NEWBORN - NExt generation high poWer fuel cells for airBORNe applications

WP12 – Project Management

D12.7 Gap analysis report - update for 2024 and IM 2024 report

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Revision History

Revision	Date	Revision summary
00	2024-12-12	Initial release
01	2025-06-20	Updated document template Updates reflecting review feedback from Clean Aviation project office - Line added for required cathode humidity in Table 4.1.2 for KT1 - Added Table 4.2.3 for KT2 listing main air system related KPIs shared with HERA - Line added to Table 4.7.2 for battery durability - Added clarification in 3.14 and created a new section 1.3 that clarifies basis for the KPI estimation. - Explanation for significant change added to section 2.10.1 - Added battery endurance KPIs to section 4.7.2 - Expanded section 2.7.2, now comparing both variants of the Miniliner (2x2 and 4x1) with two different missions of the reference aircraft.

Table 1 - Revision history

Intellectual property

Section/Chapter/Item	Owning Entity	Nature of IP	Comments
Entire deliverable	Entire NEWBORN consortium	Shared Foreground	

Table 2 - Intellectual property

Contributors

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Table 3 - List of contributors

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

REFERENCES

ID	Reference	Title	Revision
1	GA101101967	NEWBORN project Grant Agreement	2022-12-31
2	NM-WP12-SE-NO-DEL-000007	D12.6 Gap analysis - initial release and IM 2023 report	01
3	NS-WP01-SE-NO-DEL-100001	Aircraft-level requirements summary	01
4	NE-WP08-PU-NO-DEL-800021	Design report on the BMS	00
5	NC-WP06-SE-NO-DEL-000607	D6.7 Balance of plant and Hydrogen line control system electronics critical design and platform SW summary	00
6	NA-WP03-SE-NO-DEL-300005	D3.5 Air-compressor inverter design report	00
7	NT-WP05-SE-NO-DEL-500005	D5.11 Fuel Cell & BoP Thermal Management Preliminary Design Description	00
8	NE-WP08-SE-NO-DEL-800022	D8.22 Internal power distribution system design description document	00
9	NE-WP08-SE-NO-DEL-800008-00	D8.5 Design Report on mechatronic interconnection of FC, BoP and DCDC	00
10	NE-WP08-SE-NO-DEL-800032	D8.32 Motor Thermal management coolant loop design description summary	00
11	NE-WP08-SE-NO-DEL-800016-00	D8.16 Design report on the mechatronic interconnection of battery, drives, SSPCs and DCDC	00
12	NE-WP08-PU-NO-DEL-800084	D8.4 Simulation analyses update report, including Dynamic DC loads	00
13	NF-WP04-SE-NO-DEL-400010	D4.6 Stack design report	00
14	NF-WP04-SE-NO-DEL-400009	D4.7 Design Report on FCMS hardware	00
15	NA-WP03-SE-NO-DEL-300031	D3.1 Air inlets-exhaust design optimization report for target aircraft	00
16	NE-WP08-SE-NO-DEL-800007	D8.33 Design report of motor-propeller integration	01
17	NG-WP01-SE-NO-DEL-100001	D1.15 Preliminary safety analyses report	03
18	NE-WP08-SE-NO-DEL-800006	D8.30 Integrated Motor and Inverter Demonstrator design description	00
19	NA-WP03-SE-NO-DEL-300007	D3.7 Humidity management units design description document	00
20	NG-WP07-SE-NO-DEL-000001	D7.1 Multi-stack air-flow distribution test report	00
21	NB-WP09-SE-NO-DEL-900001	D9.2 Ground demonstrator preliminary mechanical design summary	00

22	**NE-WP08-SE-NO-DEL-812023**	**D8.23 Harmonized wiring interfaces description report**	**00**
23	**ND-WP03-SE-NO-DEL-300004**	**D3.19 Preliminary description of Air Systems Line design**	**00**
24	**NE-WP08-SE-NO-DEL-800005**	**D8.29 Motor, Inverter and Control CDR**	**00**
25	**NS-WP01-SE-NO-DEL-100002**	**Regional and Commuter aircraft integration concepts description**	**00**
26	**NF-WP04-SE-NO-DEL-400003**	**Preliminary stack specification**	**00**
27	**NE-WP08-PU-NO-DEL-800001**	**D8.27 Propulsion motor and inverter trade study summary**	**00**
28	**NS-WP01-SE-NO-DEL-100004**	**D1.4 Paralleling provisions requirements**	**00**
29	**NE-WP08-SE-NO-DEL-800001**	**D8.1 Electrical architecture & topology report**	**00**
30	**NT-WP05-SE-NO-DEL-500003**	**D5.3 Aircraft-level thermal management analysis report**	**00**
31	**Lefebvre, A.H., Ballal, D.R.: Gas turbine combustion, CRC press, 2010**	**Gas turbine combustion**	**N/A**
32	**TCDS No. A00016WI**	**Textron Aviation Inc., "Type Certificate Data Sheet No. A00016WI - Model 408," Department of Transportation - Federal Aviation Administration, Wichita, Kansas, March 2022**	**00**
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34	https://cessna.txtav.com/en/lp/skycourier-splash-lp	**Cessna SkyCourier data**	**00**
35	**Emission Indexes**	**Lee, D. S., Pitari, G., Grewe, V., Gierens, K., Penner, J. E., Petzold, A., ... & Sausen, R. (2010). *Transport impacts on atmosphere and climate: Aviation.* Atmospheric environment, 44(37), 4678-4734.**	**00**
36	**Gierens, K. (2021). Theory of contrail formation for fuel cells. Aerospace, 8(6), 164.**	**Fuel cell contrails**	**00**
37	https://web.archive.org/web/20181106021310/http://www.geocities.jp/nomonomo2007/AircraftDatabase/AWdata/AviationWeekPages/GTEnginesAWJan2008.pdf	**Engine data**	**00**
38	**Trainelly, L.; Riboldi, C.E.D.; Rolando, A.; Salucci, F.; Oliviero, F.; Pirnar, J.; Koopman, T.; Žnidar, A. *UNIFIER19 D1.2: The design framework for an NZE 19-seater*. 2020.**	**UNIFIER19-D1.2**	**00**

GLOSSARY

A/C	Aircraft
BMS	Battery Management System
CA	Clean Aviation
CD	Coefficient of Drag
CL	Coefficient of Lift
CAS	Calibrated AirSpeed
CM	Configuration Management / Configuration Manager
CZ	Czech Republic
DC	Direct Current
DEP	Distributed Electric Propulsion
DoD	Department of Defence
EASA	European Aviation Safety Agency
EOL	End of Life
EU	European Union
FL	Flight Level
GHG	Green-House Gas(ses)
HERA	Hybrid Electric Regional Aircraft
HLG	High Level Goals
HVDC	High Voltage DC
IADP	Innovative Aircraft Demonstrator Platforms
ID	Identifier
IFR	Instrument Flying Rules
IM	Impact Monitoring
kCAS	Knots, Calibrated Air Speed
KPI	Key Performance Indicator
LCA	Life-Cycle Analysis
LFL	Lower Flammability Limit
LH2	Liquid Hydrogen
MEA	Membrane Electrode Assembly
MLW	Mean Landing Weight
MTBF	Mean Time Before Failure
MTOW	Mean Take-Off Weight
MWE	Manufacturer's Empty Weight
MZFW	Mean Zero Fuel Weight
N/A	Not Applicable or Not Available
NEWBORN	NExt generation high poWer fuel cells for airBORNe applications
NvPM	Non-volatile Particulate Matter
OEM	Original Equipment Manufacturer
pax	Passenger(s)

PC	Project Coordinator
PEM	Proton Exchange Membrane
pp.	percentage points
ROC	Rate of Climb
RPM	Revolutions Per Minute
SAF	Synthetic / Sustainable Air Fuel
SMR	Short/Medium Range
SoA	State of the Art
SPL	Sound Pressure Level
TBC	To Be Confirmed
TL	Technical Leader
TLAR	Top Level Aircraft Requirements
TRL	Technology Readiness Level
UCA	Use-Case A
WP	Work Package

1 OBJECTIVES AND AMBITION

1.1 Deliverable objective

This deliverable serves two primary objectives:

- Deliver the Clean Aviation impact monitoring report using the recommended template, and
- Report the summary of the gap analyses.

The description of the deliverable according to the Grant Agreement is: *2024-update for gap analysis report on assumed and confirmed technology gaps to reach the project objectives, and approach to the gap mitigation and outlook. The deliverable also presents the 2024-progress versus all target indicators and maturity levels announced in the D12.23 "IM – Reference, KPIs, Targets and TRL" deliverable for the different systems/subsystems and technologies.*

The activities to generate data for this deliverable belong to the project tasks T12.9 Impact Monitoring and T12.3 Technology gap analyses, and represent work done in those tasks during the second year of the project.

1.2 Impact monitoring introduction

The Impact Monitoring principles are defined in the SRIA, the Work program, and the call topic conditions with the aim to define, assess and regularly report on the performance of project outcomes against the Clean Aviation High Level objectives set in the Council regulation. Those principles are implemented through each grant agreement with following timely expected outcomes (as presented at the start of the projects).

Due in M6	**IM – Reference, KPIs, Targets and TRL**	For each of the following KPIs, the deliverable will indicate the targeted objectives along the project, at well-defined maturity gates up to project end: ▪ the reference aircraft or technology serving as a baseline for performance comparison, ▪ the contribution to Clean Aviation High Level Goals (HLGs), ▪ the related technical performance KPIs to be defined by the technology owners, ▪ any other relevant socio-economic KPIs ▪ the TRL scale for each technology development and expected progress in terms of TRL level along the project timeline at the above maturity gates as well as at project end for the different systems/ sub-systems and technologies
Due in November of each year N	**IM – Yearly Report**	The deliverable shall present the progress v.s. all target indicators and maturity levels announced in the above reference deliverable for the different systems/sub-systems and technologies
Due every two year in November	**IM – Biennial Model Based Performance Estimate**	The IM yearly report is accompanied with a more thorough performance calculation/estimation based on a detailed model-based approach: • At aircraft level, a PANEM/GRASM calculation of the aircraft concept is provided; • At technology level, a model-based system simulation is provided. This report will be delivered every 2 years to the aircraft concept owners in charge of the assessment of the contribution to the various technologies to the aircraft concepts.
Due at project end Co-funded by the European Union	**IM – Final Assessment Report**	The deliverable shall report on the project's contribution to the CA HLGs and the final performance improvements achieved in the various domains, including the maturity reached.

The projects' outcomes will be integrated by each Aircraft concept project (SMR-ACAP and HERA) which will perform a consolidated assessment of the performance and maturity progress based on the individual technology assessments stemming from the different linked projects contributing to an aircraft concept.

They will report *on a yearly basis* as well for the relevant aircraft concepts envisaged. At aircraft concept level, this reporting will be complemented *on a biennial basis* by a detailed overall aircraft level performance simulation and related assessment with appropriate high-fidelity tools.

The Impact Monitoring deliverable will address the following 3 levels: aircraft concept, main sub-systems and underlying key technologies. The data will be provided by each Clean Aviation project as appropriate in relation to the project work scope, considering that some sub-systems might be applicable to several aircraft concepts. The data flow is therefore from the projects to SMR ACAP and HERA.

- At **Aircraft Concept level** (covered by SMR-ACAP project on SMR pillar / HERA project on HER pillar), the various concepts will be defined together with a reference aircraft, primarily for the CS-25 segment (SMR and Regional). Data for the main sub-systems will be provided by the other[1] relevant project(s) contributing to the aircraft concept architecture. These concepts should be complemented by other aircraft concepts if designed and developed beyond SMR-ACAP/ HERA (in case some critical technologies out of projects are not integrated in the selected aircraft concepts proposed by SMR ACAP and HERA in Clean Aviation Phase 1). This applies particularly to the CS-23 segment.
- At **Sub-System level** and **Key Technology level** (covered by other[2] CA Phase 1 projects delivering propulsion, wing, fuselage and empennage, systems and fuel storage, or transverse technologies), including the delivery of data to the other relevant project(s) on aircraft level.

The reports will be processed following the Impact Monitoring principles described in Appendix A.

The Impact Monitoring approach and KPI must be aligned with the **objectives and ambition** of the project, as is described in Grant Agreement Annex 1 Part B, chapter A 1.1 and A 1.2., and must follow the same principles:

- S.M.A.R.T: proposed targets must be Specific (target a specific area for improvement), Measurable (define an indicator of progress), Achievable (demonstrate that these can be accomplished during the project timeframe), Realistic (state relevant results can realistically be achieved, given available

[1] Other than SMR ACAP and HERA

[2] Other than SMR ACAP and HERA, except for the sub-system or key technologies developed as well under SMR ACAP and HERA (e.g. on-board systems).

resources), Time-related (specify when the results can be achieved). Objectives must be consistent with the expected exploitation and impact of the project.

- Relevant: proposed targets must be relevant with respect to the project objectives and contribute to the Clean Aviation Strategic Research and Innovation Agenda. Specifically, the proposed targets should detail the envisaged contributions and benefits of the project to the next generation of aircraft.
- Performance targets must be quantified for the different sub-systems and technologies
- The maturation path (e.g., starting and final TRL, potential barriers for development) within and beyond the project timeframe must contribute to the development of new aircraft with entry into service by 2035.

1.3 Clarifications on state of technology performance estimation

The values for critical product performance parameters, especially weights, are based on estimated product parameters, considering component adaptations using mature technologies (e.g. replacement of housing materials for flight-worthy components, and use-case-optimized component designs), not the weights or of components (often selected for their availability in the needed time) used on the TRL4 ground demonstrator.

2 AIRCRAFT CONCEPT LEVEL

Despite the project developing a scalable technology with modular architecture scalable across various aircraft types ranging from approximately 9-passenger aircraft up to multi-MW propulsion systems, for the purpose of the impact monitoring the deliverable focuses on alignment with 4 aircraft concepts, representing different exemplary instantiations of the technology:

- The HERA, use-cases A and B (HERA), wherein the realignment of HERA to the Ultra-efficient regional aircraft seems to make the use case A obsolete in terms of 2035 implementation, but still represents possible and valid aircraft configuration. For simplicity compared to previous IM deliverable, the two use-cases are referred to as HERA later in this deliverable.
- The Pipistrel Miniliner (Miniliner)
- Conceptual fully fuel-cell electric 80-passenger aircraft (FC80pax)

2.1 Concept aircraft

2.1.1 Concept HERA-UCA

This aircraft concept is detailed by HERA project. The high-level aircraft description:

- Two-engine regional aircraft with nominally 80 passengers
- Hybrid powertrain, combining SAF- or hydrogen-burning thermal engine and a fuel cell power source, complemented by batteries
- Fuel cell power source integrated within the fuselage, fed from an LH2 tank located in the tailcone
- 1.1 MW of peak electric propulsive power per engine
- Ceiling altitude of FL250

This use case is lately discussed for realignment with the ultra-efficient regional aircraft concept, not using fuel cell power source, and is further not discussed herein.

2.1.2 Concept HERA-UCB

This aircraft concept will be detailed by HERA project. The high-level aircraft description:

- Regional aircraft with nominally 80 passengers, powered by a combination of thermal engine and electric Distributed Electric Propulsion
- Hybrid powertrain, combining SAF- or hydrogen-burning thermal engine and a fuel cell power source, complemented by batteries
- Fuel cell power source integrated within the fuselage, fed from an LH2 tank located in the tailcone
- 1.1 MW of peak electric propulsive power per side of the aircraft
- Ceiling altitude of FL250

2.1.3 Concept Pipistrel Miniliner

This aircraft concept has been developed in the UNIFIER19 project (Trainelli, et al., 2020). The high-level aircraft description:

- Commuter aircraft with nominally 19 passengers and single pilot operations, powered by a fuel cell / battery hybrid powertrain fed by liquid hydrogen fuel, potentially using Distributed Electric Propulsion.
- Take-off distance of 800 m from grass runways.
- Low cruise altitude (4,000 ft nominal, 8,000 ft cruise ceiling), under scrutiny.
- Capable of performing 5 hops of 350 km each without refueling.
- <45 min turnaround time.
- Aircraft used for cargo operations during the night.

2.1.4 Concept Fuel cell fully electric 80-passenger regional aircraft

While the NEWBORN system technology is scalable across various classes of aircraft, the concept discussed herein covers the high end of the spectrum – a conceptual regional 80-seater aircraft with mission very similar or equivalent to the mission defined by the HERA aircraft, requiring approximately 7.8 MW of total take-off electric propulsive power, assumed delivered by 4 propulsors. It is shown primarily as an example of the propulsion system scalability to high power levels; the analyses of the aircraft feasibility are primarily focusing on the aspects of performance feasibility, systems installation feasibility, and safety. Detailed concept study of such aircraft is out of scope of the NEWBORN project. Some aspects that could be expected lacking, given the state-of-the-art, are mainly the system maintenance requirements and related commercial feasibility of such aircraft.

Such aircraft can be seen as an entry point to the fully hydrogen-electric (low/no-GWP) large air transport.

Main characteristics:

- Short range regional aircraft with nominally 80 passengers powered by four fuel cell / battery hybrid propulsion systems fed from partially redundant LH2 storage
- Take-off distance of 1315 m
- Operating ceiling of FL250, typical cruise altitude FL200

2.2 HERA Reference aircraft definition

The reference aircraft is detailed by HERA project, matching approximately the ATR72-600.

2.3 HERA Typical Mission for Impact Monitoring

Typical mission for the reference aircraft is detailed by the HERA project, matching approximately the ATR72-600.

2.4 HERA Aircraft Concept

The description of the HERA UCB concept is provided by the HERA project.

It is assumed herein that the aircraft is a 80-passenger (nominal) aircraft, with hybrid Distributed Electric Propulsion. Each side of the aircraft contains a thermal engine hybridized with one electric motor using a summing gearbox, and two additional independent electric motors. Each of the three electric motors per aircraft side rated for 370 kW. The required net available fuel cell power is 1.2 MW_{el}. The fuel cells power sources are assumed installed in the fuselage belly fairing, and the partially redundant cryogenic hydrogen tank in the tailcone.

2.5 Miniliner Reference aircraft definition

The passenger version of the Cessna SkyCourier (Textron Aviation Inc., March 2022), shown in the pictures below, is selected as reference aircraft.

The Cessna SkyCourier (Passenger Version) is a 19-seater aircraft with truss-braced high wing and T-tail, powered by 2 Pratt & Whitney Canada PT6A-65SC turboprop engines.

Table 4 – TLARs of the reference aircraft. Sources: (Textron Aviation Inc., March 2022) (Textron Aviation Inc., 2023) (Wikipedia, 2023) .

Reference Aircraft (State of the art)	
AIRCRAFT NAME	Cessna SkyCourier (Passenger version)
Fuel type	JP-8, JET A-1
Range [nm] (max) – typical	(920) – 386 (19 pax, long-range configuration, FL100, 100 nm IFR reserves)
# PAX (max) – typical	(19) – 19
MTOW [tons]	8.618
MLW [tons]	8.437
Max Payload [tons]	2.268
Full fuel Payload [tons]	0.780
MEW [tons]	5.591
MZFW [tons]	2.047
Maximum fuel weight [tons]	2.189
Cruise speed [Mach]	M = 0.35 (210 ktas @ 3048 m)
Longe range cruise speed (LRC) [Mach]	M = 0.26 (164 ktas @ 3048 m)
EIS date	May 2022 (cargo version) April 2023 (passenger version)
Airport Category	2B
Take-Off Field Length (@sea level, ISA conditions, MTOW)	1116 m
Approach speed [kts]	96 kcas (assumed 30% higher than stall speed with flaps deployed in approach configuration = 74 kcas)
Time to climb [min to FL250]	Not available
Reference Powerplant	2x Pratt & Whitney Canada PT6A-65SC
Power installed	2x 827 kW
Max Operating Altitude	7620 m
Landing Distance	917 m
Fuselage length	16.80 m
Wingspan	22.02 m
Seating configuration	

Two Pratt & Whitney Canada PT6A-65SC turboprop engines, fueled by JET A-1, are installed in the Cessna SkyCourier. The 14 CFR Part 34 Fuel Venting and Exhaust Emission Standards, as amended by Amendments 34-1 through 34-5A, have been used for the emissions assessment for certification (Textron Aviation Inc., March 2022). The data for this engine is not publicly available in the ICAO Aircraft Engine Emissions Databank (EASA, 2023). For this reason, the average Emission Index values reported by Lee et al. (Lee, 2010) for gas turbine engines are considered. The following expression is used to compute the emissions in the table below:

$$X_x\left[\frac{\frac{kg}{pax}}{nm}\right]=\frac{EI_{X_x}\cdot m_{fuel}}{\#Pax\ \cdot Range}$$

Table 5 – Emissions of reference aircraft. Sources: (Aviation Week & Space Technology, 2008)

Title	Value	Comments
SFC [kg/N*h]	Not publicly available	0.326 kg/kW*h is sfc from P&W Canada PT6A-65B[3] for maximum power takeoff (Aviation Week & Space Technology, 2008) Based on an assumption of 60% propulsive efficiency during takeoff, and a takeoff speed of 100 knots, a tsfc (thrust-specific fuel consumption) of 0.028 kg/(Nh) is estimated.
CO_2 [kg/pax/nm]	0.727	19 pax, long-range configuration, FL100, 100 nm IFR reserves – 386 nm range $MTOW - Payload\ @\ 386\ nm^4\ (1724\ kg) - MEW = 1303\ kg$ Subtracting reserve fuel for 100 nm is roughly $1303\ kg \cdot \frac{386\ nm}{386\ nm + 100\ nm} = 1035$ kg. This is used as fuel weight for the reference mission. EI=3.16 kg CO2/kg fuel
NOx [kg/pax/nm]	3.2E-3	Same mission as above. EI=0.014 kg NOx/kg fuel
H2O [kg/pax/nm]	0.285	Same mission as above. EI=1.24 kg H2O/kg fuel
NvPM [kg/pax/nm]	5.75E-5	Same mission as above. EI=2.5E-5 kg soot/kg fuel
SO2 [kg/pax/nm]	1.84E-3	Same mission as above. EI=8E-4 kg SO2/kg fuel
Contrails[5]	Quantification is very uncertain.	

The noise standard 14 CFR Part 36, amended by Amendments 36-1 through 36-31, has been used for the noise assessment of the reference aircraft (Textron Aviation Inc., March 2022). The noise assessment of the reference aircraft is not publicly available.

