatial planning tools, integrating spatial characteristics of bus routes and infrastructure for both hydrogen and battery-electric mobility.

ZEMoS starts with the identification of potential bus routes that enable an efficient transition to sustainable propulsion methods. The project uses modelling techniques to assess the potential of FCE and BE buses for selected routes. In addition, the analysis considers potential locations for new charging and HRSs as well as further future developments, such as new charging infrastructure or increases in demand. This approach includes a thorough comparison of FCE and BE buses for different routes and includes a prioritisation strategy via a bus planning tool, which is a computational mathematical optimization model. Using this model, the number of e-buses (BE or FCE) are optimized based on the total costs of substitution for each specific bus line from diesel propulsion to ZEM propulsion.

4.2.1 Limitations and key assumptions

Regarding the bus planning tool, a single technology is designated for each bus line, resulting in a homogeneous fleet. Buses are exclusively assigned to one line, with entire lines being subcontracted to different bus operators. Diesel buses are not replaced on a one-to-one basis; instead, the minimum number of buses required for each technology is computed. To address robustness, a minimum battery level is implemented. Depot locations are provided in the dataset, while the H2-charging station is located outside the depot, with its position detailed in the data. For instance, all buses commence their service fully charged, operating from a singular depot. In a later step, these parameters will be specified for every specific bus line. Charging stations for a particular technology offer uniform loading infrastructure and identical charging power.

For FCE buses it is assumed that, regardless of the amount of H2 charged, the charging time corresponds to fully charging the bus. In the case of BE vehicles, the charging time for a full charge is computed by dividing the battery capacity by the power of the charging station. Additionally, linear charging behavior is presumed. For example, using 50 % of the charging time for a full charge increases the energy level of the battery by 50 % of its total capacity. Energy consumption is assumed to be linear and decreases by a constant value per driven kilometer. A visit to a charging node is only allowed if the battery level falls below 80 %. Scheduling conflicts at charging stations are not considered, allowing for the potential simultaneous charging of multiple buses. Finally, the effects of battery deterioration are not considered in the model.

4.2.2 Computational Study

The first computational study for the bus planning model involved different settings. For each configuration, line, and technology, detailed information was recorded including the number of buses required, service trip assignments, specific occupation level, distance driven per bus, recharging/refueling details, energy requirements for charging stations, and consumed energy per bus.

In the base setting, the tank/battery capacity at 100 % of Salzburger Verkehrsverbund's provided values, energy requirements per km, and other specified parameters for each selected bus line is assumed. Taking into account all the parameters, the computational study determines the necessary number of buses per technology and line, which lead to the most cost-effective substitution of yearround live-operating diesel buses. The results from the initial model were documented and will be periodically reevaluated with collected real-case data through the CIP and are intended, when fully developed, to build a robust basis for future strategic investment decisions.

To test robustness, alternative parameter settings were explored. For FCEV, a scenario with a 20 % increase in energy consumption per km was assessed. For ONC (BE buses with over night charging in depot) and OPC (BE buses with both over night charging in depot and opportunity charging at terminal stops), the minimum charging level was raised to 50 %. As expected, an increase in required buses was observed, particularly for lines with distant depots. Overall, these first evaluations provide insights into the model's adaptability and robustness under different scenarios, contributing to its refinement within the R&D ZEMoS project.

5 Conclusion

The ZEMoS project has brought together a consortium of energy and transport companies with scientific partners, including leading research organizations, expertise hubs in geoinformatics, and institutes specializing in energy system conversion and hydrogen technologies. These partners are collectively leveraging the project to strengthen research capabilities in alternative propulsion technologies for public transport, economic and socio-technical analyses in the context of FCE and BE mobility as well as the optimization of electrolysis operations and waste heat management. Their collaborative efforts within the project significantly impact the energy flagship region, positioning Austria for the development of a green hydrogen economy and reinforcing the leading position of Austrian companies within the consortium.