To define the reference acoustic emissions, due to the lack of public data on the Cessna SkyCourier noise assessment, the results from UNIFIER19 D3.3 (UNIFIER19, September 2022) on the acoustic emission assessment of a conventional twin-prop aircraft are used. The described configuration is similar to the

[3] Data for PT6A-65SC not available, considered PT6A-65B as closest.
[4] From payload-range diagram, around 3,800 lb = 1724 kg payload for 386 nm range. 19 passengers indicated, but assumed that 19 passengers do not lead to maximum payload.
[5] Field not mandatory since contrails are dependent on the actual altitude flown and the specific atmospheric conditions. Today, there is no metric at single mission level that allows the assessment of contrails without the corresponding atmospheric model (and assumptions about latitude and season).

Cessna SkyCourier, and TLARs are in line with the concept aircraft, hence serving as reference for Impact Monitoring purposes. These results are presented in Figure 1.

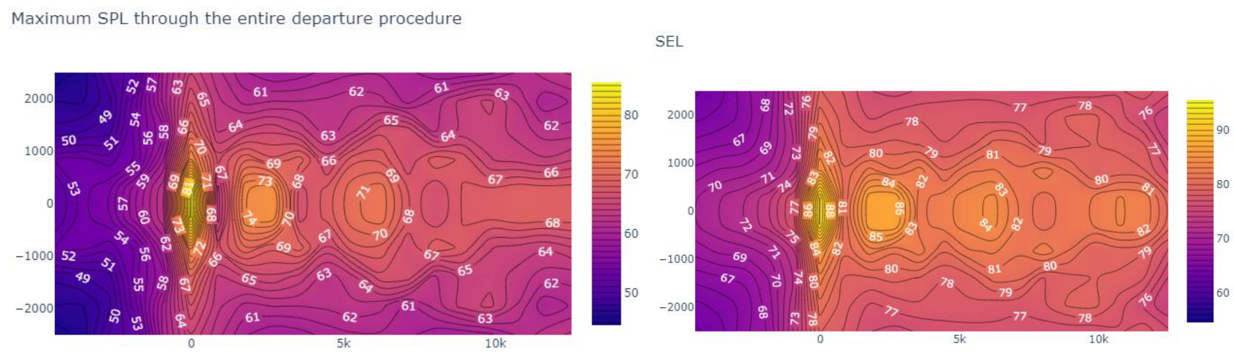

Figure 1: Left: Maximum Sound Pressure Levels [dB] for reference aircraft (UNI19-CO) on the ground through the entire departure procedure. Right: Sound Exposure Levels on the ground for the entire departure procedure for conventional twin turbo-prop aircraft. Source: UNIFIER19 D3.3 (UNIFIER19, September 2022).

2.6 Miniliner Typical Mission for Impact Monitoring

The reference mission of the Cessna SkyCourier (Passenger version) for Impact Monitoring purposes is taken as the UNIFIER19 mission, as recommended by CAJU. It consists of 5 hops of 350 km range, flying at FL40 **with 8 passengers** at 150kts, with 100 km IFR reserve and 45min of loitering. **The number of passengers was reduced as SkyCourier cannot perform the required 5 hops with IFR reserve with full payload and keep the MTOM below 8618kg limit.**

The UNIFIER19 mission is shown in Figure 2.

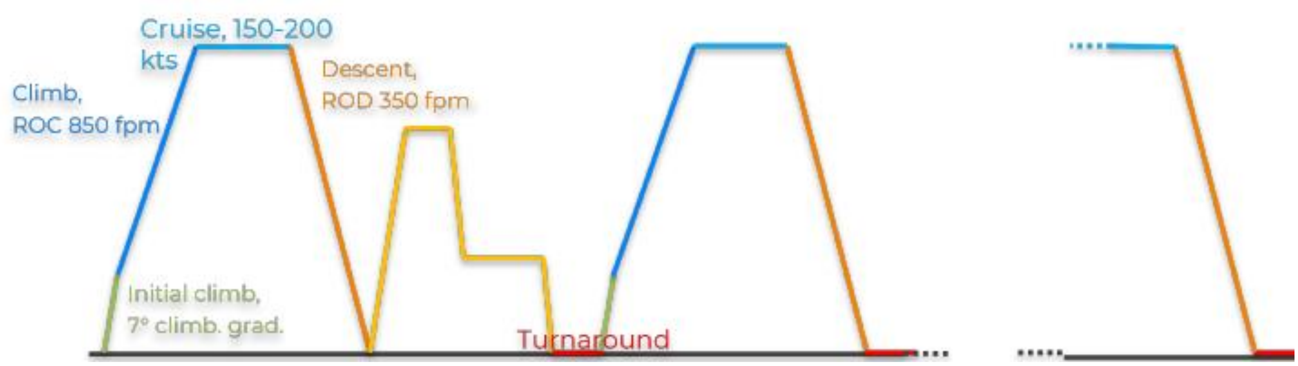

Figure 2: 5-hop mission profile of the Pipistrel Miniliner. Source: UNIFIER19 project.

2.7 Miniliner Aircraft Concept

2.7.1 Miniliner Aircraft concept definition

The Miniliner concept originally defined in the UNIFIER19 project was used as the initial aircraft concept for the NEWBORN project. This concept was further extended and improved during the NEWBORN project execution, to integrate more accurately the fuel cell systems, cryogenic tank, and propulsion.

The original concept is depicted in Figure 3, wherein its evolution throughout the project is depicted in Figure 4 and Figure 5.

The first concept represents solution with assumed better performance, while the second concept represents solution with lower technical risk and with sooner entry into service.

Figure 3: Pipistrel Miniliner concept. This concept is illustrative; high-level aircraft concept definition can change with future developments and studies.

Figure 4: Alternative concept of the Pipistrel Miniliner developed throughout the NEWBORN project

Figure 5: Frontal view – Alternative concept of the Pipistrel Miniliner developed throughout the NEWBORN project

The TLARs for the passenger version are presented in the tables below, as reference.

Table 6 – TLARs of the concept aircraft. Source: UNIFIER19 project (UNIFIER19, September 2022) (Trainelli, et al., 2020).

CONCEPT NAME	Miniliner-UNIFIER19– 5 hops version
TLARs	
Fuel type(s) (Jet-A1, SAF, Elec., H2)	Liquid hydrogen
Design Range [nm] (max - ferry) - typical	(1566 nm max/ferry) – 189 nm per hop – 945 nm in 5 hops with 19 passengers
# PAX (max) - typical	(19) – 19
Max Payload [tons]	2.280[6]
Cruise speed [Mach]	0.23 (150 kt @ 4000 ft)
Take-Off Field Length (@sea level, ISA conditions, MTOW)	800 m
Approach speed [Kts]	~88 kcas (assumed ~30% higher than stall speed with flaps deployed in approach configuration = ~68 kt) Stall speed with flaps retracted at design weight = 92 kt
Time to climb [min to FL80]	4.7 min (ROC = 850 ft/min to FL40)
Airport category	2B
MTOW	8618 kg
Fuel weight	324 kg
Tank weight	306 kg
MEW	5634 kg
MZFW	8014 kg
Max engine power	1.1 MW
Fuselage length	17 m
Seating configuration	1-2
Wingspan	20 m

[6] 100 kg per pax + carry-on baggage; 20 kg per checked luggage; 19 passengers. Assumptions from UNIFIER19 D3.3 [8]

Table 7 – Key subsystems of the concept aircraft. Source: UNIFIER19 project (Trainelli, et al., 2020) (UNIFIER19, September 2022).

Key Sub-Systems		
Sub-system	Description	CA project
Propulsion	LH2-fuelled fuel cell system connected to propellers providing main thrust. Considerations are being made on the use of a tail propeller. Two different open options for main propulsion layout – distributed electric propulsion and more traditional 2-propeller version.	NEWBORN, HyPoTraDe
Fuselage & Empennage	V1: Single aisle, 2x1 seats configuration, high-wing with DEP propellers, V-tail. V2: Single aisle, 2x1 seats configuration, low-wing with 2 propellers, T-tail.	N/A
Systems and H2 storage	Integral load-bearing liquid hydrogen tank.	fLHYing tank, H2ELIOS
Wing	Wing structure adapted to no fuel storage and installation of DEP propellers.	N/A
Transverse	Single Pilot Operations	DARWIN (SESAR3)

Operational assumptions:
- Regulation allows the use of small airfields for commercial operations.
- Perform several mission hops without refueling.
  - Refueling of the aircraft at hub airports, which are expected to have LH2 refueling infrastructure available.
  - No refueling of the aircraft at small airfields, assuming LH2 refueling infrastructure will not be available.
- Continuous operation of the aircraft during day and night.
  - 45 min turnaround time.
  - Aircraft used for cargo operations during the night (no overnight storage in hangar[7]).

[7] This assumption related to the CONOPS is expected to allow for a potential relaxation of the requirement of 24h dormancy time, which arises from storage of the aircraft in a closed hangar overnight with no active ventilation.

2.7.2 Miniliner Aircraft-level key performance metrics

Table 8 – Environmental KPIs of concept aircraft. Sources: UNIFIER19 project (Trainelli, et al., 2020) (UNIFIER19, September 2022) + (Gierens, 2021)

Environmental KPIs @ A/C level					
Title	**Target**	**SoA (SkyCourier)**	**Status**	**% vs reference**	**Comments**
GHG emission reduction	100%	0%	100%	-100%	Assuming no climate impact from water vapor or contrails due to low cruise altitude and no nvPM.
CO_2 [kg/pax/nm]	0.0	0.727	0.0	-100%	No carbon dioxide from use of hydrogen.
NOx [kg/pax/nm]	0.0	3.2E-3	0.0	-100%	No NOx from use of fuel cells.
H2O [kg/pax/nm]	0.162	0.285	0.162	-7%	$EI_{H2} = 9.0\ \frac{kgH2O}{kgH2}$ $EI_{JetA} = 1.237\ \frac{kg\ H2O}{kgJet\ A}$.
NvPM [kg/pax/nm]	0.0	5.75E-5	0.0	-100%	No NvPM from use of hydrogen. Obtained from EI of NvPM for reference system. No data on mass and number available.
SO2 [kg/pax/nm]	0.0	1.84E-3	0.0	-100%	No SO2 from use of hydrogen.
Contrails	Quantification is very uncertain.				Climate impact with hydrogen and fuel cells expected to be lower than jet engines[8]

The estimates herein are valid for the Miniliner in a private configuration, certified with the 2x2 system configuration. For commercial version used for "ticketed" air transport flights, the change of the fuel cell system architecture from 2x2 to 4x1 configuration is necessary, based on the feedback from EASA.

[8] For detailed explanation, the authors suggest the reader refers to state-of-the-art scientific literature (e.g., Gierens [12]). State-of-the-art literature is still mainly qualitative, or quantitative with very high uncertainty range. Hence, only a qualitative indication is provided.

Table 9 shows an updated environmental KPI, based on the latest evolution of Miniliner, during the NEWBORN project, including the 4x1 fuel cell system architecture. Please note that the reference data for the Skycourier has also been updated to reflect the newly available long-range cruise speed information (164 KTAS@FL100) and range (483NM), obtained in 2024.

Table 9 – Environmental KPIs of an updated version of the concept aircraft during the NEWBORN project. Sources: UNIFIER19 project (Trainelli, et al., 2020) (UNIFIER19, September 2022) + (Gierens, 2021)

Environmental KPIs @ A/C level					
Title	**Target**	**SoA (SkyCourier)**	**Status**	**% vs reference**	**Comments**
GHG emission reduction	100%	0%	100%	-100%	Assuming no climate impact from water vapor or contrails due to low cruise altitude and no nvPM.
CO_2 [kg/pax/nm]	0.0	0.292	0.0	-100%	No carbon dioxide from use of hydrogen.
NOx [kg/pax/nm]	0.0	1.3E-3	0.0	-100%	No NOx from use of fuel cells.
H2O [kg/pax/nm]	0.114	0.114	0.116	+2%	$EI_{H2} = 9.0 \frac{kgH2O}{kgH2}$ $EI_{JetA} = 1.237 \frac{kg\ H2O}{kgJet\ A}$.
NvPM [kg/pax/nm]	0.0	2.3E-6	0.0	-100%	No NvPM from use of hydrogen. Obtained from EI of NvPM for reference system. No data on mass and number available.
SO2 [kg/pax/nm]	0.0	7.4E-5	0.0	-100%	No SO2 from use of hydrogen.
Contrails	Quantification is very uncertain.				Climate impact with hydrogen and fuel cells expected to be lower than jet engines[9]

[9] For detailed explanation, the authors suggest the reader refers to state-of-the-art scientific literature (e.g., Gierens [12]). State-of-the-art literature is still mainly qualitative, or quantitative with very high uncertainty range. Hence, only a qualitative indication is provided.

Table 10 – Energy consumption of concept aircraft. Source: Own elaboration (PVS).

Energy Consumption @ A/C level					
Title	**Target**	**SoA (SkyCourier)**	**Status**	**% vs ref**	**Comments**
Kerosene/SAF consumption [kg/pax/nm]	0 kg/pax/nm	0.23 kg/pax/nm	0 kg/pax/nm	-100%	No kerosene.
Hydrogen consumption [kg/pax/nm]	0.018 kg H2/pax/nm 270-300 kg LH2	-	0.018 kg H2/pax/nm 310 kg LH2	N/A	
Battery energy consumption [Wh/pax/nm]	480-560 kg battery 250 Wh/kg, depleted to 30% 84-98 kWh	-	542 kg 230 Wh/kg 125 kWh	N/A	Battery is sized for power, not for energy.
Total Energy Consumption [Wh/pax/nm]	10,000 kWh for 19 pax, 865 nm 608 Wh/pax/nm	18,570 kWh for 8 pax, 865 nm 2,684 Wh/pax/nm	10,355 kWh 630 Wh/pax/nm	~36%	Difference in energy consumption mainly attributed to difference in flight speed.

Table 10 compares the performance of Miniliner in a private configuration, certified with the 2x2 fuel cell system, with the reference aircraft flown on non-extended mission matching the performance of the Miniliner, i.e. carrying additional onboard fuel instead of some passengers.
The Table 11 below compares the Miniliner in a 4x1 fuel cell configuration, needed for regular "ticketed" air transport flights, operated at the mission equivalent to the nominal capability of the reference aircraft.

Table 11 – Energy consumption of an updated concept aircraft during the NEWBORN project. Source: Own elaboration (PVS).

Energy Consumption @ A/C level					
Title	**Target**	**SoA (SkyCourier)**	**Status**	**% vs ref**	**Comments**
Kerosene/SAF consumption [kg/pax/nm]	0 kg/pax/nm	0.092 kg/pax/nm	0 kg/pax/nm	-100%	No kerosene.
Hydrogen consumption [kg/pax/nm]	0.013 kg H2/pax/nm 117 kg LH2	-	0.013 kg H2/pax/nm 117 kg LH2	N/A	
Battery energy consumption [Wh/pax/nm]	480-560 kg battery	-	542 kg 230 Wh/kg 125 kWh	N/A	Battery is sized for power, not for energy.

	250 Wh/kg, depleted to 30% 84-98 kWh				
Total Energy Consumption [Wh/pax/nm]	3928 kWh for 19 pax, 483 nm 428 Wh/pax/nm	10160 kWh for 19 pax, 483 nm 1,107 Wh/pax/nm	428 Wh/pax/nm	39% of ref. A/C	-61% reduction in comparisson with ref. A/C, or 39% of ref. A/C.

Table 12 – Noise performance of concept aircraft. Source: UNIFIER19 project (UNIFIER19, September 2022)

Noise performance @ A/C level					
Title	**Target**	**SoA (SkyCourier)**	**Status**	**% vs reference**	**Comments**
Noise performance	See Figure 11	See Figure 1	-	-15 dB (SPL at ICAO noise assessment procedure point).	From UNIFIER19 D3.3 results (UNIFIER19, September 2022).

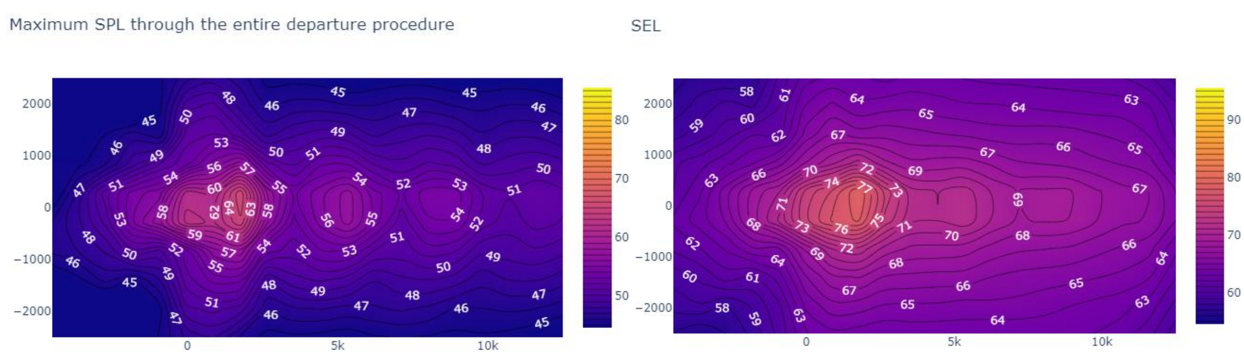

Figure 6: Left: Maximum Sound Pressure Levels [dB] for C7A-HARW aircraft on the ground through the entire departure procedure. Right: Sound Exposure Levels on the ground for the entire departure procedure for C7A-HARW aircraft. Source: UNIFIER19 D3.3 (UNIFIER19, September 2022).

TRL Level

Table 13 – TRL evolution of concept aircraft.

Technology Readiness Level (using definition in Annex B, section 4)					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2024-2025[10]	2024-2025[11]	2025-2026[12]	2028[13]
Year Achieved	2022[14]	2024	-	-	-

Additional metrics

Table 14 – Additional KPIs of concept aircraft (DEP version).

Additional KPIs / Other Quantified Performance Targets at project end and beyond					
Title	**Target**	**SoA (SkyCourier)**	**Status**	**% vs reference**	**Comments**
Industrial readiness	TRL9	TRL9	TRL2	N/A	TRL2 reached with UNIFIER19 project (UNIFIER19, September 2022)
Safety	DEP improves attitude control of the airplane during failure conditions. Battery recharging improves safety margin against sudden loss of power. Independent power provision lines improve powertrain reliability.				From UNIFIER19 D3.3 results (UNIFIER19, September 2022)
Reliability	DEP and independent power provision lines improve system reliability.				From UNIFIER19 D3.3 results (UNIFIER19, September 2022)

10 "Active R&D is initiated. Results of laboratory tests for critical subsystems." – Achieved with NEWBORN, H2ELIOS, fLHYIng tank, HyPoTraDe.
11 "Basic technological components are integrated." – Achieved with NEWBORN, H2ELIOS, fLHYIng tank, HyPoTraDe.
12 "High-fidelity laboratory integration of components." – Achieved with NEWBORN, H2ELIOS, fLHYIng tank, HyPoTraDe.
13 "Representative prototype tested in relevant environment".
14 "Publications that outline the application and that provide analysis to support the concept" – Developed under UNIFIER19 project (https://www.unifier19.eu/)

Cost effectiveness	€ 0.322 cost per available seat km	~€ 0.5 cost per available seat km	-	-8.5%	From UNIFIER19 D3.3 results (UNIFIER19, September 2022). Assuming Single Pilot Operations.
LCA	Refer to UNIFIER19 D3.3 results (UNIFIER19, September 2022).				From UNIFIER19 D3.3 results (UNIFIER19, September 2022)
Market acceptance	Potential 40,000 customers for Venice (VCE) airport.				From UNIFIER19 D1.2 results (Trainelli, et al., 2020)
Operability	Conversion of small airfields into transport nodes	Limited to commercial airports	-	50% EU airfields have >800 m runway.	From UNIFIER19 D1.2 results (Trainelli, et al., 2020)

Table 15 – Potential barriers to concept aircraft.

Potential Barriers
Reluctance of travelers to use a novel means of transport substituting road and rail transport. Lack of liquid hydrogen refueling infrastructure in major hubs. Liquid hydrogen cost non-competitive with kerosene cost by EIS date.

2.8 FC80pax Reference aircraft definition

The reference aircraft is identical to the reference aircraft for the HERA UCA described in section 2.2 and will be described by the HERA project, i.e. ATR72.

2.9 FC80pax Typical Mission for Impact Monitoring

The typical mission is very similar of identical to the HERA UCA mission in section 2.3. For the detailed analyses internal to the project, the following mission was however assumed.

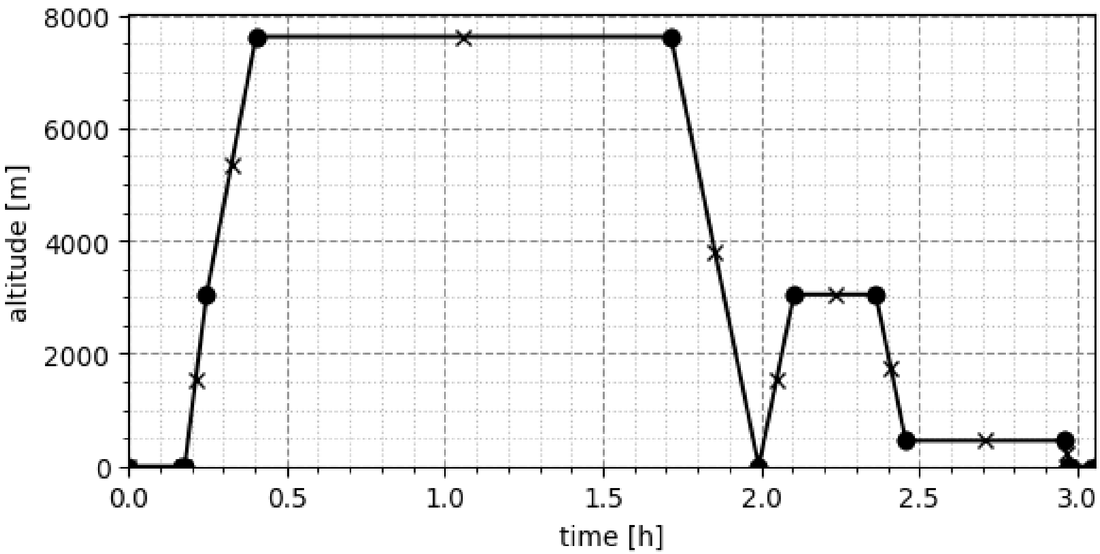

Figure 7: Assumed mission of the Fuel cell fully electric 80-pax aircraft

The details of the mission are then included in

Table 16 below.

Table 16 - Detailed mission information of the assumed Fuel cell fully electric 80-pax aircraft

Segment	Rate of climb (ft/min)	Initial altitude (ft)	Final altitude (ft)	Speed (kCAS)
Take-off	/	0	0	0.0
Fast climb	2400	0	10000	140.0
Slow climb	1600	10000	25000	140.0
Cruise	/	25000	25000	205.0
Descent	1500	25000	0	200.0

2.10 FC80pax Aircraft Concept

The concept of the regional 80-seater aircraft with mission very similar or equivalent to the mission defined by the HERA aircraft, requiring approximately 8.0 MW of total take-off shaft power, assumed delivered by 4 propulsors, is provided herein. It is shown primarily as an example of the propulsion system technology scalability to high power levels; the aim is to demonstrate **performance** feasibility of such aircraft, focusing on the aspects of flight performance, systems installation, and safety. Detailed concept study of such aircraft is out of scope of the NEWBORN project - some aspects that are expected lacking given the state-of-the-art, are mainly the system maintenance requirements and related commercial feasibility of such aircraft, resulting from massive deployment of new technologies. This aircraft concept can be seen as an entry point to the fully hydrogen-electric (low/no-GWP) large air transport.

Main characteristics:

- Short range regional aircraft with nominally 80 passengers powered by four fuel cell / battery hybrid propulsion systems fed from partially redundant LH2 storage
- Take-off distance of 1315 m
- Operating ceiling of FL250, typical cruise altitude FL200

2.10.1 FC80pax Aircraft concept definition

Concept Aircraft - Fuel cell fully-electric 80-passenger regional aircraft	
CONCEPT NAME	FC80pax
TLARs	
Fuel type(s) (Jet-A1, SAF, Elec., H2)	Liquid hydrogen
Propulsor configuration	4 fully electric propulsion systems (4x2 MW_{peak})
Powertrain configuration	Fuel cell + battery hybrid; 4 independent fuel cell power sources
Maximum fuel cell power	7.2 MW desired, 7 MW acceptable
Battery power	1.9 MW (emergency use)
Typical takeoff power	7.8 MW
Typical cruise power	5.4 MW
Design Range [nm] (max) - typical	500
# PAX (max) - typical	80
Max Payload [tons]	8.0
Cruise speed [Mach]	0.50 (205 KCAS@25000ft)
Take-Off Field Length (@sea level, ISA conditions, MTOW)	1315 m
Approach speed [Kts]	Final approach speed: 125 KCAS, stall speed in landing configuration: 92 KCAS
Operating altitude ceiling	FL250
Typical cruise altitude	FL200
Time to climb	est. 15 min to FL250
Airport category	3C
MTOW	39843 kg
Fuel weight	845 kg
Tank weight	1389 kg
MEW	est. 30600 kg

It should be noted that the baseline component assumptions have evolved during the NEWBORN project, reflecting the progression of technical understanding. A more realistic Gravimetric Index (GI) for the LH_2 tank, based on existing market solutions, has been incorporated. Additionally, battery power requirements and FC requirements have been revised downward, resulting in reduced battery weight. While these updates have led to a slightly heavier aircraft overall, the assumptions now better reflect the current state-of-the-art technologies and practical feasibility.

- Further data provided in
  - [2] NEWBORN D1.1 rev 02, Aircraft-level requirements summary
  - [3] NEWBORN D1.2 rev 00, Regional and Commuter aircraft integration concepts description

Key subsystems and their characteristics contributing to the A/C concept and under which CA project these are developed:

Key Sub-Systems		
Sub-system	Description	CA project
Propulsion	Fully electric, scalable to multi-MW levels	NEWBORN, CS2
Fuel cell power sources	Fuel cell power source, scalable to achieve 8 MW at aircraft level, split between 4 independent propulsion buses. The aircraft concept assumed 1.2 kW/kg power density of the fuel cell propulsion system including its thermal management.	NEWBORN, HyPoTraDe
Batteries	Battery system scalable to provide ~3.5 MW at aircraft level, split between 4 power buses.	NEWBORN, HyPoTraDe
Aircraft DC power distribution network	3 voltage and power levels: HVDC propulsion bus, secondary power bus, and 28V bus	HECATE, NEWBORN
Fuselage & Empennage	Aircraft fuselage and empennage: depending on the detailed aircraft configuration, either 30.65 (fuel cell systems located in the belly fairing and in the center section of the cargo) or 34.2m (aft-located fuel cell systems, more cargo space). 5 abreast. Assuming 3.73 m fuselage width and 3.45 m fuselage height.	N/A
Wing	Matching wing, assuming 35.24 wingspan	Possibly HERWINGT (NEWBORN consortium is now aware about details of the HERWINGT project)
Systems and H2 storage	Conformal, high gravimetric index liquid hydrogen cryogenic tank with redundancy. The aircraft concept assumes a gravimetric index of ~0.378 at this stage, but trades with respect to other systems' weight is of course possible.	H2ELIOS, NEWBORN Cryogenic tank optimized for redundancy not included in Phase 1 CA projects and is herein proposed for Phase 2
Transverse	Certification aspects and new approaches to certification	H2ELIOS, NEWBORN, HECATE, HERA, CONCERTO

It needs to be stressed that this concept doesn't define one specific and unique aircraft configuration, but a set of 4 configurations with very similar performance, based on the analyses. The main difference lies in the location of the fuel cell power sources – either located next to the cryogenic tank near the empennage or distributed below the floor. The main difference is in the available cargo space and length of the fuselage.

The second difference lies in the location of the batteries, wherein they can be either distributed below the floor to counterbalance the change in the center of gravity or located in the aircraft wing.

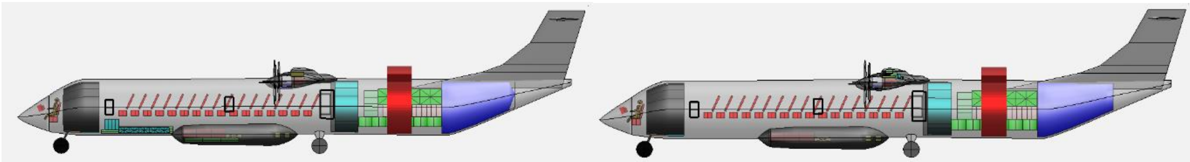

Figure 8: Conceptual fuel cell full-electric regional aircraft with fuel cell integrated near the tailcone

Left: concept with batteries distributed below the floor. Right: concept with batteries in wings.

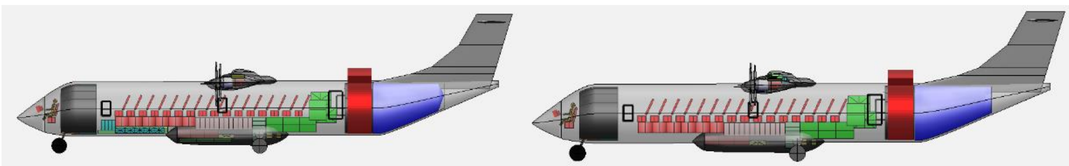

Figure 9: Conceptual fuel cell full-electric regional aircraft with fuel cell integrated below the floor

Left: concept with batteries distributed below the floor. Right: concept with batteries in wings.

The estimated MTOW is then between 47 t and 48.6 t, depending on the configuration.

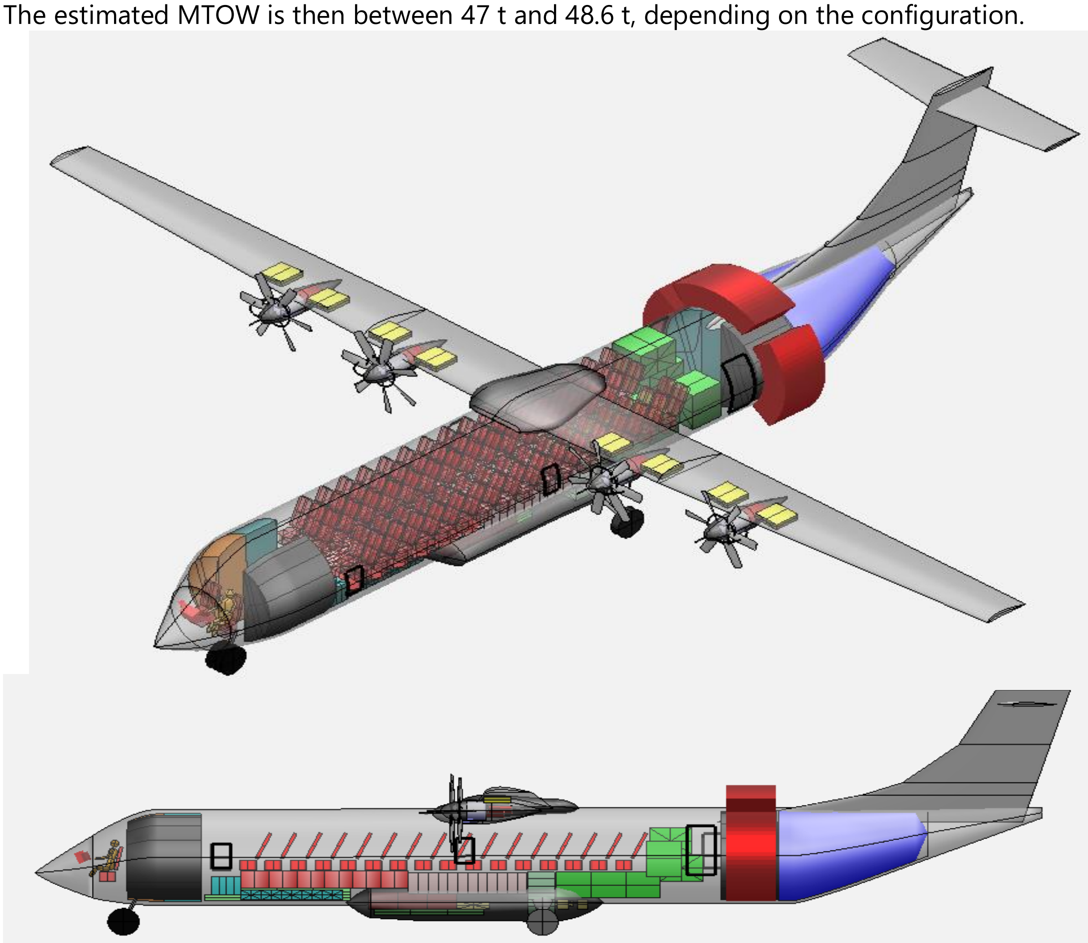

Figure 10: Conceptual fuel cell fully electric 80-pax regional aircraft

For better alignment with the HERA project assumptions, we below list the KPIs for the shorter configuration with the batteries below the floor.

Table 17 - Assumed power profiles of the fuel cell fully electric regional aircraft (per propulsor)

	Time [mm:ss]	Shaft power (per propulsor) [kW]
Taxi out	10:00	225
Take-off	00:40	1992
Fast climb	04:10	1973
Slow climb	09:22	1637
Cruise	78:42	1357
Descent	16:40	242
Diversion climb	06:40	1453
Diversion cruise	15:32	1095
Diversion descent	05:40	0
Loiter	30:00	599
Descent	01:00	64
Taxi in	05:00	225

2.10.2 FC80pax Aircraft level key performance metrics

Environmental and performance KPIs

Define the different metrics linked to Clean Aviation program objectives that will be monitored as part of the Impact Monitoring assessment.

Environnemental KPIs @ A/C level					
Title	**Target**	**SoA**	**Status**	**% vs reference**	**Comments**
GHG emission reduction excl. contrails	100%	-	100%	100%	
CO_2 [kg/pax/nm]	0	0.142	0	-100%	Fully powered by LH2 fuel cells [11] 3.08 g CO_2 from 1g of kerosene
NOx [kg/pax/nm]	0	0.55×10^{-3} - 0.78×10^{-3}	0	-100%	From source [15]
H2O [kg/pax/nm]	0.171	0.066	0.171	259%	Each 2 protons of H_2 combine with one O^+ ➔ H2 consumption *9 [11] 1.24 g H_2O from 1g of kerosene
NvPM [mass & number]	0	0.46×10^{-6} – 2.30×10^{-6}	0	-100%	From source [15]
SO2 [kg/pax/nm]	0	6×10^{-3} max	0	-100%	ASTM4294 defines maximum sulfur content is 0.3% wt. Real sulfur content is likely lower.
Contrails	Unable to quantify at this stage				

Energy Consumption @ A/C level					
Title	**Target**	**SoA**	**Status**	**% vs reference**	**Comments**
Kerosene/SAF consumption [kg/pax/nm]	0	0.046 (recalculation for 80pax)	0	-100%	ATR 72 kerosene consumption of 0.040 kg/pax/NM
Hydrogen consumption [kg/pax/nm]	0.019 (0.023)	0	0.019 (0.023)	+100 %	0.019 is the net consumption; 0.023 is the consumption including the volume of unused emergency fuel reserve considered wasted.
Battery energy consumption [Wh/pax/nm]	0	0	0	N/A	The onboard batteries are assumed to be recharged during the descend phase of the flight
Total Energy Consumption [Wh/pax/nm] or [MJ/pax/nm]	2.4 MJ/pax/nm	1.97 MJ/pax/nm	2.4 MJ/pax/nm	+22%	Note: the fuel cell aircraft calculations currently use non-optimal thermal management system with significant additional drag, improvements are subject to the project scope

Noise performance @ A/C level					
Title	**Target**	**SoA**	**Status**	**% vs reference**	**Comments**
Noise performance	See Figure 11	See Figure 11.	N/A, out of scope of the project	-15 dB (SPL at ICAO noise assessment procedure point).	Note: data based on a CS-23 platform, assumed to have a similar overall dB reduction on CS-25 for propeller driven aircraft. From UNIFIER19 D3.3 results [12]. Ratio (-15 dB) assumed agnostic to the aircraft type

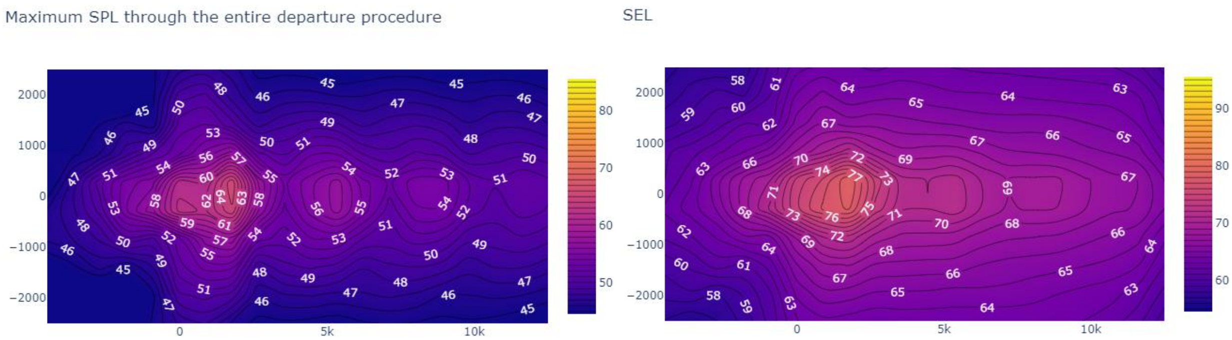

Figure 11: Left: Maximum Sound Pressure Levels [dB] for C7A-HARW aircraft on the ground through the entire departure procedure. Right: Sound Exposure Levels on the ground for the entire departure procedure for C7A-HARW aircraft. Source: UNIFIER19 D3.3 [12].

TRL Level

The development of the fully electric fuel cell regional aircraft is currently not considered pursued within the Clean Aviation project. The concept is currently based on high-level feasibility simulations and therefore at TRL2-3.

Additional metrics

Additional KPIs / Other Quantified Performance Targets at project end and beyond					
Title	**Target**	**SoA**	**Status**	**% vs reference**	**Comments**
Industrial readiness timeframe	2035+	N/A	N/A – out of project scope	N/A	The aircraft industrial readiness heavily depends on the prior operational experience and certification readiness. We strongly believe the commercial CS-23 deployment is needed before entry into practice.

Potential Barriers
Certification aspects, manufacturing readiness of the aircraft fuselage and the wing, operators' acceptance of the technology

3 SUB-SYSTEM LEVEL

The project NEWBORN develops and integrates several subsystems which together form the fuel cell propulsion system. To maintain consistency with the aircraft-level impact monitoring assessment, these are reported here separately.

Table 18 below defines the applicability of the technologies developed in the project to the aircraft concepts introduced.

Table 19 then defines the mapping of the grant agreement definition of subsystems and the aircraft view of the subsystems.

Table 18 - Applicability summary of the subsystems to different aircraft concepts

Subsystem **Aircraft concept**	Fuel Cell Power Source Subsystem	Battery Subsystem	Propulsion Subsystem	LH2 Storage and Distribution Subsystem
HERA-UCA	Either same as UCB or N/A, depending on HERA/REG pillar decision	Either same as UCB or new requirements needed for UER	Either SS 3a, or N/A	SS 4a
HERA-UCB	SS 1a	SS 2a	N/A	SS 4a
Miniliner	SS 1b	SS 2b	SS 3b	SS 4b
FC 80Pax	SS 1c	SS 2c	SS 3c	SS 4c
Project demonstrator	Matches: 150% power of SS 1b ** 50% power of SS 1a	Matches 70% of total battery capacity needed for SS 2b (both sides of aircraft) in terms of power and capacity	Matches SS 3b	Planned backup solution for integrated demonstrator, system developed Matches SS 4b

* SS = Subsystem concepts in the chapters below in this section

** The fuel cell power source subsystem demonstrates higher power than needed for the Miniliner for two main reasons: a) Alignment with the scaling concept to HERA, demonstrating better alignment b) preparation for early flight trials on CS-23 platform with worse aerodynamic performance than the conceptual Miniliner.

Table 19 - Mapping of the aircraft & impact monitoring subsystems to the project grant agreement definition of the subsystems

Project subsystem / work package **Aircraft subsystem**	Hydrogen line	Air line	Stack and recirculation	Thermal management	Control	Electric power and propulsion
Fuel cell power source	◑	●	●	●	●	◑
Battery	◌	◌	◌	●	●	◑
Electric propulsion	◌	◌	◌	●	◑	●
Liquid hydrogen storage	●	◌	◌	◑	●	◌

● denotes the aircraft subsystem aspect is primarily covered by the project subsystem / work package

◑ denotes the respective project subsystem / work package covers aspects of the aircraft subsystem, without being its main focus

◌ denotes there is a limited or no relation between the project subsystem / work package and the aircraft subsystem

3.1 Reference sub-systems definition

Reference Sub-system (State of the art) – Flying fuel cell power sources based on automotive fuel cell systems, adapted for low-altitude flight demonstrations, such as demonstrators using PowerCell S3 automotive stack technology or Ballard Power FCgen-HPS stacks with custom-built balance of plants. Examples: ZeroAvia or Universal Hydrogen demonstrators.	
Key characteristics	Value or description
General fit for purpose	Only demonstrators using various automotive fuel cell stack and BoP technologies
Ceiling altitude	Varies, but generally very low (<10k ft)
Stack specific power	Varies, but between 2.3 – 4.7 kW/kg on ground, non-aerospace designs
System specific power	~0.5 kW/kg
System efficiency at ground altitude	Varies, ~45%
Maximum operating altitude	Approximately 5000 ft with significant performance and life degradation
System output voltage	Varies
System lifetime	Significant immediate degradation at target altitude
Power scalability	Blocks by ~100 kW power, not realistically scalable beyond approximately 1 MW.
Installation environment	Controlled temperature and pressure
Maximum coolant temperature	80 °C

Rationale for the selection of the reference sub-system: Multiple demonstrators so far have been built with fuel cell systems based on traditional automotive stacks. The values are estimated based on publicly available data.

Reference Sub-system (State of the art) - Battery (Pipistrel Velis Electro reference)	
Key characteristics	Value or description
Battery pack energy density	161 Wh/kg
Battery pack power density	0.56 kW/kg
Volumetric energy density	206 Wh/l
Nominal voltage	Variable output voltage, nominal 345 V
Maximum charge / discharge C rates	Max charge: 40A (~ 1.21C rate) Max discharge: 120A (3.64C rate)

Rationale for the selection of the reference sub-system: The only certified air-worthy system available.

Reference Sub-system (State of the art) - Electric propulsion (MagniX magni 650 EPU, equipped on Eviation Alice. The system includes a direct drive electric motor and inverters.)	
Key characteristics	Value or description
Propeller speed	1200-1300 RPM
Maximum peak (take off) power	640 kW
Maximum continuous power	560 kW
Maximum torque	3000 Nm
Voltage level	500-800 VDC
Mass	200 kg
Power density – integrated system (incl. gearbox, thermal management, lubrication, ..)	2.8 kW/kg (est.)
Efficiency – motor	~95% depending on the operating point
Efficiency – inverter	~95% depending on the operating point
Scalability to MW levels	Questionable, likely not possible
Partial discharge immunity to HV at altitude	Undisclosed, assumed not solved

Rationale for the selection of the reference sub-system: This is the most powerful commercially available motor.

Reference Sub-system (State of the art) - Liquid hydrogen storage SAG LH2 Tank solution developed for heavy-duty road transport applications	
Key characteristics	Value or description
Gravimetric Index	*Weight of LH2 with respect LH2 storage function dedicated elements [%] (for a reference LH2 amount)* *SAG LH2 Tank: 9,1 % for 40 LH2 kg*
Tank Pressure conditions	Subcooled pressure refueling: 16 bar Boil-off pressure = max. operating pressure: 20 bar Min operation pressure: 5 bar
Boil-Off (venting)	*Typical rate of LH2 venting outside the tank [%/day]* *SAG LH2 Tank: 3%*
Dormancy with zero venting at mission end	*Time until it is needed to start venting with a 20% (TBC with OEMs) capacity [hours]* *SAG LH2 Tank: It is known at 50% level: 8 days*
LH2 flow	*Designed for GH2 supply of 0-7 g/s*

Rationale for the selection of the reference sub-system: There is no flight-worthy system existing. There are also other non-vacuum-insulated systems demonstrated, but with significant technological gaps.

3.2 Sub-system Concept 1a – Fuel cell power source – HERA-UCA & HERA-UCB

3.2.1 Sub-system concept definition

This subsystem represents the Fuel Cell Power Source developed in NEWBORN, upscaled for the power requirements of the HERA aircraft concepts.