Especially for S-AG, the project stands as a pivotal opportunity for the approval of the feasibility of the supply of local customers with affordable green hydrogen and green electricity. The technical enhancements to the electrolyser plant, facilitated by competent partners, aim to establish a reliable hydrogen production facility, ensuring long-term economic stability. S-AG not only expands its business into a new area with a fresh customer segment but also gains a robust foundation for navigating the challenges of decarbonization and energy transition through collaborative scientific and technical partnerships.

6 Outlook

The transition of the current energy system towards a sustainable, crisis-resistant and affordable energy system is one the most drastic interventions in the European economy. To date, it is not yet entirely clear how the future energy system will resemble, although it is clear that hydrogen will play a central role in this system. The implementation of the energy transition and the associated ramp-up of the hydrogen economy starts on a small scale. Therefore, in addition to its hydrogen activities in the federal state of Salzburg (Austria), S-AG is also strongly present in the WIVA P&G, which was officially awarded as “European Hydrogen Valley of the Year 2023” at the Clean Hydrogen Partnership awards 2023 in Brussels, Belgium[38]. More specifically, the WIVA P&G consists of three valleys (Western, Central and Central Alps) that extend across Austria and the neighboring regions. As shown in Figure 5, S-AG is participating in the development of a Clean Hydrogen Partnership hydrogen valley with the working title Central Alps. S-AG strives to further strengthen its partnership with Tyrol and this region to support the emerging local hydrogen economy in this valley and beyond.

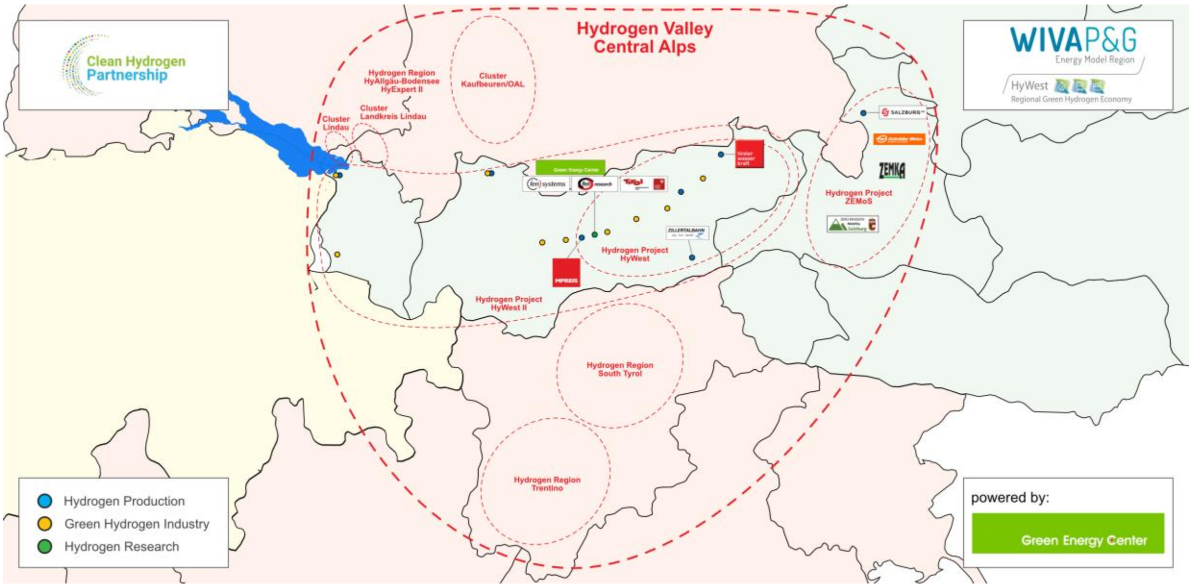

Figure 5 Overviw of hydrogen Central Alps Valley

Acknowledgments: This project is supported with funds from the Climate and Energy Fund and implemented in the framework of the RTI-initiative “Flagship region Energy”. FFG Project Nr. FO999900979 *& 2. ENIN Ausschreibung (Nr.* FO999905916) *are associated to the energy model region WIVA P&G.*

38 *https://www.clean-hydrogen.europa.eu/media/news/clean-hydrogen-partnership-awards-2023-celebrate-excellence-and-innovation-2023-11-24_en*