The high-level description of the Sub-system Concept 1a:

- Altitude ceiling of FL250
- Integration in non-pressurized, non-climatized environment, except from specific elements (control system electronics, technology for adaptation to non-controlled environment is available at TRL9).
- Assuming fuselage installation
- Close integration with the other subsystems, especially liquid hydrogen tank and battery
- Minimum power level of 1200 kW_{el} net (available for the aircraft primary and secondary power use) as a SHALL requirement, 1300 kW_{el} as WOULD LIKE

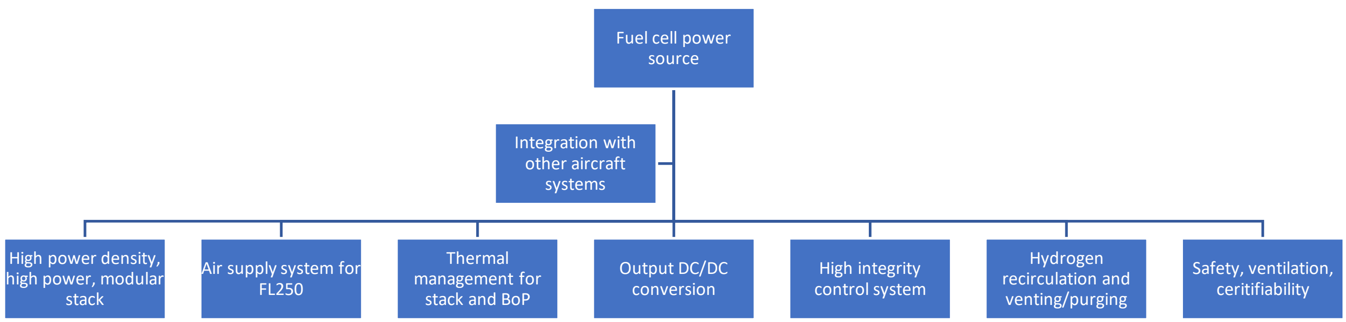

Figure 12: Composition of the fuel cell power source technology demonstrated in NEWBORN

The fuel cell power source (system from the NEWBORN project perspective, sub-system from the aircraft perspective) is composed of the elements depicted in Figure 12. The main components include:

- Modular & scalable stack system, composed of 300 kW (gross power) modules called substacks,
- Hydrogen recirculation and pressure control loops, venting, and purging,
- Air supply capable of providing sufficient flow-rate and pressure at FL250,
- Output (bus-tie) DC/DC converters, connected to common HVDC bus,
- High integrity control system,
- And provisions for ventilation, leak detection, and other equipment necessary to ensure safety and certifiability.

Sub-system Concept definition: Fuel cell power source – HERA-UCA & HERA-UCB	
Key characteristics	Value or description
High efficiency	>50% at system level, cruise
High power density	>1.2 kW/kg at level of the power source as shown I.e. 1000 kg for assumed power level of 1200 kW per aircraft side
Altitude ceiling	FL250
Maximum fuel cells operating temperature	>100 °C (coolant outlet temperature) Architecture readiness for high temperature PEM fuel cells
Output voltage	Stabilized output voltage compatible with HERA/HECATE concept, nominally 830 V DC.

3.2.2 Aircraft concept applicability

The decision on the possible realignment of the HERA UCA towards ultra-efficient regional aircraft is pending. Nevertheless, the system maintains alignment with the UCB of HERA. The TRL4 demonstrator subsystem developed in the project is applicable for the use case B with following modifications:

- Equivalent of 4 demonstrator systems installed in the aircraft, 2 on the left and 2 on the right side of the aircraft,
- Detailed re-optimization for the power use-case after clarifying the final aircraft platform requirements,
- Adaptation of the mechanical arrangement to the use case requirement,
- Replacement of multiple subcomponents where environmentally non-representative alternative is used by the airworthy components (product development and design, not technology development),
- Development of platform-optimal compressor (product development and design, known technology at TRL9 – no technology development),
- Integration with the dual-redundant cryogenic tank assumed necessary for the platform instead of single-lane
- Integration with the aircraft system (flight control platform, structures, interconnects, etc.)

3.2.3 Sub-system Level Key Performance Metrics

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	>50% in cruise	55.0% T/O 51.8% @ FL250	~45% on ground	+5 pp vs. target, +10 pp vs. SoA	The state of the art is not capable of operating at the defined altitude and therefore the state of the art could also be treated as having close to 0% efficiency. Value for ground efficiency is used for the reference. Assumes air compressors optimized for specific platform (product design, known technology)

Additional KPIs

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Power level [kW]	1300 per aircraft side	1440	Doesn't exist	110% of target	
Altitude ceiling	FL250	FL250	<FL100	100% of target	The systems publicly demonstrated so far don't have sufficient performance to operate at requested altitudes
Entry into service – CS-25 (HERA)	2035	2035	N/A	On target	Latest plans for EIS of HERA UCB have not been provided by HERA, the technology will be available for EIS in 2035
System power density [kW/kg]	>1.2	Est. 1.26 – 1.37	~0.5	105%-114% of target, >250% of SoA	1.26 kW/kg dry weight of the fuel cell power source system, including stacks, all BoP, mounting provisions, control, and thermal management excluding the radiators Estimate uses production components (i.e. not demonstration components) 1.37 kW/kg include incorporation of technologies developed in-kind in parallel of the NEWBORN project
Stack power density [kW/kg]	>5	3.75 – 6.64	<4.7	75-133% of target	Fuel cell stack (cell package): 6.64 kW/kg

					Core stack with balance of stack & enclosure flange: 4.85 kW/kg Stack module with housing and auxiliaries: 4 kW/kg (joint housing with multiple stacks)
System availability	>99% proposed. Targeting 1e-4 for the demonstrator.	1e-3 – 1e-4	>99%	On target	
System life	>20 000 hrs	>20 000 hrs	~2000 hrs	1000%	Note: The value of state of the art is an engineering judgement – best case estimate based on the extrapolation of existing technologies to aerospace conditions. The status estimate includes regular maintenance at >5000h intervals.

TRL Level

Technology Readiness Level – scalable fuel cell power source for HERA					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2025	2026	2027	2028
Year Achieved	2022	-	-	-	-

The TRL levels according to definition in Annex B, section 4.

Additional KPIs / Other Quantified Performance Targets at project end and beyond					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Safety – critical hazard probability	10^{-10}	10^{-10}	N/A	On target	To the best of our knowledge no SoA system meets this

Potential Barriers
Certifiability

3.3 Sub-system Concept 1b – Fuel cell power source – Miniliner

3.3.1 Sub-system concept definition

This subsystem represents the Fuel Cell Power Source developed in NEWBORN, **downscaled** for the power requirements of the Miniliner aircraft concept.

Note: The evolution in the 2nd project year, thanks to the detailed interaction with EASA, indicates that a change of the fuel cell power source configuration for this aircraft will benefit from the 4x1 arrangement of the fuel cell power sources, to increase the system availability for the intended use case of commercial small-size airliner. Two values are there therefore reported here, one for the 2x2 configuration sufficient for the general aviation 19-pax aircraft, and one for the 4x1 configuration of fuel cells for the commercial airline use.

The high-level description of the Sub-system Concept 1b:

- Altitude ceiling of FL250 as a SHOULD requirement, FL080 as a SHALL requirement
- Integration in non-pressurized, non-climatized environment, except from specific elements (control system electronics, technology for adaptation to non-controlled environment is available at TRL9).
- Fuselage integration
- 2x2 configuration: Minimum power level of 480 kW_{el} net (available for the aircraft primary and secondary power use)
- 4x1 configuration: Minimum power level of 240 kW_{el} net (available for the aircraft primary and secondary power use)

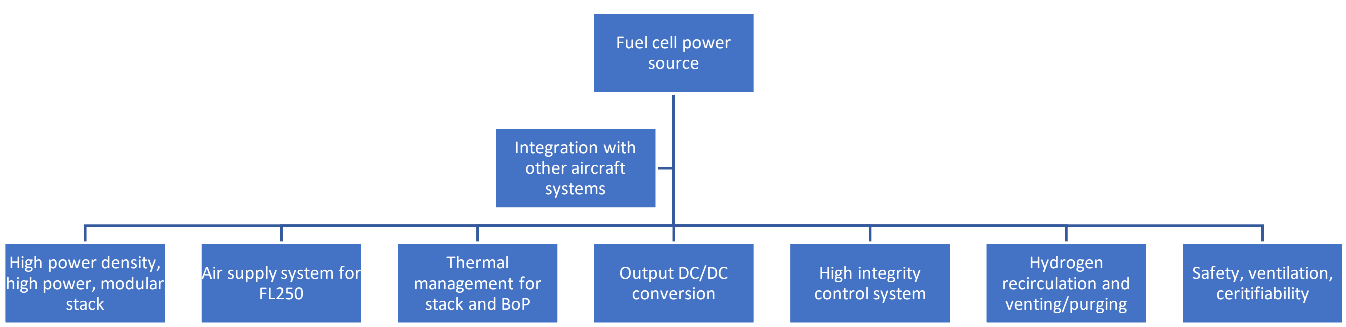

Figure 13: Composition of the fuel cell power source technology demonstrated in NEWBORN

The fuel cell power source (system from the NEWBORN project perspective, sub-system from the aircraft perspective) is composed of the elements depicted in Figure 13. The main components include:

- Modular & scalable stack, composed of 300 kW (gross power) modules called substacks,
- Hydrogen recirculation and pressure control loops, venting, and purging,
- Air supply capable to providing sufficient flow-rate and pressure at FL250,

- Output (bus-tie) DC/DC converters, connected to common HVDC bus,
- High integrity control system,
- And provisions for ventilation, leak detection, and other equipment necessary to ensure safety and certifiability.

Sub-system Concept definition: Fuel cell power source – Miniliner	
Key characteristics	Value or description
High efficiency	>50% at system level, cruise
High power density	>1.2 kW/kg at level of the power source as shown i.e. 400 kg for the assumed power level of 480 kW as a SHOULD requirement >0.92 kW/kg for the 4x1 configuration as the SHALL requirement
Altitude ceiling	FL250 as SHOULD, FL080 as SHALL
Maximum fuel cells operating temperature	>100 °C (coolant outlet temperature) Architecture readiness for high temperature PEM fuel cells
Output voltage	Stabilized output voltage, nominally 830 V DC.

3.3.2 Aircraft concept applicability

The TRL4 demonstrator subsystem developed in the project is applicable for the use case with following modifications:

- Down-scaled version of the system with 1 or 2 substacks per stack instead of 3; four or two systems per aircraft
- **Direct fit** to eventual retrofit CS-23 19-passenger platforms with lower fuselage performance than Miniliner concept
- **Optional** to reduce installation volume: Replacement of the air supply system machines by motorized turbo-compressor (known technology, product development),
- Detailed co-optimization with the aircraft platform design (product development),
- Adaptation of the mechanical arrangement to the use case requirement,
- Replacement of multiple subcomponents where environmentally non-representative alternative is used by the airworthy components (product development and design, not technology development),
- Integration with the aircraft system (flight control platform, structures, interconnects, etc.)

3.3.3 Sub-system Level Key Performance Metrics

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	>50% in cruise	54.2% T/O 52.9% cruise	~45%	+2.0 pp in cruise, + 4.2 pp during T/O +7.9-9.2 pp vs. SoA	The state of the art is not capable of operating at the defined altitude and therefore the state of the art could also be treated as having close to 0% efficiency. Value for ground efficiency is used for the reference. Assumes air compressors optimized for specific platform (product design, known technology)

Additional KPIs

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Power level	480 kW per aircraft side	>480 kW per aircraft side	N/A	On target	SoA values not available in matching power level
Altitude ceiling	FL180 SHOULD, FL080 SHALL	FL180, FL250 possible with added weight	<FL100	On target	The systems publicly demonstrated so far don't have sufficient performance to operate at requested altitudes
Entry into service – CS-23	2030	2030	N/A	On target	
System power density [kW/kg]	>1.2 for 2x2 >0.92 for 4x1	2x2: 1.2 kW/kg 4x1: 0.92 kW/kg	~0.5	On target, 184%-240% vs. ref	Weight of the fuel cell power source system, including stacks, all BoP, mounting provisions, control, and thermal management excluding the radiators

					The 4x1 configuration includes additional components for system redundancy. Estimate uses production components (i.e. not demonstration components)
Stack power density [kW/kg]	>5	3.75 – 6.64	<4.7	75%-133% of target	Fuel cell stack (cell package): 6.64 kW/kg Core stack with balance of stack & enclosure flange: 4.85 kW/kg Stack module with housing and auxiliaries: 3.75 kW/kg
System availability	>99% proposed. Targeting 1e-4 for the demonstrator.	1e-3 – 1e-4	>99%	On target	
System life	>20 000 hrs	>20 000 hrs	~2000 hrs	On target	Note: The value of state of the art is an engineering judgement – best case estimate based on the extrapolation of existing technologies to aerospace conditions. Assumes regular maintenance in >5000h intervals.

TRL Level

Technology Readiness Level – scalable fuel cell power source for Miniliner					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2025	2026	2027	2028
Year Achieved	2022	-	-	-	-

The TRL levels according to definition in Annex B, section 4.

Additional KPIs / Other Quantified Performance Targets at project end and beyond					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**

Safety – critical hazard probability	10^{-10}	10^{-10}	N/A	N/A	To the best of our knowledge no SoA system meets this

Potential Barriers
Certifiability

3.4 Sub-system Concept 1c – Fuel cell power source – FC80pax

3.4.1 Sub-system concept definition

This subsystem represents the Fuel Cell Power Source developed in NEWBORN, upscaled for the power requirements of the 80-passenger fully fuel-cell electric aircraft concept.

The high-level description of the Sub-system Concept 1c:

- Altitude ceiling of FL250
- Integration in non-pressurized, non-climatized environment, except from specific elements (control system electronics, technology for adaptation to non-controlled environment is available at TRL9).
- Assuming fuselage installation
- Close integration with the other subsystems, especially liquid hydrogen tank and battery
- Minimum power level of 2x3.6 MW_{el} net (available for the aircraft primary and secondary power use) as a SHALL requirement, 2x4 MW_{el} as SHOULD requirement

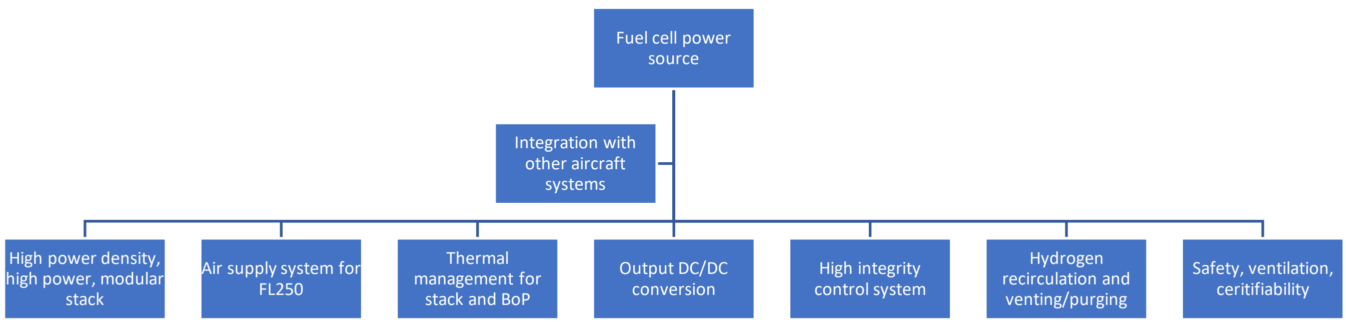

Figure 14: Composition of the fuel cell power source technology demonstrated in NEWBORN

The fuel cell power source (system from the NEWBORN project perspective, sub-system from the aircraft perspective) is composed of the elements depicted in Figure 14. The main components include:

- Modular & scalable stack system, composed of 300 kW (gross power) modules called substacks,
- Hydrogen recirculation and pressure control loops, venting, and purging,
- Air supply capable to providing sufficient flow-rate and pressure at FL250,
- Output (bus-tie) DC/DC converters, connected to common HVDC bus,
- High integrity control system,
- And provisions for ventilation, leak detection, and other equipment necessary to ensure safety and certifiability.

Sub-system Concept definition: Fuel cell power source – FC80pax	
Key characteristics	Value or description
High efficiency	>50% at system level, cruise
High power density	>1.2 kW/kg at level of the power source as shown I.e. 3333 kg for 4000 kW system per aircraft side
Altitude ceiling	FL250
Maximum fuel cells operating temperature	>100 °C (maximum outlet temperature) Architecture readiness for high temperature PEM fuel cells
Output voltage	Stabilized output voltage compatible with HERA/HECATE concept, nominally 830 V DC.

3.4.2 Aircraft concept applicability

The TRL4 demonstrator subsystem developed in the project is applicable for the use case with following modifications:

- Equivalent of 4 independent sets by 3 demonstrator systems installed in the aircraft, 2 sets on the left and 2 sets on the right side of the aircraft,
- Detailed re-optimization for the power use-case after clarifying the final aircraft platform requirements,
- Adaptation of the mechanical arrangement to the use case requirement,
- Replacement of multiple subcomponents where environmentally non-representative alternative is used by the airworthy components (product development and design, not technology development),
- Development of platform-optimal compressor set (product development and design, known technology at TRL9 – no technology development) including its upscaling to twice the mass flow,
- Integration with the dual-redundant cryogenic tank necessary for the platform instead of single-lane,
- Adaptation of the hydrogen evaporation control for 2 hydrogen supply lines connected to single tank side,
- Integration with the aircraft system (flight control platform, structures, interconnects, etc.),
- **Continued enhancement of the system reliability & reduction of maintenance requirements**
- **System simplification**

It should be noted that the proposed system for the FC80pax has been analyzed as flyable, providing sufficient performance and safety, but lacking in simplicity – the overall parallel number of units is considered too high for cost-efficient aircraft maintenance. It is nevertheless proposed herein as a possible steppingstone towards the fully fuel-cell electric regional aircraft, perhaps as a flying technology demonstrator.

3.4.3 Sub-system Level Key Performance Metrics

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	>50% in cruise	>50% both for take-off and cruise conditions	~45% on ground	+5 pp	The state of the art is not capable of operating at the defined altitude and therefore the state of the art could also be treated as having close to 0% efficiency. Value for ground efficiency is used for the reference. Assumes air compressors optimized for specific platform (product design, known technology)

Additional KPIs

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Power level [kW]	3600 - 4000 per aircraft side	4320	Doesn't exist	108%-120% of target	
Altitude ceiling	FL250	FL250	<FL100	On target	The systems publicly demonstrated so far don't have sufficient performance to operate at requested altitudes
Entry into service – CS-25 FC80pax	Est. 2045	Est. 2045	N/A	On target	
System power density [kW/kg]	>1.2	1.37	~0.5	114% of target, 274% of SoA	Dry weight of the fuel cell power source system, including stacks, all BoP, mounting provisions, control, and thermal management excluding the radiators Estimate uses production components (i.e. not

					demonstration components). The estimate includes incorporation of additional technologies developed in parallel as in-kind, outside of the NEWBORN project.
Stack power density [kW/kg]	>5	4-6.64	<4.7	80%-133% of target	Fuel cell stack (cell package): 6.64 kW/kg Core stack with balance of stack & enclosure flange: 4.85 kW/kg Stack module with housing and auxiliaries: ~4 kW/kg (joint housing with multiple stacks)
System availability per propulsion line (1 of 4)	>99% proposed. Targeting 1e-4 for the demonstrator.	1e-3 – 1e-4	>99%	On target	Availability of sufficient power. Current level of technology, however, will suffer in failure rate of many redundant systems and improvements of reliability are needed.
System life	>20 000 hrs	>20 000 hrs	~2000 hrs	On target	Note: The value of state of the art is an engineering judgement – best case estimate based on the extrapolation of existing technologies to aerospace conditions. Assumes regular maintenance in >5000h intervals.

TRL Level

Technology Readiness Level – scalable fuel cell power source for FC80pax					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2025	2026	Dependent on platform availability	Dependent on platform availability
Year Achieved	2022	-	-	-	-

The TRL levels according to definition in Annex B, section 4.

Additional KPIs / Other Quantified Performance Targets at project end and beyond					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**

Safety – critical hazard probability	10^{-10}	10^{-10}	N/A	On target	To the best of our knowledge no SoA system meets this

Potential Barriers
Certifiability

3.5 Sub-system Concept 2a – Battery – HERA

Some details of the high-level description of the battery system used for HERA-UCA & HERA-UCB (before the possible realignment of the HEA-UCA to UER concept) are shared with the NEWBORN. Unfortunately, not all data is known, and some specifications have been estimated based on provided data and literature of similar aircraft.

General information regarding battery pack design for NEWBORN:

- Altitude ceiling of FL250
- Modular and scalable battery system, from 21 kWh to over 1 MWh of capacity with selected type of battery cell
  - Design of battery modules is modular and scalable as well to enable different type of cells for an even more flexible design.
  - Modular design also allows adjustments to voltage, for example, to achieve >1kV pack (will not be tested for NEWBORN).
  - Significant improvement regarding safety as thermal runaway can be contained to only a small section of the battery pack instead of losing the entire battery pack.
  - Maintenance and replacement of modules is easier as each module is lighter compared to the entire battery pack. Modules can also be serviced individually.
- Improved thermal runaway protection thanks to unique thermal runaway containment design of casing for high energy/power battery cells.
- Significant efficiency boost in cooling capacity compared to SoA certified battery pack.

For the HERA aircraft the following information is estimated:

- The aircraft uses two battery packs; each pack capable of:
  - Providing power of at least 750 kW
  - Gross capacity estimated at 250 kWh
    - Estimated required usable energy: 180 kWh
    - Reserve capacity for SoH purposes: 20 kWh
    - Not usable due to insufficient power available: 50 kWh (20%)
  - Fast charging at 4C

3.5.1 Sub-system concept definition

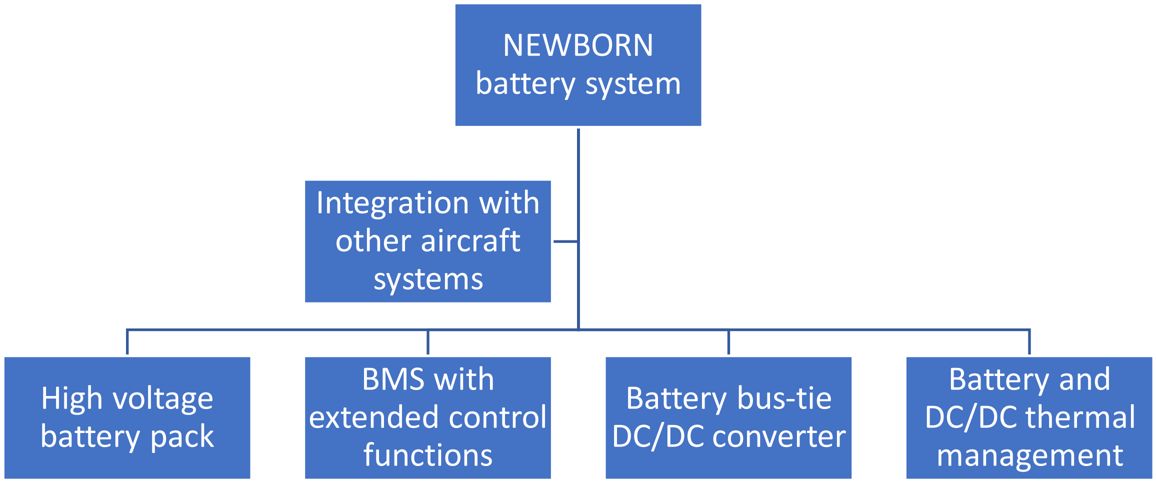

Figure 15: Composition of the battery technology demonstrated in NEWBORN

The NEWBORN battery is composed of the elements shown in Figure 15. It is assumed that the HERA aircraft will use a similar composition for the battery system. This results in the following systems for the HERA aircraft:

Two battery packs, each with a gross capacity of 250 kWh. Specifications of this battery can be found in

Table 20 – Sub-system concept definition.

- Battery management System
    - Cell voltage balancing
    - Safety monitoring of battery pack
    - SoC and SoH calculation of battery cells
- Battery bus-tie DC/DC converter
- Battery and DC/DC thermal management
    - Cooling of battery pack and DC/DC converter
    - Independent from other cooling loops in A/C
    - Pre-cooling and heating of battery pack before flight

Table 20 – Sub-system concept definition for HERA (UCB)

Sub-system Concept definition: Battery – HERA-UCB	
Key characteristics	Value or description
Maximum continuous charge voltage	806 V
Nominal battery pack voltage	685V
Minimum battery pack voltage	500 V
Discharge cut-off voltage	480 V
Capacity	372 Ah
	255 kWh
Maximum continuous discharge current	1860 A
Maximum peak discharge power	1380 kW
Minimum power at cut-off voltage	893 kW
Maximum continuous charge current	1488 A
Battery mass	1104 kg
Battery pack energy density.	231 Wh/kg
Battery pack peak power	1.25 kW/kg
Resistant to thermal runaway (1):	Battery modules shall be designed to contain a thermal runaway and prevent propagation to other modules or to the aircraft.
Resistant to thermal runaway (2):	BMS shall have protective functions to maintain cells within their safe operating conditions
Resistant to thermal runaway (3):	Failure of one battery pack shall not cause other battery packs in parallel to fail.
Output voltage	Stabilized voltage, compatible with HECATE/HERA power distribution system, nominal 830 V

To ensure battery safety, thermal runaway containment measures are taken to contain a thermal runaway within a module, preventing it from spreading to other modules in the pack or to the rest of the aircraft. This is achieved by designing the battery pack with features such as firewalls, thermal barriers, and pressure relief valves that can isolate the failed module and prevent the release of heat, gas, and flames to other parts of the pack.

Design of the battery modules is done with MOC3 SC-VTOL in mind. This document is created by the European Union Aviation Safety Agency (EASA) and describes a means of compliance for certifying battery systems for propulsive applications regarding the dangers of thermal runaway and minimum required fire safety measures to ensure safe operations.

3.5.2 Aircraft concept applicability

Even though there is some information publicly available about demonstrators of fuel cell powered aircraft without batteries, NEWBORN consortium is convinced that battery is beneficial for four main reasons:

1) The battery power density is higher than the integrated fuel cell power system, therefore sizing the fuel cell system for cruise power and relying on battery for take-off and initial climb makes more sense.
2) The fuel cell power source is a relatively complex device. To achieve necessary availability of the aircraft propulsion (especially in critical phases of flight, such as during the take-off after V1 and during initial climb) the necessary parallelization of the fuel cell power systems with sufficient independence would hamper the system reliability.
3) Preheating of the fuel cell system, especially during the cold day conditions, requires energy. While it is possible to utilize ground source, the aircraft without batteries could get stranded in case of emergency or safety landing on airfield without such infrastructure.
4) The battery can function as a peaking plant during cruise, stabilizing the HVDC bus and improving system dynamic response when making a flight manoeuvre.

When comparing the NEWBORN battery and the requirements for the HERA application, significant differences in capacity and maximum power can be seen. However, thanks to the modular design of the NEWBORN battery, the battery can be scaled up to meet these HERA requirements:

The NEWBORN 127.5 kWh demonstrator consists of 12 modules in a 2S6P configuration. To maintain a compatible voltage, two modules need to remain in series. The number of modules in parallel can be increased to 12, resulting in a NEWBORN-HERA battery configuration of 2S12P using the modules developed under NEWBORN. This results in the following specifications found in Table 21 for the NEWBORN-HERA battery:

Table 21 – NEWBORN-HERA battery

Key performance parameter	Unit	Value
Capacity	kWh	510 (2x255)
Peak power	kW	2760 (2x1380)
Battery pack mass	kg	2208 (2x1104)

Adaptation of the output DC/DC conversion system, BMS, and thermal management system for higher power levels are also needed, considered a product design with known technology.

Disclaimer about the chemistry:

The battery developed under NEWBORN will use SoA cells developed in 2022/2023. However, entry into service is planned in 2035, meaning a significant improvement in battery cell technology can be achieved to improve energy density.

Assuming an annual improvement in gravimetric energy density of 5%, after 10 years, in 2033, the battery technology could have been improved by around 63%. This would improve gravimetric energy density on pack level from the current 231 Wh/kg demonstrated for NEWBORN to approximately 376 Wh/kg.

It is however expected that those future cells are solid state cells, which are expected to have lower power density. Alternatively, these cells could be lithium cells with a liquid or semi-solid (a kind of gel substance) with high silicon content blend for the anode, which has a significant potential to improve the capacity of future battery cells.

3.5.3 Sub-system Level Key Performance Metrics

Note that the battery itself during use is completely emission free. Hence, there is no table with emission targets as these are not applicable for the battery.

No LCA has been performed yet to determine potential emissions during production, recycling, and other indirect emissions during operation (such as CO2 emissions of producing the electricity to charge the battery) – this activity is in the scope of the project throughout its duration.

To improve the sustainability aspects of the battery pack over its entire lifetime it will be designed with end of life in mind. Some practical steps to improve battery sustainability are:

- Design battery pack for end of life
    - Easy disassembly by avoiding fastening methods like glue and epoxies where possible.
    - Reusability of parts of battery pack (e.g. casing and BMS hardware)
    - Avoid composites and other materials with poor recyclability where possible.
- The modular design allows single module service or replacement if needed instead of needing to replace entire battery pack.

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	~95% @ nominal operation ~70% @ max power for emergency case	~95% @ nominal operation ~70% @ max power for emergency case	N/A	On target	There is no reference system to compare the battery against.

Below in Table 22 are provided the NEWBORN-HERA battery KPIs based on two NEWBORN batteries in parallel to meet the requirements for the HERA application.

The column "Target" shows the battery parameters for a HERA battery using the "quantified performance targets at project end and beyond" from the NEWBORN Grant Agreement. The column with "Status" indicates the parameters of the NEWBORN-HERA battery pack using the technology of the NEWBORN project in current status.

Table 22 – HERA KPIs

	KPIs				
Title	**Target (NEWBORN)**	**Status (assumed at conceptual design)**	**SoA (Pipistrel Velis Electro**	**% vs reference**	**Comments**
Battery pack capacity	250 kWh	255 kWh	11 kWh	102% of target, 2300% of SoA	Scaled up performance targets from NEWBORN GA to meet HERA aircraft capacity and power demands.
Battery pack mass	1316 kg	1104 kg	72 kg	84%* of target	
Battery pack peak power	921 kW	1380 kW	40 kW	150% of target	

***In case of mass, lower is better.**

It can be seen that the NEWBORN-HERA battery meets the battery capacity target, has a lower mass and has a higher peak power.

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2026	2027
Year Achieved	2022	2023	Exp. Q1/2025		

Additional metrics

Additional KPIs / Other Qualitative Performance Targets at project end and beyond					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Resistant to thermal runaway of full module	MOC-3 SC-VTOL compliant	MOC-3 SC-VTOL compliant	MOC-3 SC-VTOL compliant	N/A	Battery certification requirements for CS-25 currently don't exist, assuming similar requirements

Potential Barriers
- Scarcity of materials, continued shipping issues with longer lead times. - Risk of rapid development of battery technology, making the battery pack developed in the 2023-2025 timeframe not fulfilling the full potential of battery technology for Clean Aviation phase 2.

3.6 Sub-system Concept 2b – Battery – Miniliner

The battery pack of the Miniliner will be similar as the HV battery pack developed for the NEWBORN project in work package 8, task 8.7 and task 8.9, except for a custom cell capacity of 26.4 Ah per cell is needed to achieve the desired battery pack capacity, which is a minor modification not reflecting a technology change and is mandated by cell supply lead time compliance with the project timeframe.

General information regarding battery pack design for NEWBORN:

- Altitude ceiling of FL250 as SHOULD, FL080 as SHALL
- Modular and scalable battery system, from 21 kWh to over 1 MWh of capacity with selected type of battery cell
    - Design of battery modules is modular and scalable as well to enable different type of cells for an even more flexible design.
    - Modular design also allows adjustments to voltage, for example, to achieve >1kV pack (will not be tested for NEWBORN).
    - Significant improvement regarding safety as thermal runaway can be contained to only a small section of the battery pack instead of losing the entire pack.
    - Maintenance and replacement of modules is easier as each module is lighter compared to the entire pack. Modules can also be serviced individually.
- Improved thermal runaway protection thanks to unique thermal runaway containment design of casing for high energy/power cells.
- Significant efficiency boost in cooling capacity compared to SoA certified battery pack.

The Miniliner aircraft will use a battery pack similar to the NEWBORN battery pack developed in work package 8 task 8.7 and 8.9:

- The aircraft uses two battery packs, combined capable of:
    - Providing a combined power of at least 600 kW for 7 min
    - Gross capacity estimated at 182 kWh
        - Estimated required usable energy: 127 kWh
        - Reserve capacity for SoH purposes: 9 kWh at the upper end and 46 kWh at the lower end of battery SoC (i.e. during normal operations, the battery SoC is limited between 95% and 25%)
        - Not usable due to insufficient power available: 18 kWh (10%)
    - Fast charging at 4C

3.6.1 Sub-system concept definition

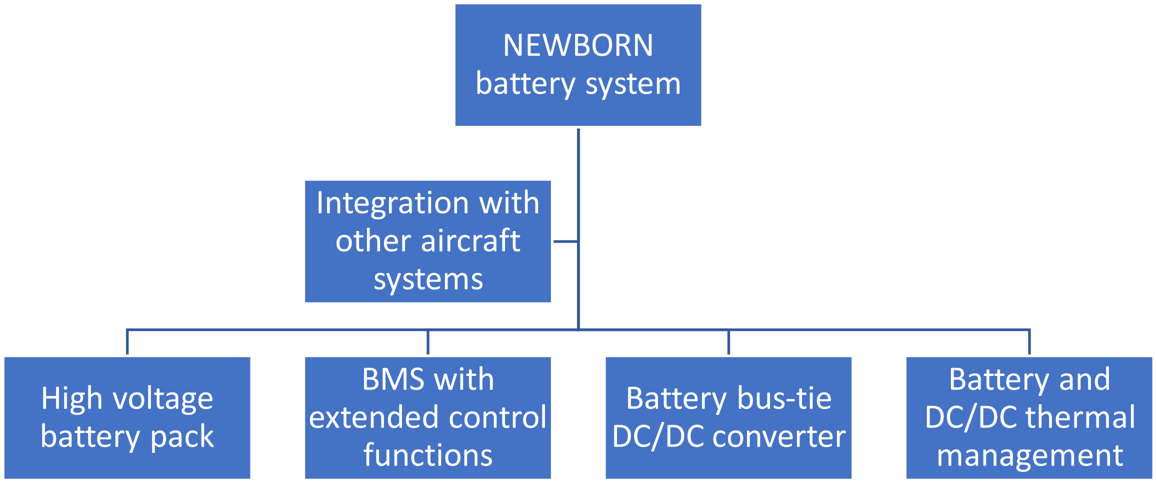

Figure 16: Composition of the battery technology demonstrated in NEWBORN

The NEWBORN battery is composed of the elements shown in Figure 16. It is assumed that the Miniliner aircraft will use a similar composition of the battery system. This results in the following systems for the Miniliner aircraft:
Two battery packs, with a gross capacity of 91 kWh each (182 kWh total). Specifications of this battery can be found in Table 23.

- Battery management System
    - Cell voltage balancing
    - Safety monitoring of battery pack
    - SoC and SoH calculation of battery cells
- Battery bus-tie DC/DC converter
- Battery and DC/DC thermal management
    - Cooling of battery pack and DC/DC converter
    - Independent from other cooling loops in A/C
    - Pre-cooling and heating of battery pack before flight

Table 23 – Sub-system concept definition for Miniliner

Sub-system Concept definition: Battery - Miniliner	
Key characteristics	Value or description
Maximum continuous charge voltage	806 V
Nominal battery pack voltage	685 V
Minimum battery pack voltage	500 V
Discharge cut-off voltage	480 V
Capacity	310 Ah
	212 kWh
Maximum continuous discharge current	1550 A
Maximum peak discharge power	1150 kW
Minimum power at cut-off voltage	744 kW
Maximum continuous charge current	1240 A
Battery mass	920 kg
Battery pack energy density.	231 Wh/kg
Battery pack peak power	1.25 kW/kg
Resistant to thermal runaway (1):	Battery modules shall be designed to contain a thermal runaway and prevent propagation to other modules or to the aircraft.
Resistant to thermal runaway (2):	BMS shall have protective functions to maintain cells within their safe operating conditions
Resistant to thermal runaway (3):	Failure of one battery pack shall not cause other battery packs in parallel to fail.
Output voltage	Stabilized voltage, nominal 830 V

More information on the developed battery is available in D8.1 Electrical architecture & topology report D8.18 Battery prototype design description document.

To ensure battery safety, thermal runaway containment measures are taken to contain a thermal runaway within a module, preventing it from spreading to other modules in the pack or to the rest of the aircraft. This is achieved by designing the battery pack with features such as firewalls, thermal barriers, and pressure relief valves that can isolate the failed module and prevent the release of heat, gas, and flames to other parts of the pack.

Design of the battery modules is done with MOC3 SC-VTOL in mind. This document is created by the European Union Aviation Safety Agency (EASA) and describes a means of compliance for certifying battery systems for propulsive applications regarding the dangers of thermal runaway and minimum required fire safety measures to ensure safe operations.

3.6.2 Aircraft concept applicability

Even though there is some information publicly available about demonstrators of fuel cell powered aircraft without batteries, NEWBORN consortium is convinced that battery is beneficial for four main reasons:

1) The battery power density is higher than the integrated fuel cell power system, therefore sizing the fuel cell system for cruise power and relying on battery for take-off and initial climb makes more sense.
2) The fuel cell power source is a relatively complex device. To achieve necessary availability of the aircraft propulsion (especially in critical phases of flight, such as during the take-off after V1 and during initial climb) the necessary parallelization of the fuel cell power systems with sufficient independence would hamper the system reliability.
3) Preheating of the fuel cell system, especially during the cold day conditions, requires energy. While it is possible to utilize ground source, the aircraft without batteries could get stranded in case of emergency or safety landing on airfield without such infrastructure.
4) The battery is beneficial, even though not necessary, for improvement of the system dynamic response.

A battery pack for the Miniliner application using battery modules developed under the NEWBORN project would ideally have nine strings. However, due to the requirement for the number of strings to be divisible by two, either eight or ten strings are needed.

Based on the aircraft specifications it was found that power at SoC and capacity fade due to ageing are both too challenging with only eight strings in parallel. Hence, a NEWBORN-Miniliner battery pack consisting of 10 strings in parallel (2S10P configuration) is suggested. This results in the specifications found in Table 24 for the NEWBORN-Miniliner battery pack. By switching to a tailored battery cell with a capacity of 26.4 Ah instead of 31 Ah, the pack can be optimized to meet exactly 182 kWh to reduce pack weight.

Table 24 – NEWBORN-Miniliner battery

Key performance parameter	Unit	Value
Capacity	kWh	212 (2x106))
Peak power	kW	1150 (2x575)
Battery pack mass	kg	920 (2x460)

The battery developed under NEWBORN will use SoA cell developed in 2022/2023. However, entry into service is planned in 2035, meaning a significant improvement in battery cell technology can be achieved to improve energy density and reduce weight.

Assuming an annual improvement in gravimetric energy density of 5%, after 10 years, in 2033, the battery technology could have been improved by around 63%. This would improve gravimetric energy density on pack level from the current 231 Wh/kg demonstrated for NEWBORN to approximately 376 Wh/kg.

It is however expected that those future cells are solid state cells, which are expected to have lower power density. Alternatively, these cells could be lithium cells with a liquid or semi-solid (a kind of gel substance) with high silicon content blend for the anode, which has a significant potential to improve the capacity of future battery cells.

3.6.3 Sub-system Level Key Performance Metrics

Note that the battery itself during use is completely emission free. Hence, there is no table with emission targets as these are not applicable for the battery.

No LCA has been performed yet to determine potential emissions during production, recycling, and other indirect emissions during operation (such as CO2 emissions of producing the electricity to charge the battery) – this activity is in the scope of the project throughout its duration.

To improve the sustainability aspects of the battery pack over its entire lifetime it will be designed with end of life in mind. Some practical steps to improve battery sustainability are:

- Design battery pack for end of life
  - Easy disassembly by avoiding fastening methods like glue and epoxies where possible.
  - Reusability of parts of battery pack (e.g. casing and BMS hardware)
  - Avoid composites and other materials with poor recyclability where possible.
- The modular design allows single module service or replacement if needed instead of needing to replace entire battery pack.

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	~95% @ nominal operation ~70% @ max power for emergency case	~95% @ nominal operation ~70% @ max power for emergency case	N/A	On target	There is no reference system to compare the battery against.

Below in Table 25 are provided the NEWBORN-Miniliner battery KPIs based on the NEWBORN demonstrator battery.

The column "Target" shows the battery parameters for a Miniliner battery using the "quantified performance targets at project end and beyond" from the NEWBORN Grant Agreement. The column with "Status" indicates the parameters of the NEWBORN-Miniliner battery pack using the technology of the NEWBORN project in current status.

Table 25 – Miniliner KPIs

KPIs					
Title	**Target (NEWBORN)**	**Status (assumed at conceptual design)**	**SoA (Pipistrel Velis Electro)**	**% vs reference**	**Comments**
Battery pack capacity	182 kWh	212 kWh	11 kWh	117% of target, 1927% of SoA	Performance targets from NEWBORN GA compared to NEWBORN-Miniliner battery.
Battery pack mass	727 kg	920 kg	72 kg	127%***** of target	
Battery pack peak power	600 kW	1150 kW	40 kW	192% of target, 2875% of SoA	

***In case of mass, lower is better.**

The higher weight is caused by availability of the optimal cells in the project timeframe for the demonstration, the target is fully achievable with the intended cells. Additional weight is caused by the battery achieving much higher capacity than needed for the recently updated requirements for the Miniliner.

It can be seen that the NEWBORN-Miniliner battery has 17% more capacity than desired, mostly due to the need of an additional string to keep the number of strings divisible by two. Also pack mass is higher than desired, although improvements in cell chemistry and by optimising cell capacity can improve this with technology available today. Peak power requirement of 600 kW is met with significant margin.

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2026	2027
Year Achieved	2022	2023	Exp. Q1/2025		

Additional metrics

Additional KPIs / Other Qualitative Performance Targets at project end and beyond					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Resistant to thermal runaway of full module	MOC-3 SC-VTOL compliant	MOC-3 SC-VTOL compliant	MOC-3 SC-VTOL compliant	N/A	Battery certification requirements for CS-23 are in development, assuming similar requirements

Potential Barriers
- Scarcity of materials, continued shipping issues with longer lead times. - Risk of rapid development of battery technology, making the battery pack developed in the 2023-2025 timeframe not fulfilling the full potential of battery technology for Clean Aviation phase 2.

3.7 Sub-system Concept 2c – Battery – FC80pax

All battery requirements for the FC80pax aircraft have been estimated, based on NEWBORN deliverable D1.4.

General information regarding battery pack design for NEWBORN:

- Altitude ceiling of FL250
- Modular and scalable battery system, from 21 kWh to over 1 MWh of capacity with selected type of battery cell
  - Design of battery modules is modular and scalable as well to enable different type of cells for an even more flexible design.
  - Modular design also allows adjustments to voltage, for example, to achieve >1kV pack (will not be tested for NEWBORN).
  - Significant improvement regarding safety as thermal runaway can be contained to only a small section of the battery pack instead of losing the entire battery pack.
  - Maintenance and replacement of modules is easier as each module is lighter compared to the entire battery pack. Modules can also be serviced individually.
- Improved thermal runaway protection thanks to unique thermal runaway containment design of casing for high energy/power battery cells.
- Significant efficiency boost in cooling capacity compared to SoA certified battery pack.

For the FC80pax aircraft the following information is estimated:

- The aircraft uses 8 battery packs which are combined to be capable of:
  - Providing power of at least 1877 kW

- Gross capacity estimated at 329 kWh
- Fast charging at 4C

3.7.1 Sub-system concept definition

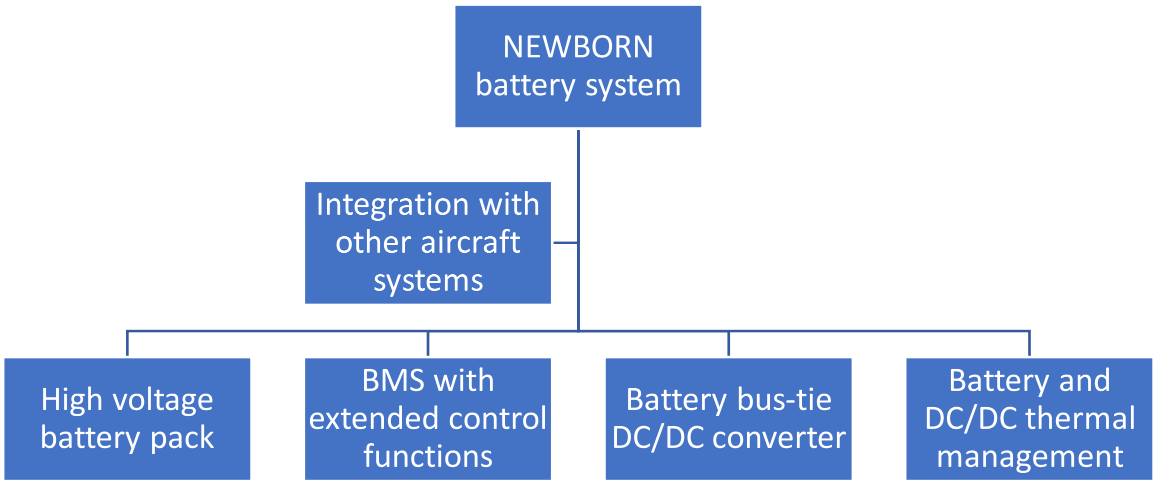

Figure 17: Composition of the battery technology demonstrated in NEWBORN

The NEWBORN battery is composed of the elements shown in Figure 17. It is assumed that the FC80pax aircraft will use a similar composition for the battery system. This results in the following systems for the FC80pax aircraft:
Eight battery packs, with a gross capacity of 41 kWh each (329 kWh total). Specifications of this battery can be found in Table 26.

- Battery management System
  - Cell voltage balancing
  - Safety monitoring of battery pack
  - SoC and SoH calculation of battery cells
- Battery bus-tie DC/DC converter
- Battery and DC/DC thermal management
  - Cooling of battery pack and DC/DC converter
  - Independent from other cooling loops in A/C
  - Pre-cooling and heating of battery pack before flight

Table 26 – Sub-system concept definition for FC80pax

Sub-system Concept definition: Battery – FC80pax	
Key characteristics	Value or description
Maximum continuous charge voltage	806 V
Nominal battery pack voltage	685 V
Minimum battery pack voltage	500 V
Discharge cut-off voltage	480 V
Capacity	496 Ah
	340 kWh
Maximum continuous discharge current	2480 A
Maximum peak discharge power	1840 kW
Minimum power at cut-off voltage	1190 kW
Maximum continuous charge current	1984 A
Battery mass	1472 kg
Battery pack energy density.	231 Wh/kg
Battery pack peak power	1.25 kW/kg
Resistant to thermal runaway (1):	Battery modules shall be designed to contain a thermal runaway and prevent propagation to other modules or to the aircraft.
Resistant to thermal runaway (2):	BMS shall have protective functions to maintain cells within their safe operating conditions
Resistant to thermal runaway (3):	Failure of one battery pack shall not cause other battery packs in parallel to fail.
Output voltage	Stabilized voltage, nominal 830 V

More information on the developed battery is available in D8.1 Electrical architecture & topology report and D8.18 Battery prototype design description document.

To ensure battery safety, thermal runaway containment measures are taken to contain a thermal runaway within a module, preventing it from spreading to other modules in the pack or to the rest of the aircraft. This is achieved by designing the battery pack with features such as firewalls, thermal barriers, and pressure relief valves that can isolate the failed module and prevent the release of heat, gas, and flames to other parts of the pack. Design of the battery modules is done with MOC3 SC-VTOL in mind. This document is created by the European Union Aviation Safety Agency (EASA) and describes a means of compliance for certifying battery systems for propulsive applications regarding the dangers of thermal runaway and minimum required fire safety measures to ensure safe operations.

3.7.2 Aircraft concept applicability

Even though there is some information publicly available about demonstrators of fuel cell powered aircraft without batteries, NEWBORN consortium is convinced that battery is beneficial for four main reasons:

1) The battery power density is higher than the integrated fuel cell power system, therefore sizing the fuel cell system for cruise power and relying on battery for take-off and initial climb makes more sense.
2) The fuel cell power source is a relatively complex device. To achieve necessary availability of the aircraft propulsion (especially in critical phases of flight, such as during the take-off after V1 and during initial climb) the necessary parallelization of the fuel cell power systems with sufficient independence would hamper the system reliability.
3) Preheating of the fuel cell system, especially during the cold day conditions, requires energy. While it is possible to utilize ground source, the aircraft without batteries could get stranded in case of emergency or safety landing on airfield without such infrastructure.
4) The battery is beneficial, even though not necessary, for improvement of the system dynamic response.

When comparing the NEWBORN battery and the requirements for the FC80pax application, significant differences in capacity and maximum power can be seen. However, thanks to the modular design of the NEWBORN battery, the battery can be scaled up to meet these FC80pax requirements:

The NEWBORN 127.5 kWh demonstrator consists of 12 modules in a 2S6P configuration. To maintain a compatible voltage, two modules need to remain in series. The number of modules in parallel can be changed to two per pack to achieve the desired 41 kWh with a 2S2P configuration per pack, resulting in a NEWBORN- FC80pax battery configuration of 2S16P for the entire aircraft using the modules developed under NEWBORN. This results in the following specifications found in Table 27 for the NEWBORN- FC80pax battery:

Table 27 – NEWBORN- FC80pax battery

Key performance parameter	Unit	Value
Capacity	kWh	340 (8x42.5)
Peak power	kW	1840 (8x230)
Battery pack mass	kg	1472 (8x184)

Disclaimer about the chemistry:

The battery developed under NEWBORN will use SoA cells developed in 2022/2023. However, entry into service is planned in 2035, meaning a significant improvement in battery cell technology can be achieved to improve energy density and reduce weight.

Assuming an annual improvement in gravimetric energy density of 5%, after 10 years, in 2033, the battery technology could have been improved by around 63%. This would improve gravimetric energy density on pack level from the current 231 Wh/kg demonstrated for NEWBORN to approximately 376 Wh/kg.

It is however expected that those future cells are solid state cells, which are expected to have lower power density. Alternatively, these cells could be lithium cells with a liquid or semi-solid (a kind of gel substance) with high silicon content blend for the anode, which has a significant potential to improve the capacity of future battery cells.

3.7.3 Sub-system Level Key Performance Metrics

Note that the battery itself during use is completely emission free. Hence, there is no table with emission targets as these are not applicable for the battery. No LCA has been performed yet to determine potential emissions during production, recycling, and other indirect emissions during operation (such as CO2 emissions of producing the electricity to charge the battery) – this activity is in the scope of the project throughout its duration.

To improve the sustainability aspects of the battery pack over its entire lifetime it will be designed with end of life in mind. Some practical steps to improve battery sustainability are:

- Design battery pack for end of life
    - Easy disassembly by avoiding fastening methods like glue and epoxies where possible.
    - Reusability of parts of battery pack (e.g. casing and BMS hardware)
    - Avoid composites and other materials with poor recyclability where possible.
- The modular design allows single module service or replacement if needed instead of needing to replace entire battery pack.

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	~95% @ nominal operation ~70% @ max power for emergency case	~95% @ nominal operation ~70% @ max power for emergency case	N/A	On target	There is no reference system to compare the battery against.

Below in Table 28 are provided the NEWBORN-FC80pax battery KPIs based on two NEWBORN batteries in parallel to meet the requirements for the FC80pax application.

The column "Target" shows the battery parameters for a FC80pax battery using the "quantified performance targets at project end and beyond" from the NEWBORN Grant Agreement. The column with "Status" indicates the parameters of the NEWBORN- FC80pax battery pack using the technology of the NEWBORN project in current status.

Table 28 – FC80pax KPIs

KPIs					
Title	**Target (NEWBORN)**	**Status (assumed at**	**SoA (Pipistrel**	**% vs reference**	**Comments**

		conceptual design)	Velis Electro)		
Battery pack capacity	329 kWh	340 kWh	11 kWh	103% of target, 3091% of SoA	Scaled up performance targets from NEWBORN GA to meet FC80pax aircraft capacity and power demands.
Battery pack mass	1317 kg	1472 kg	72 kg	112%* of target	
Battery pack peak power	1877 kW	1840 kW	40 kW	98%	

***In case of mass, lower is better.**

It can be seen that the NEWBORN-FC80pax battery matches the desired capacity quite close (103%). Battery pack mass is higher than expected, although improvements in cell chemistry will likely compensate for this before planned EIS of aircraft. Battery pack peak power is also very close at 98% of the desired power, with the remaining difference easily achievable in needed timeframe thanks to continuous improvements in cell chemistry.

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2026	2027
Year Achieved	2022	2023	Exp. Q1/2025		

Additional metrics

Additional KPIs / Other Qualitative Performance Targets at project end and beyond					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Resistant to thermal runaway of full module	MOC-3 SC-VTOL compliant	MOC-3 SC-VTOL compliant	MOC-3 SC-VTOL compliant	N/A	Battery certification requirements for CS-25 currently don't exist, assuming similar requirements

Potential Barriers
- Scarcity of materials, continued shipping issues with longer lead times. - Risk of rapid development of battery technology, making the battery pack developed in the 2023-2025 timeframe not fulfilling the full potential of battery technology for Clean Aviation phase 2.

3.8 Sub-system Concept 3a – Electric propulsion – HERA-UCA

3.8.1 Sub-system concept definition

The electric propulsion system developed in NEWBORN is focusing on demonstration of the 1 MW electric motor and inverter, including their integration with auxiliary systems into a demonstration propulsion system. Additional design margin is assumed to enable slight increase of the continuous power beyond this level and to reduce the project technical risks.

The electric propulsion technology developed within NEWBORN is applicable to the originally assumed HERA-UCA propulsion system with product modifications necessary for the integration into the hybrid powertrain assumed in HERA. This includes:

- Increase of the continuous power from 1.05 MW to 1.1 MW (considered simple scaling achievable easily in the product design phase)
- Use of HERA-specific summing gearbox, governor, and oil system
- Most importantly: HERA has defined lower motor envelope diameter or 0.4 m (SHALL) or 0.3 m (SHOULD), as opposed to the NEWBORN design for the diameter of 0.5 m for fully electric propulsion system. Adaptation of the motor aspect ratio might be needed, not impacting the principal technologies demonstrated, but requiring different specific product optimization and design. Alleviation of some other parameters compared to NEWBORN is acceptable, such as low shaft speed limitation, reduced efficiency target of 96% being acceptable, etc.

The HERA use-case A (HERA-UCA) is however currently open for realignment with the needs of the Ultra-efficient Regional Aircraft concept, which would need different (lower power) motor-generator, yielding lower hybridization ratio compared to original HERA UCA. The data below relate to the original HERA project needs.

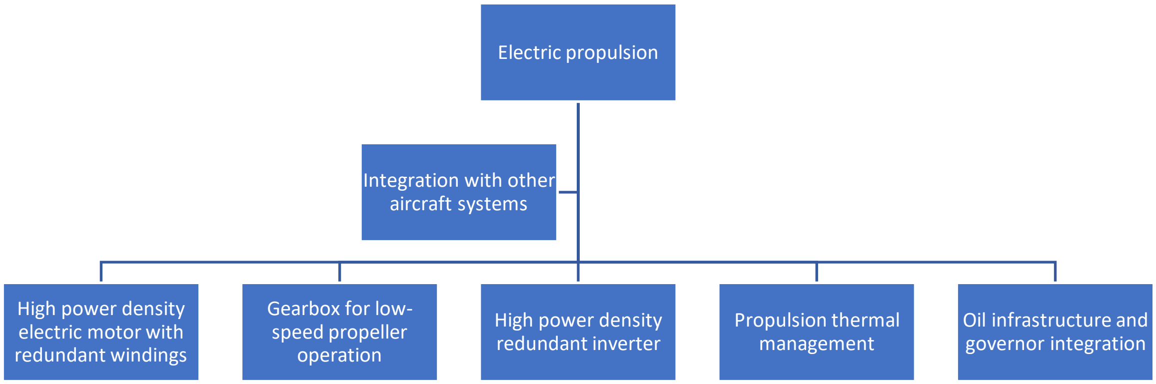

Figure 18: Composition of the electric propulsion technology demonstrated in NEWBORN

Sub-system Concept definition: High power density propulsion system – HERA-UCA	
Key characteristics	Value or description
Propeller speed	Optimized for hybrid engine installation, matching the summing gearbox
Motor type	PMSM
Maximum continuous power	1100 kW
Power density – motor	~18 kW/kg (current estimate)
Power density – inverter	18 - 21.5 kW/kg (current estimate)
Power density – integrated propulsion system (incl. gearbox, thermal management, lubrication, ..)	>4.3 kW/kg, further optimization in progress
Efficiency – motor	>98 % @ nominal speed
Efficiency – inverter	>98 % @ maximum power
Partial discharge immunity to HV at altitude	Ensured.
Motor diameter	<0.4 m

3.8.2 Aircraft concept applicability

The electric propulsion technology developed within NEWBORN is applicable to HERA-UCA propulsion system with certain level of modifications, necessary for the integration into the hybrid powertrain assumed in HERA. This includes:

- Increase of the continuous power from 1.05 MW to 1.1 MW (considered simple scaling achievable easily in the product design phase)
- Mating with the HERA-specific summing gearbox, governor, and oil system
- Adaptation of the motor aspect ratio (not impacting the principal technologies demonstrated but requiring different specific product optimization and design. Alleviation of some other parameters compared to NEWBORN is acceptable, such as low shaft speed limitation, reduced efficiency target of 96% being acceptable, etc.)

3.8.3 Sub-system Level Key Performance Metrics

The contribution of the electric propulsion system to the aircraft performance metrics is indirect, they serve as one of the critical enablers for both hybrid and fully-electric aircraft.

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Motor Energy Efficiency [%]	>96% SHALL >98% SHOULD	98%	95%	40% of losses +3 pp efficiency	Rated speed efficiency
Inverter Energy Efficiency [%]	>98%	98%	95%	40% of losses +3 pp efficiency	Rated speed efficiency

Quantitative KPIs

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Power density – motor [kW/kg]	10 SHALL, 15 SHOULD	18	5-8	225-360%	High influence of required RPM, not yet defined by HERA
Power density – inverter [kW/kg]	15 SHALL, 20 SHOULD	18	5-10	180-360%	

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	2023	2026	2027	2028
Year Achieved	<2022	2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

Potential Barriers
N/A

3.9 Sub-system Concept 3b – Electric propulsion – Miniliner

3.9.1 Sub-system concept definition

The electric propulsion system developed in NEWBORN is focusing on demonstration of the 1 MW electric motor and inverter, including their integration with auxiliary systems into a demonstration propulsion system. Additional design margin is assumed to enable slight increase of the continuous power beyond this level and to reduce the project technical risks.

As the design of the aircraft concept is preliminary, and the propulsion system power requirements are preliminary, the propulsion system is designed with sufficient performance margin. Moreover, the both conventional wing-mounted configuration and the one tail-mounted main propeller supported by wing-mounted DEP folding propulsors are considered as feasible, the requirements for the motor power are defined as ranges.

The propulsion system is an integrated electrical propulsion subsystem, integrated with the independent oil & cooling units, governor, and mated to the low-speed propeller.

The main characteristics:

- Low propeller speed of 1200 rpm
- Motor diameter <0.5m
- Single-stage speed reduction from the motor to propeller
- 830 V DC nominal input bus
- Power range from 630 (SHALL) – 1000 kW (SHOULD)

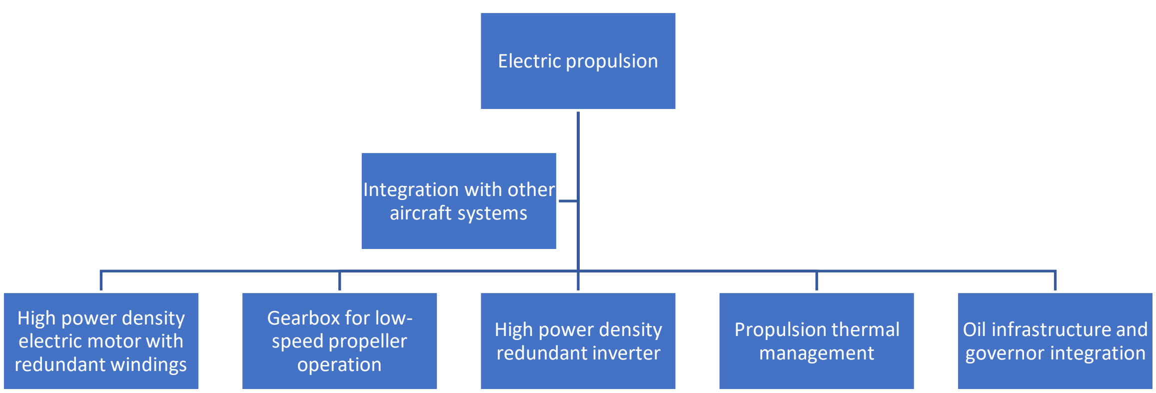

Figure 19: Composition of the electric propulsion technology demonstrated in NEWBORN

Sub-system Concept definition: High power density propulsion system - Miniliner	
Key characteristics	Value or description
Propeller speed	1200 rpm
Motor speed	Supporting single-stage reduction to 1200 rpm
Motor diameter	<0.5 m
Maximum continuous power	1000 kW
Power density – motor	~18 kW/kg (current estimate)
Power density – inverter	~18 kW/kg (current estimate)
Power density – integrated propulsion system (incl. gearbox, thermal management, lubrication, ..)	>4 kW/kg, further optimization in progress
Efficiency – motor	>98 % @ nominal speed
Efficiency – inverter	>98 % @ maximum power
Partial discharge immunity to HV at altitude	Ensured.
Input voltage	830 V nominal

3.9.2 Aircraft concept applicability

The electric propulsion technology developed within NEWBORN is directly applicable for the Miniliner concept. Depending on the final aircraft performance, the power level could be further reduced from 1000 kW to the optimum value in the range of 630 – 1000 kW.

The power level is **directly applicable** for the installation in an eventual retrofit CS-23 19-pax platform with lower aerodynamic performance than the Miniliner concept.

3.9.3 Sub-system Level Key Performance Metrics

The contribution of the electric propulsion system to the aircraft performance metrics is indirect, they serve as one of the critical enablers for both hybrid and fully-electric aircraft.

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Motor Energy Efficiency [%]	> 98%	98%	95%	40% of losses +3 pp efficiency	Nominal speed
Inverter Energy Efficiency [%]	>98%	98%	95%	40% of losses +3 pp efficiency	Maximum power

Quantitative KPIs

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Power density – motor [kW/kg]	15	18	5-8	225-360%	Excluding auxiliaries
Power density – inverter [kW/kg]	18	18	5-10	180-360%	Excluding cooling

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	2023	2026	2027	2028

Year Achieved	<2022	2023	Planned in 2025	-	-

The TRL levels according to definition in Annex B, section 4.

Potential Barriers
N/A

3.10 Sub-system Concept 3c – Electric propulsion – FC80pax

3.10.1 Sub-system concept definition

The electric propulsion technology developed within NEWBORN is applicable to the FC80pax propulsion system with certain level of modifications, necessary to achieve higher propulsive power. This includes:

Either:

- Paralleling of 2 developed motors and inverters using a summing gearbox. Resulting aircraft would yield 8 motors and 8 inverters, sets of 2 always powering 1 propeller out of 4.
- Adaptation (up-scaling) the governor, oil, and cooling system by a factor of 2 (known technology, no risk).

Or:

- Increase of the continuous power from 1.05 MW to 2.1 MW, complemented by re-optimization of the optimum motor speed – considered a major redesign and a technology change, however already demonstrated by one of the NEWBORN partners at TRL4 at 3 MW.
- Scaling up of the governor, oil, and cooling system by a factor of 2 (known technology, no risk).

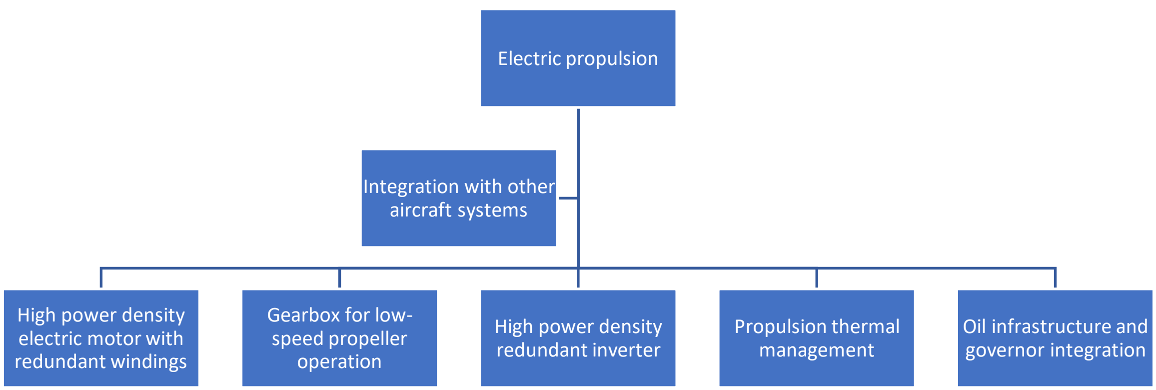

Figure 20: Composition of the electric propulsion technology demonstrated in NEWBORN

Sub-system Concept definition: High power density propulsion system – FC80pax	
Key characteristics	Value or description
Maximum continuous power	2100 kW
Power density – motor	~18 kW/kg (current estimate)
Power density – inverter	18 - 21.5 kW/kg (current estimate)
Power density – integrated propulsion system (incl. gearbox, thermal management, lubrication, ..)	>4.3 kW/kg, further optimization in progress
Efficiency – motor	>98 % @ nominal speed
Efficiency – inverter	>98 % @ maximum power
Partial discharge immunity to HV at altitude	Ensured.

3.10.2 Aircraft concept applicability

The electric propulsion technology developed within NEWBORN is applicable to the FC80pax propulsion system with modifications necessary to achieve higher propulsive power.

Either:

- Paralleling of 2 developed motors and inverters using a summing gearbox. Resulting aircraft would yield 8 motors and 8 inverters, sets of 2 always powering 1 propeller out of 4.
- Adaptation (up-scaling) the governor, oil, and cooling system by a factor of 2 (known technology, no risk).

Or:

- Increase of the continuous power from 1.05 MW to 2.1 MW, complemented by re-optimization of the optimum motor speed – considered a major redesign and a technology change, however already demonstrated by one of the NEWBORN partners at TRL4 at 3 MW.
- Scaling up of the governor, oil, and cooling system by a factor of 2 (known technology, no risk).

3.10.3 Sub-system Level Key Performance Metrics

The contribution of the electric propulsion system to the aircraft performance metrics is indirect, they serve as one of the critical enablers for both hybrid and fully-electric aircraft.

Energy Consumption @ Sub-system level (before integration)					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Motor Energy Efficiency [%]	> 98%	98%	95%	40% of losses +3 pp efficiency	Nominal speed
Inverter Energy Efficiency [%]	>98%	98%	95%	40% of losses +3 pp efficiency	Maximum power

Quantitative KPIs

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Power density – motor [kW/kg]	15	18	5-8	225-360%	
Power density – inverter [kW/kg]	18	18	5-10	180-360%	

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	2023	-	-	-
Year Achieved	<2022	2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

Potential Barriers
N/A

3.11 Sub-system Concept 4a – LH2 storage – HERA

3.11.1 Sub-system concept definition

The liquid hydrogen storage subsystem developed in the NEWBORN project (relying on the H2ELIOS project technology), focuses on the integration of the overall liquid hydrogen storage tank. The technology demonstrator is developed as a single tank with auxiliary equipment shown below in Figure 21Figure 21. While and alternative plan for the integrated system demonstration using more conventional cryogenic tank was decided in NEWBORN to reduce the project risks, this document is presented the KPIs for the actual H2ELIOS + NEWBORN based solution (see note below) developed within those projects. It is assumed that CS-25 aircraft will need at least a dual redundant set of tanks and auxiliary equipment. While a trivial approach would be to install two such tanks in the aircraft, the technology can be also easily adapted to provide a partially redundant liquid hydrogen storage solution, which duplicates the elements prone to failures, while exploiting the potential of communalizing the isolation elements, yielding even higher gravimetric index. Figures provided in this section provide the expected potential impact when scaling up the sub-system assuming certain further optimization of the storage concept.

Note: The development risks of the H2ELIOS project, with high probability of impact to the NEWBORN project, have necessitated the NEWBORN project to reevaluate the unit to be used for the demonstration of the integrated system during the demonstration phase. While the concept is retained, along with the hydrogen conditioning and supply line design, the cryogenic storage vessel currently planned for the demonstration is a commercially available ground transport segment unit with lower gravimetric index. This significantly reduces project risks, while continuing on the design with the H2ELIOS tank concept to enable its use after sufficient maturation.

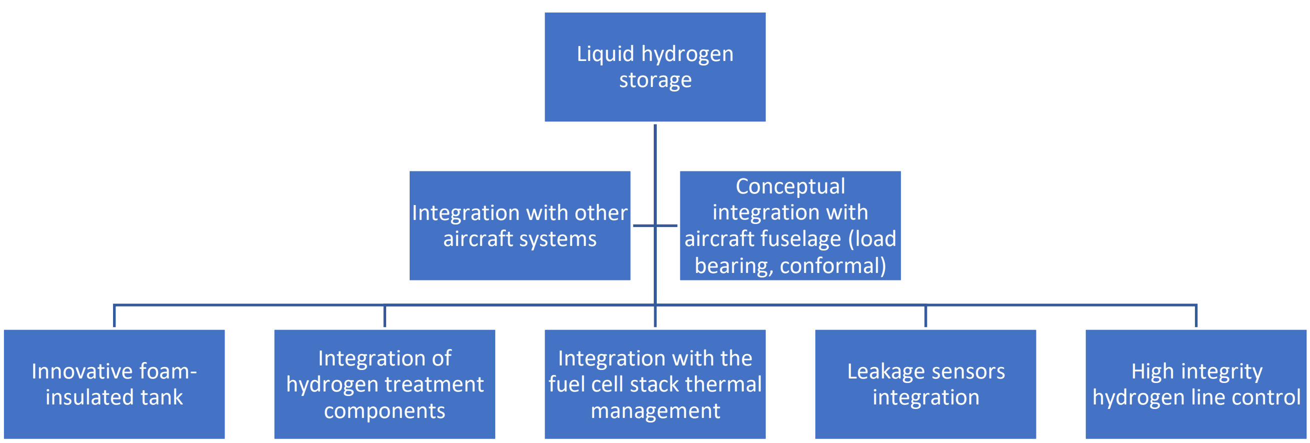

Figure 21: Composition of the liquid hydrogen storage technology presented in NEWBORN

Sub-system Concept definition: Liquid hydrogen storage – HERA	
Key characteristics	Value or description
Conceptual technology	~~Load bearing~~**, conformal tank, dual foam insulated. Inherently safe with respect to the hazard of vacuum loss.
Load bearing**	No**
Conformal	Yes, external tank structure is the airframe (in principle, within the rear fuselage section).**
Gravimetric index – Isolated tank (excluding aircraft structure) *	0.41 @ 600 kg assumed LH2 needed for HERA
Gravimetric index – tank including hydrogen preconditioning and venting equipment (excluding aircraft structure) *	0.34 @ 600 kg assumed LH2 needed for HERA
Incorporation of the hydrogen treatment equipment	Yes, in an insulated equipment bay
H2 flow requirements	42 g/s continuous; 52 g/s transient peak

*Guidance on values provided: An isolated tank has better GI than the one including the preconditioning & venting equipment because we are adding components, but that addition would weight more if performed in an isolated tank. A dual tank with redundancy has slightly worse GI due to the addition of piping, control equipment and insulation. Specifically for HERA a/c, due to its hybrid powertrain configuration there are not needed redundant tanks as the thrust is not relaying only in LH2 powered systems.

**Linked project H2ELIOS supplying the cryogenic vessel technology has revised the project scope to not include load bearing aspects to meet certifiability requirements within the necessary timeframe; this characteristic and KPI is therefore obsolete and retained only for context.

3.11.2 Aircraft concept applicability

It is assumed that for CS-25 aircraft, the hydrogen storage and treatment solution will be dual redundant, with partial redundancy in the insulation. However, due to specific aircraft architecture design solutions, a complete dual tank approach could be also considered, with impact to gravimetric index.

In case of HERA UCA & UCB, the LH2 tank is positioned in the rear fuselage just behind the pressure bulkhead (non-pressurized area) and have a conical trunk shape with spherical dome ends. Due to the position of the powerplant elements, LH2 supply and conditioning equipment installed in the front end of the tank in a ventilated and monitored area to avoid H2 concentration in case of leakage. Further structural integration implementation is possible and could consider more intimate structural arrangements of this LH2 storage concept. Considering the volume devoted to LH2 storage in the a/c the redundancy provisions needed would imply an actual partition of that volume generation two independent tanks that would need its own piping arrangement. The concept still benefits from some non-safety critical synergies regarding insulation which mitigate gravimetric index drop.

Main structural arrangement between tail (T-type) and fuselage would not interfere in this a/c configuration as per information provided from the OEM.

3.11.3 Sub-system Level Key Performance Metrics

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Gravimetric Index (for 600 kg LH2)	>35%	34,4%	N/A	98% of target	Current DEWAR technology reaches even lower GI values for greater capacity. Reference case (SAG Heavy-Duty truck tank concept) has a 9,1% for a much smaller tank (40 kg LH2)
Dormancy with zero venting at 600 kg / 1 bar (starting condition)	>12 hours	12 hours	N/A	100% of target	No comparable technology. Reference case (SAG Heavy-Duty truck tank concept) has a holding time of 8 days for a much smaller tank (40 kg LH2).

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2025	2029
Year Achieved	2022	2024	Planned for 2025	-	-

The TRL levels according to definition in Annex B, section 4.

Potential Barriers
- Airworthiness authority and other regulators feedback on the solution characteristics, either due to a delay in the information delivery or to an identification of major showstoppers. - Availability of LH2 at reasonable costs and quantities to perform tests. - Major challenges in a/c integration of hydrogen technologies (not related with storage) that could block the project (i.e., propulsion, contrails effects, etc.). Not specifically addressed in NEWBORN.

3.12 Sub-system Concept 4b – LH2 storage – Miniliner

3.12.1 Sub-system concept definition

The liquid hydrogen storage subsystem developed in the NEWBORN project (and adapted from H2ELIOS), focuses on the integration of the overall liquid hydrogen storage tank. The envisaged product based in the developed technology is a single tank with auxiliary equipment shown below in Figure 22.

Note: The development risks of the H2ELIOS project, with high probability of impact to the NEWBORN project, have necessitated the NEWBORN project to reevaluate the unit to be used for the demonstration of the integrated system during the demonstration phase. While the concept is retained, along with the hydrogen conditioning and supply line design, the cryogenic storage vessel currently planned for the demonstration is a commercially available ground transport segment unit with lower gravimetric index. This significantly reduces project risks, while continuing on the design with the H2ELIOS tank concept to enable its use after sufficient maturation.

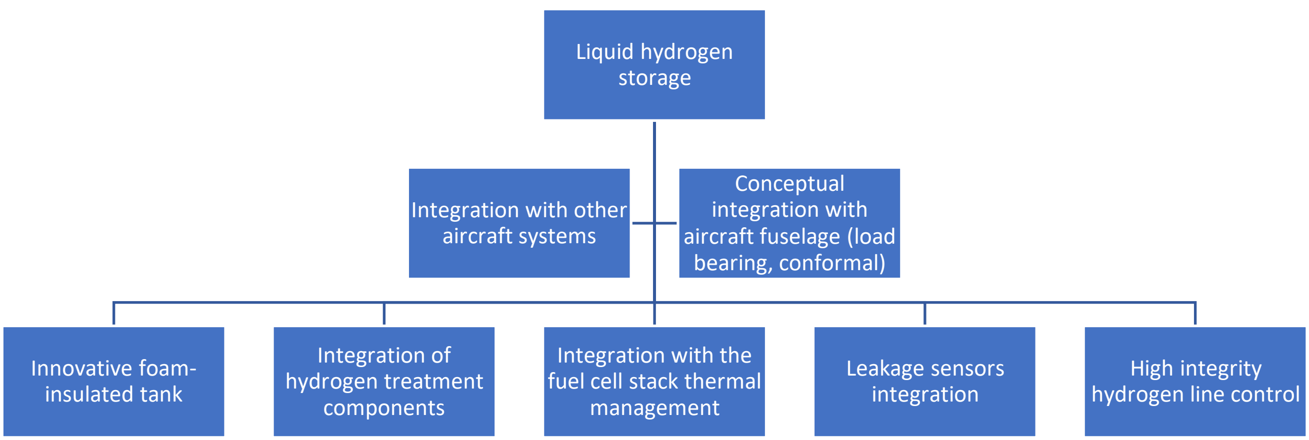

Figure 22: Composition of the liquid hydrogen storage technology demonstrated in NEWBORN

Sub-system Concept definition: Liquid hydrogen storage - Miniliner	
Key characteristics	Value or description
Conceptual technology	~~Load bearing~~**, conformal tank, dual foam insulated. Inherently safe with respect to the hazard of vacuum loss.

Load bearing**	No**
Conformal	Yes, external tank structure is the airframe (in principle, within the rear fuselage section).**
Gravimetric index – Isolated tank (excluding aircraft structure) *	Single tank: 0.30 @ 300 kg LH2 assumed needed for Miniliner
Gravimetric index – tank including hydrogen preconditioning and venting equipment (excluding aircraft structure) *	Single tank: 0.25 @ 300 kg LH2 assumed needed for Miniliner
Incorporation of the hydrogen treatment equipment	Yes, in an insulated equipment bay
H2 flow requirements	18,3 g/s continuous; 23 g/s transient peak

*Guidance on values provided: An isolated tank has better GI than the one including the preconditioning & venting equipment because we are adding components, but that addition would weight more if performed in an isolated tank. A dual tank with redundancy has slightly worse GI due to the addition of piping, control equipment and insulation.

** Linked project H2ELIOS supplying the cryogenic vessel technology has revised the project scope to not include load bearing aspects to meet certifiability requirements within the necessary timeframe; this characteristic and KPI is therefore obsolete and retained only for context.

3.12.2 Aircraft concept applicability

The developed subsystem is applicable to all hydrogen powered aircraft, ranging from small general aviation aircraft to larger regional aircraft platforms. It is assumed that for CS-25 aircraft, the hydrogen storage and treatment solution will be dual redundant, with partial redundancy in the insulation. However, due to specific aircraft architecture design solutions, a complete dual tank approach could be taken too. Technology developed within H2ELIOS/NEWBORN is completely scalable in that sense.

For the Miniliner a/c configuration. The LH2 tank would be positioned in the rear fuselage in a non-pressurized area and have a complete cylindrical shape with spherical dome ends. Due to the position of the powerplant elements, LH2 supply and conditioning equipment would be installed in the front end of the tank in a ventilated and monitored area to avoid H2 concentration in case of leakage.

Main structural arrangement between tail (V-type) and fuselage would not interfere in this a/c configuration as per information provided from the OEM.

3.12.3 Sub-system Level Key Performance Metrics

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Gravimetric Index (for 300 kg LH2)	>35%	25%	20% for 500 kg of LH2	+15 p.p. vs. SoA, 57% vs. target	Current DEWAR technology reaches even lower GI values for greater capacity. Reference case (SAG Heavy-Duty truck tank concept) has a 9,1% for a much smaller tank (40 kg LH2)
Dormancy with zero venting at 150 kg / 3,5 bar (starting condition)	>4 hours	12 hours	N/A	300% of target	No comparable technology. Reference case (SAG Heavy-Duty truck tank concept) has a holding time of 8 days for a much smaller tank (40 kg LH2).

<u>TRL Level</u>

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2025	2029
Year Achieved	2022	2024	Planned in 2025	-	-

The TRL levels according to definition in Annex B, section 4.

Potential Barriers
- Airworthiness authority and other regulators feedback on the solution characteristics, either due to a delay in the information delivery or to an identification of major showstoppers. - Availability of LH2 at reasonable costs and quantities to perform tests. - Major challenges in a/c integration of hydrogen technologies (not related with storage) that could block the project (i.e., propulsion, contrails effects, etc.). Not specifically addressed in NEWBORN.

3.13 Sub-system Concept 4c – LH2 storage – FC80pax

3.13.1 Sub-system concept definition

The liquid hydrogen storage subsystem developed in the NEWBORN project (and adapted from H2ELIOS), focuses on the integration of the overall liquid hydrogen storage tank. The envisaged product based in the developed technology is a single tank with auxiliary equipment shown below in Figure 23. It is assumed that CS-25 aircraft will need at least a dual redundant set of tanks and auxiliary equipment. While a trivial approach would be to install two such tanks in the aircraft, the technology can be also easily adapted to provide a partially redundant liquid hydrogen storage solution, which duplicates the elements prone to failures, while exploiting the potential of communalizing the isolation elements, yielding even higher gravimetric index. Figures provided in this section provide the expected potential impact when scaling up the sub-system assuming certain further optimization of the storage concept.

Note: The development risks of the H2ELIOS project, with high probability of impact to the NEWBORN project, have necessitated the NEWBORN project to reevaluate the unit to be used for the demonstration of the integrated system during the demonstration phase. While the concept is retained, along with the hydrogen conditioning and supply line design, the cryogenic storage vessel currently planned for the demonstration is a commercially available ground transport segment unit with lower gravimetric index. This significantly reduces project risks, while continuing on the design with the H2ELIOS tank concept to enable its use after sufficient maturation.

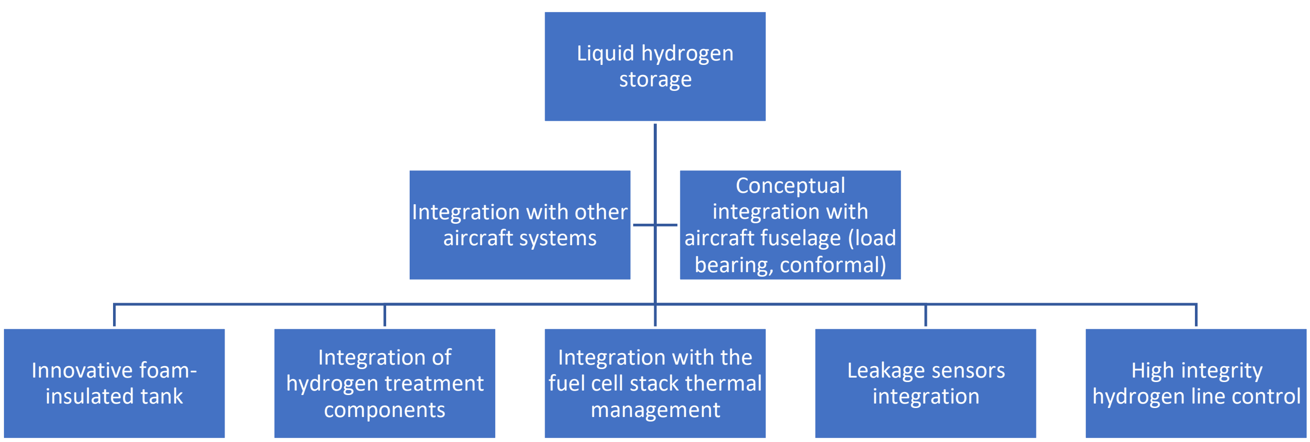

Figure 23: Composition of the liquid hydrogen storage technology demonstrated in NEWBORN

Sub-system Concept definition: Liquid hydrogen storage – FC80pax	
Key characteristics	Value or description
Conceptual technology	~~Load bearing~~**, conformal tank, dual foam insulated. Inherently safe with respect to the hazard of vacuum loss.
Load bearing**	No**
Conformal	Yes, external tank structure is the airframe (in principle, within the rear fuselage section).**
Gravimetric index – Isolated tank (excluding aircraft structure) *	0.51 @ 1.100 kg needed for FC80pax
Gravimetric index – tank including hydrogen preconditioning and venting equipment (excluding aircraft structure) *	0.43 @ 1.100 kg
Incorporation of the hydrogen treatment equipment	Yes, in an insulated equipment bay
H2 flow requirements	140 g/s continuous; 172 g/s transient peak

*Guidance on values provided: An isolated tank has better GI than the one including the preconditioning & venting equipment because we are adding components, but that addition would weight more if performed in an isolated tank. A dual tank with redundancy has slightly worse GI due to the addition of piping, control equipment and insulation.

** Linked project H2ELIOS supplying the cryogenic vessel technology has revised the project scope to not include load bearing aspects to meet certifiability requirements within the necessary timeframe; this characteristic and KPI is therefore obsolete and retained only for context.

3.13.2 Aircraft concept applicability

It is assumed that for CS-25 aircraft, the hydrogen storage and treatment solution will be dual redundant, with partial redundancy in the insulation. However, due to specific aircraft architecture design solutions, a complete dual tank approach could be also considered.

In case of FC80Pax configuration, the LH2 tank would be positioned in the rear fuselage just behind the pressure bulkhead (non-pressurized area) and have a conical trunk shape with spherical dome ends. Due to the position of the powerplant elements, LH2 supply and conditioning equipment would be installed in the front end of the tank in a ventilated and monitored area to avoid H2 concentration in case of leakage. Further structural integration implementation is possible and could consider more intimate structural arrangements of this LH2 storage concept. Considering the volume devoted to LH2 storage in the a/c the redundancy provisions needed would imply an actual partition of that volume generation two independent tanks that would need its own piping arrangement. The concept still benefits from some non-safety critical synergies regarding insulation which mitigate gravimetry drop.

Main structural arrangement between tail (T-type) and fuselage would not interfere in this a/c configuration as per information provided from the OEM.

3.13.3 Sub-system Level Key Performance Metrics

KPIs					
Title	**Target**	**Status**	**SoA**	**% vs reference**	**Comments**
Gravimetric Index (for 1100 kg LH2)	>50%	43%	20% for 500 kg of LH2	+15 p.p. vs. SoA, 86% of target	Current DEWAR technology reaches even lower GI values for greater capacity. Reference case (SAG Heavy-Duty truck tank concept) has a 9,1% for a much smaller tank (40 kg LH2).
Dormancy with zero venting at 150 kg / 3,5 bar (starting condition)	>12 hours	12 hours	N/A	100% of target	No comparable technology. Reference case (SAG Heavy-Duty truck tank concept) has a holding time of 8 days for a much smaller tank (40 kg LH2).

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2025	2029
Year Achieved	2022	2024	Planned in 2025	-	-

The TRL levels according to definition in Annex B, section 4.

Potential Barriers
- Airworthiness authority and other regulators feedback on the solution characteristics, either due to a delay in the information delivery or to an identification of major showstoppers. - Availability of LH2 at reasonable costs and quantities to perform tests. - Major challenges in a/c integration of hydrogen technologies (not related with storage) that could block the project (i.e., propulsion, contrails effects, etc.). Not specifically addressed in NEWBORN.

3.14 Summary of the main propulsive systems KPIs

Note: The definition of the KPIs contracted in the Grant Agreement and the ones requested by Clean Aviation for impact monitoring are different. The values herein are provided to enable simplified comparison with competing technologies at the aircraft level.

The values are based on estimated product component weights, not the weights of components used on the TRL4 ground demonstrator.

	Subsystem weight [kg]				**Peak FC power [kW]**	**SFC** [15] **[H2 g/pax/nm]**	**Water emissions [g/pax/nm]**	**Total E cons. [MJ/pax/nm]**
	FC Power source [16]	**Battery system**	**Electric propulsion system**[17]	**LH2 storage system**[18]				
HERA-UCA	2x1096 or N/A	2x1104 (for 2x255 kWh)[19]	2x255 (for 1.1 MW)[20]	1144 (for 600 kg of LH2) or N/A	2x1440 or N/A	Estimation to be provided by HERA project.		
HERA-UCB	2x1096	2x1104 (for 2x255 kWh)	N/A	1144 (for 600 kg of LH2)	2x1440			
Miniliner	2x400 or 4x265	2x460 (for 2x106 kWh)	2x250 (for 1.0 MW)	900 (for 300 kg of LH2)	2x480 or 4x240	18	162	2.27
FC 80pax	2x3056	8x184 (for 8x42.5 kWh total)	4x488 (for 4x2.1 MW)	1458 (for 1100 kg of LH2)	4x2160	19	171	2.4

[15] For reference missions defined in the deliverable, different per aircraft type
[16] Dry weight including stacks with housing, BoP, output DC/DC conversion, thermal management excluding the radiators. Weight estimate for production components (i.e. not the ground demonstrator.)
[17] Motor, inverters, thermal management systems, lubrication system, gearbox, governor.
[18] Dry weight, including valves, preconditioning, and venting. Including partial redundancy for HERA, FC80pax, and Miniliner
[19] Necessary battery capacity and maximum power are still being analyzed by HERA, the value is based on internal assumption within the NEWBORN project and will change once more accurate requirements are defined by HERA.
[20] Integration in/with thermal engine can lead to further reduction, refer to HPA projects for hybrid propulsion

It needs to be noted that direct comparison of the weights with traditional technology is not possible at the subsystem level, and can be only performed at aircraft level to take into account the multitude of integration aspects. Refer to [3] (including latest revision, continuously updated throughout the project) for the in-depth analysis. Some of the reasons are:

A) No direct comparability of functions – the clean-sheet aircraft will either differ in or completely lack the kerosene fuel system, the APU is typically not needed for aircraft with plurality of fuel cell systems, the electric high power distribution is very aircraft integration dependent, drag from the fuel cell thermal management system plays significant role and must be aerodynamically co-designed with the aircraft, and others.

B) The increased weight and drag of the fuel cell propulsion system compared to kerosene turbine has a snowball effect on the aircraft weight, and consequently on the needed power, and consequently weight and drag – point studies cannot cover this.

C) The redundancy/availability requirements for the electric propulsion are different from the traditional turbine engines and must be considered during the sizing for specific aircraft FHA.

D) The detailed co-design of the aircraft with the propulsion system is needed.

E) The synergic use of fuel cell/battery system with other functions of the aircraft has to be carefully studied.

F) The piping, wiring, and installation is dissimilar to traditional systems, and has to be carefully optimized.

We therefore argue that any meaningful comparison must be made at the conceptual aircraft level utilizing the presented subsystems, and not at the subsystem level with respect to alternative propulsive solutions.

4 KEY TECHNOLOGY LEVEL

The key technologies in the project are:

- Aircraft-optimized modular high power density fuel cell stack with higher operating temperature with lightweight humidity management
- Stack air supply line (subsystem) for FL250
- Self-regulated, load bearing, conformal LH2 tank
- High power density electric motor and inverter
- Parallelizable high power density DC/DC converters
- Next generation microtube heat exchangers with low pressure drop
- High voltage battery pack
- High power density air compressor inverter for non-pressurized environment

4.1 Key technology 1 – Aircraft-optimized modular high power density fuel cell stack with higher operating temperature

4.1.1 Key Technology Concept Definition

Key technology definition: Aircraft-optimized modular high power density fuel cell stack with higher operating temperature	
Key characteristics	Value or description
Typical stack efficiency	~60% (trade with weight of other system components)
Maximum operating temperature	>100 °C (coolant outlet temperature)
Technology	PEM
Power	Modular in range of 300 – 1000 kW, further parallelizable to 4 MW per aircraft side
Fit for purpose	Aircraft-optimized, not automotive
Target durability	20 000 hours (with maintenance)
Power density	>5 kW/kg

4.1.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Power density	5 kW/kg	3.75 – 6.64 kW/kg depending on boundary definition	<4.7 kW/kg	+6 pp.	Fuel cell stack (cell package): 6.64 kW/kg Core stack with balance of stack & enclosure flange: 4.85 kW/kg Stack module with housing and auxiliaries: 3.75 kW/kg
Power per single module	300 kW gross	300 kW gross	100-130 kW	300%	Parallelizable
Operating temperature	100 °C	100 °C	85 °C	+15 °C	Safe coolant outlet temperature
Stack BoL efficiency at take-off conditions	>55%	>56%	~50%	+1 pp vs. target, +6 pp vs. SoA	Varies depending on the specific optimization for aircraft. Not an important value, system efficiency is what matters.
Required cathode air relative humidity	<=50%	40-50%	30-50%	Not relevant	The humidity requirement added based on explicit request of Clean Aviation project office, despite not being considered critical for the Balance of Plant architecture of NEWBORN.

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	2023	2025	2026	2028
Year Achieved	<2022	2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

4.2 Key technology 2 – Stack air supply line (subsystem) for FL250 with lightweight humidity management

4.2.1 Key Technology Concept Definition

Key technology definition: Stack air supply line (subsystem) for FL250 with lightweight humidity management	
Key characteristics	Value or description
Air supply for the high power stack	FL250 ceiling altitude for propulsion
Air supply architecture re-scalable for SPU use case	Conceptual design for FL450
Lightweight humidity management for the stack	Avoid using membrane humidifiers, MTBF > 40 000 hrs
High humidity management durability and compatibility with the higher temperature stack	

4.2.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Ceiling altitude	FL250	FL250	<FL100	On target	
Scalability to high altitude	FL450	FL450	<FL100	On target	
Compatibility with high temp fuel cells	100 °C	100 °C	85 °C	On target	
Mass for 720 kW fuel cell power source power use	<180 kg	120 kg	N/A	66%	No reference

Mass for HERA single side system	<200 kg	~145 kg	N/A	72.5%	No reference
Air intercooler total unit mass	<10 kg	5 kg	N/A	50%	

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2025	2027	2028
Year Achieved	2022	2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

4.2.3 Technology Level Key Performance Metrics Relevant for HERA

The following figures were shared with the HERA project (key metrics only herein):

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Ceiling altitude	FL250	FL250	<FL100	On target	
Mass for HERA single side system (out of 2)	<200 kg	~145 kg	N/A	72.5%	No reference
Maximum dry air inlet for air supply subsystem per aircraft	<1.5 kg/s	1.32 kg/s	N/A	88%	
Air outlet temperature	No target	40-60 °C	N/A	N/A	Not a KPI for NEWBORN but critical for aircraft

4.3 Key technology 3 – Self-regulated, load bearing, conformal LH2 tank

4.3.1 Key Technology Concept Definition

Key technology definition: Self-regulated, load bearing, conformal LH2 tank	
Key characteristics	Value or description
Conceptual technology	Conformal tank easily adapted to fully cylindrical or trunk conical geometries for adaptation in rear fuselage, dual foam insulated, safe with respect to the hazard of vacuum loss
Hydrogen supply flow rate	12 g/s (cont.) & 15 g/s (pk.) for the demonstrator, 22 g/s cont. for single side of HERA
Vaporization and preheating	Thermally driven vaporizer and preheater including control integrated with the tank
Safety venting	Including, redundant
Integration	Functionally integrated with the fuel cell power source

4.3.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Gravimetric Index (for 150 kg demonstrator)	>35%	20% for an optimized product	20% for 500 kg of LH2	57% of target	Current DEWAR technology reaches even lower GI values for greater capacity. (It has not been found a direct comparable case)
Gravimetric Index (for 600 kg LH2 product)	>35%	34,4%	20% for 500 kg of LH2	+30 p.p. vs. SoA, 98% of target	Current DEWAR technology reaches even lower GI values for greater capacity. (It has not been found a direct comparable case)

Dormancy with zero venting at 150 kg / 3,5 bar (starting condition)	>12 hours	12 hours	12 hours	On target	No comparable technology.
Demonstrator hydrogen mass flow	>12 g/s	>15 g/s	N/A	On target	
Range of hydrogen temperature control	±10 K from nominal	±10 K from nominal	N/A	On target	
Supply line evaporation rate control	0-15 g/s	0-15 g/s	N/A	On target	
H2 supply pressure	4.5 – 6 barA	4.5 – 6 barA	N/A	On target	
Minimum hydrogen evaporator power transfer	8 kW for unit optimized for 3 substacks	10 kW	N/A	N/A	
Minimum hydrogen preheater power transfer	48 kW for unit optimized for 3 substacks	60 kW	N/A	N/A	

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2025	2029
Year Achieved	2022	2024	Planned in 2025	-	-

The TRL levels according to definition in Annex B, section 4.

4.4 Key technology 4 – High power density electric motor and inverter

4.4.1 Key Technology Concept Definition

Key technology definition: High power density electric motor and inverter	
Key characteristics	Value or description
Electric Motor	>1 MW, conceptually scalable to other power levels
Propulsion inverter	>1 MW, internally redundant

4.4.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/ technology**
Motor power density	18 kW/kg	18 kW/kg	5-8 kW/kg	225-360%	
Motor efficiency	>98%	98%	~95%	40% of losses +3 pp.	Nominal speed eff.
Inverter power density	18 kW/kg	18 kW/kg	5-10 kW/kg	180-360%	
Inverter efficiency	>98%	98%	~95%	40% of losses +3 pp.	Max P eff.

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	<2023	2026	2027	2028
Year Achieved	<2022	<2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

4.5 Key technology 5 – Parallelizable high power density DC/DC converters

4.5.1 Key Technology Concept Definition

Key technology definition: Parallelizable high power density DC/DC converters	
Key characteristics	Value or description
Fuel cell stack DC/DC converter	Bus-tie high voltage DC/DC converter with efficiency of >98%, scalable by parallelization to multi-MW levels
Battery DC/DC converter	Battery high voltage DC/DC converter with efficiency of >98%

4.5.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Power density – stack bus-tie DC/DC converters [kW/kg]	>20 technology 15 kW/kg in the demonstrator application	18 kW/kg	2-5	400-1000%	The power density of the DC/DC converter in the application depends on the details of their use, especially in this case the range of input voltage.
Efficiency – stack bus-tie DC/DC converters [%]	>98%	98%	95-96%	2-3 pp.	Maximum power efficiency
Power density – battery DC/DC converters [kW/kg]	>20 technology 18 kW/kg in the demonstrator application	18 kW/kg	2-5	400-1000%	The power density of the DC/DC converter in the application depends on the details of their use, especially in this case the range of input voltage.

Efficiency – battery DC/DC converters [%]	>98%	98%	95-96%	2-3pp.	Maximum power efficiency

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	2023	2025	2026	2028
Year Achieved	<2022	<2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

4.6 Key technology 6 – Next generation microtube heat exchangers with low pressure drop

4.6.1 Key Technology Concept Definition

Key technology definition: Next generation microtube heat exchangers with low pressure drop	
Key characteristics	Value or description
Stack and BoP cooling heat exchangers	Microtube heat exchangers with optimized pressure drop

4.6.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Heat rejection for demonstrator	754 kW + 142 kW (2 loops)	815 kW + 142 kW	N/A	N/A	The heat exchangers are very specific and no SoA can be easily quantified.
Heat rejection proj. for Miniliner	455 kW + 103 kW (2 loops)	455 kW + 103 kW	N/A	N/A	
Coolant pressure drop	<50 kPa & 25 kPa	~45 kPa & 30 kPa	N/A	N/A	Reference not available
Total core mass (excl. ducting and manifolding) for demonstrator	<150 kg	130 kg wet mass of the core	~200 kg	~75%	Reference value is an engineering judgement, as heat exchangers' weight is very sensitive to definition of boundary conditions

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	<2023	2025	2026	2028
Year Achieved	<2022	<2023	Project partner in administration, discussing with alternative suppliers.		

The TRL levels according to definition in Annex B, section 4.

4.7 Key technology 7 – High voltage battery pack

4.7.1 Key Technology Concept Definition

Key technology definition: High voltage battery pack	
Key characteristics	Value or description
Nominal voltage	800 V
Energy capacity	At least 100 kWh
Power capacity	At least 350 kW

4.7.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Maximum voltage	800 V	806V max voltage	400 V	100% of target, 200% vs. SoA	Pipistrel Velis Electro
Energy capacity	>100 kWh	127.5 kWh	10 kWh	127% of target, 1000% of SoA	Pipistrel Velis Electro
Power	>350 kW	446 kWcont., 690 kWpk.	47 kW	127% of target, 744%	Pipistrel Velis Electro
Battery endurance (full depletion)	>500 cycles	>500 cycles	500 cycles	100%	Pipistrel Velis Electro
Battery endurance (flights)	>2000 flights	>2000 flights	2000 flights	100%	Pipistrel Velis Electro

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6

Year Planned	2022	2023	2024	2025	2027
Year Achieved	2022	2023	Est. Q1/2025		

The TRL levels according to definition in Annex B, section 4.

4.8 Key technology 8 – High power density air compressor inverter for non-pressurized environment

4.8.1 Key Technology Concept Definition

Key technology definition: High power density air compressor inverter for non-pressurized environment	
Key characteristics	Value or description
Electric air compressor inverter	High-efficiency, high power density inverter/motor controller for electric air compressors, immune to high voltage effect at altitude

4.8.2 Technology Level Key Performance Metrics

Main technology performance metrics

KPIs / Quantified Performance Targets at project end and beyond (efficiency, kg, kW, CL/CD, etc.)					
Title	**Target**	**Status**	**SoA**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Efficiency	>98.5	98.5	~96	+ 2.5 pp	Max power eff.
Power density	20 kW/kg	20 kW/kg	~3 kW/kg	666%	Existing aerospace designs

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	<2022	<2023	2025	2026	2028
Year Achieved	<2022	<2023	-	-	-

The TRL levels according to definition in Annex B, section 4.

5 GAP ANALYSIS – 2024

This section summarizes the technology gap analysis for the introduction of the systems into practice, reflecting the state of knowledge at the end of November 2024. This list is not considered final but reflects the state of current knowledge.

Table 29 – Main technology gaps towards productization

	Aircraft deployment		
Key technology	**CS-23**	**CS-25 hybrid**	**CS-25 fully fuel cell electric**
Fuel cell stack (section 4.1)	Continuous improvements in MEA durability (EOL performance improvement) needed. Characterization of composition of relevant air pollutants in aircraft operating environment.		Demonstration aircraft: no gap. Production aircraft: Continuous reduction of maintenance requirements.
Air supply subsystem (s. 4.2)	No technology gap, only development of optimized production units. Further development of air filtering solutions to cover requirements of future MEAs.		Demonstration aircraft: no gap. Production aircraft: ~3x up-scaling of powers/flow rates
Cryogenic tank (s. 4.3)	Crashworthiness, life and durability improvements, detailed design of the structural health monitoring. Dual-redundant tank (for some applications).	Development of dual-redundant tank, volume upscaling, crashworthiness	
Motor and inverter (s. 4.4)	Oil-cooled inverter (instead of EGW)	No technology gap, machine redesign to different aspect ratio and optimum speed	Power level upscaling or machine paralleling design
DC/DC converters (s. 4.5)	Development of buck/boost topology converter in addition to the existing – enabler for better system power density for >500kW FC power source		Higher operating voltage converter and DC bus (improvement over the values reported for the concept herein)
Heat exchangers (s. 4.6)	No technology gap, but production design adaptation of the geometric arrangement for efficient aircraft installation is critical. Integration with the aircraft specific aerodynamic design is critical for deployment. Integration with the aircraft-specific variable geometry actuators (and their potential development) is needed. New suppliers.		
Battery (s. 4.7)	No gap, but continuous improvements in power and energy density have dramatic effect on	No gap, but further development of higher power optimized (higher C	No gap, but continuous improvements in power and energy density have dramatic

	aircraft performance. Increase of cycle life to drive down the cost.	rates) batteries will dramatic effect on aircraft performance. Cell durability improvements (or cost reduction of power-optimized chemistry cells)	effect on aircraft performance. Improvement: compatibility with higher voltage power distribution system.
Air compressor inverter (s. 4.8)	No gap	No gap	Demonstration aircraft: no gap Production aircraft: possible change in internal inverter configuration

Table 30 - Gaps towards deployment on other project elements

Control system: development of the DO-254, DO-160G, and DO-178C compliant control system, ideally for non-pressurized environment (known technology)
Thermal management system and ram channels: detailed co-optimization with the aircraft aerodynamics (known technology)
Ventilation and H2 leak detection: platform-specific design of the ventilation and leak detection system geometric arrangement
General development and qualification of flight-worthy production designs of all components
Air filters: development of fuel cell specific air filter production units
Propulsion system: simplification of the lubrication and cooling system – single shared medium (improvement of power density)
Collection of detailed flight data for prognostic health monitoring algorithms development (needs instrumented demonstrator aircraft with sufficient amount of flight hours in various operating conditions)

Table 31 - Generic technologies, further development, and infrastructure gaps

Clean-sheet aircraft platforms design (not retrofits)
Ground infrastructure development
Development of the full concept of operations, including ATM aspects, onboard energy management, airport operations, etc.
Liquid hydrogen production (and transportation) infrastructure development, electric power generation infrastructure development supporting the LH2 production
Development of CS-23 certification baseline (final Special Condition, final Means of Compliance) **Development of CS-25 certification baseline (expected rule-based, not performance-based) – needs prior service experience on CS-23**
Redundant component supply base development for most production components
Standardization (H2 distribution, LH2 supply, HVDC bus and all connected components, ...)
Reduction of unit cost through production volume & commonality supported by standardization
Improvements: Improvements in cryotank gravimetric index, power density of all system components, and installation volume
Improvements: higher distribution system (and DC/DC converters) voltage while being immune to partial discharge
Improvements: Development of higher temperature (~180 °C) PEM fuel cell stacks (non-PBI) with high durability and cruise efficiency of >45%
Airport operations concepts and design
Study of long-term low-concentration hydrogen exposure embrittlement immunity of various materials
ATM procedures optimized for fuel cell aircraft
Development of standard operating procedures
Active distributed arc fault detection integration to the HVDC power distribution
Maintenance, repair and overhaul, and disposal infrastructure development
Development and expansion of the test infrastructure towards production-oriented testing (qualification, acceptance testing, ...)

6 ANNEXES

A. Impact Monitoring organization

CLEAN AVIATION

C2 - Confidential

Impact Contribution Monitoring Principles

PRINCIPLE : the Impact Contribution Monitoring will strive to provide information at aircraft level on GHG reduction potential of technologies developed at TRL 6 during the life of the Clean Aviation programme in relation to the SRIA & SBA objectives.

ALIGNMENTS:

- ✓ Impact Contribution to be monitored through the SMR & HER pillars.
- ✓ It is assumed that the projects selected following the open calls and independent evaluations will enable the achievement of the high level impact objectives at aircraft level. *Clarification required to determine if the projects identified through the calls and project deliverables committed through the Grant Agreements shall demonstrate the achievement of the SBA GHG commitments (-30% ACAP & -50% HERA)*
- ✓ The Reference Aircraft configurations + assumptions will be defined by ACAP & HERA and communicated to the respective project partners.
- ✓ In Phase I, the consolidation of data and assessment shall be performed through ACAP & HERA + mechanism for projects which are not related or taken into account in the SMR/HER pillars.
  Requirement to ensure that a viable solution is identified to use the same tool and initial data in Phase II.

REQUIREMENTS:

- Impact Contribution assessment tool at aircraft level/mission to be identified by ACAP & HERA in accordance with their Grant Agreements.
- On the basis of the communicated Reference Aircraft and configuration hypotheses, the TC may recommend to the Governing Board for adoption additional criteria and metrics against which the impact contributions could be measured. The Governing Board to discuss potential alternative routes to single technology impact contribution monitoring.
- Any evaluations by external advisory bodies deemed necessary for Phase I are to be performed using the same coordinated assumptions as those applied by ACAP/HERA.
- Some technologies will be developed but will not bring an impact when assessed in relation to the ACAP//HERA Reference a/c and some components/sub-systems might bring a value but not on the retained a/c configuration, but another proven configuration. Technical discussions to take place when appropriate between the private partners and the programme office to address this matter and identify mitigating actions.

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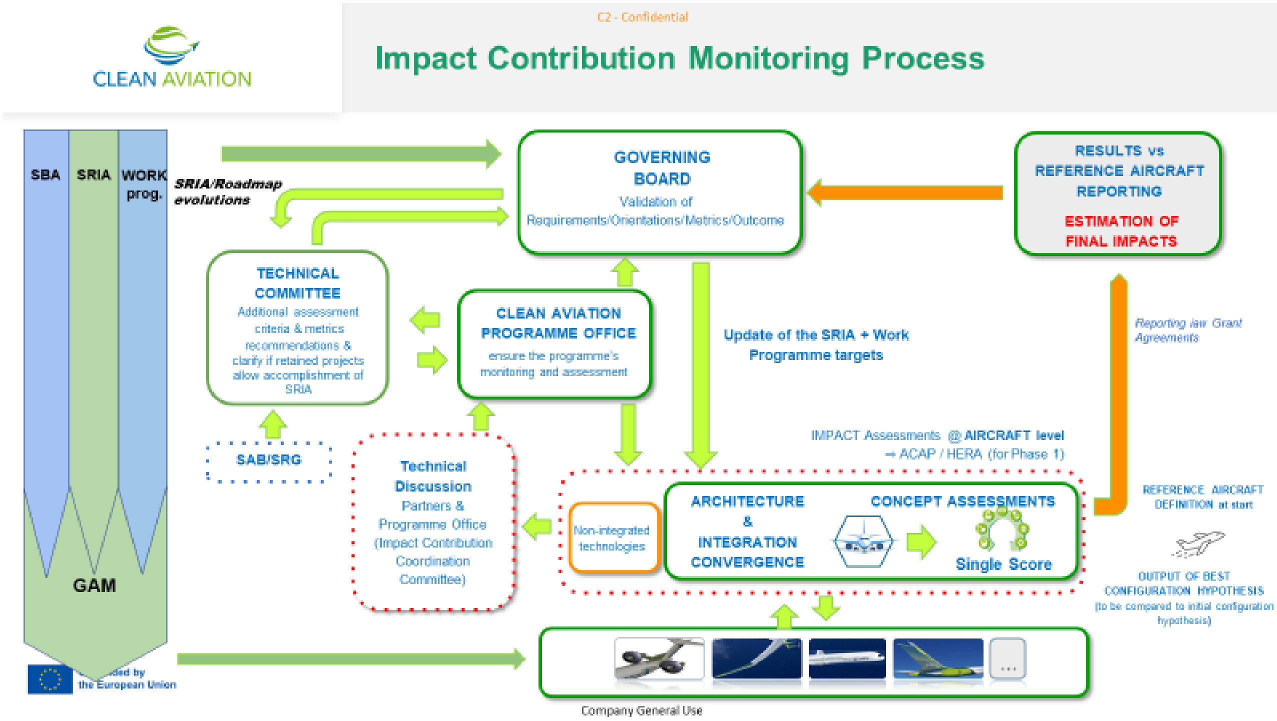
C2 - Confidential
Impact Contribution Monitoring Process
SBA
SRIA
WORK prog.
GAM
SRIA/Roadmap evolutions
GOVERNING BOARD
Validation of Requirements/Orientations/Metrics/Outcome
RESULTS vs REFERENCE AIRCRAFT REPORTING
ESTIMATION OF FINAL IMPACTS
TECHNICAL COMMITTEE
Additional assessment criteria & metrics recommendations & clarify if retained projects allow accomplishment of SRIA
CLEAN AVIATION PROGRAMME OFFICE
ensure the programme's monitoring and assessment
Update of the SRIA + Work Programme targets
Reporting iaw Grant Agreements
SAB/SRG
Technical Discussion
Partners & Programme Office (Impact Contribution Coordination Committee)
IMPACT Assessments @ AIRCRAFT level
→ ACAP / HERA (for Phase 1)
Non-integrated technologies
ARCHITECTURE & INTEGRATION CONVERGENCE
CONCEPT ASSESSMENTS
Single Score
REFERENCE AIRCRAFT DEFINITION at start
OUTPUT OF BEST CONFIGURATION HYPOTHESIS
(to be compared to initial configuration hypothesis)
the European Union
Company General Use

B. Technology Readiness Level

This Annex provides additional guidance to define the Technology Readiness Level (TRL)s for the purpose of the Clean Aviation Phase 1 project Impact Monitoring.

The technology readiness level is a method of estimating the maturity of technologies during the acquisition phase of a program. TRL was developed by NASA and later the US Department of Defense, with the European Commission advising EU-Funding research projects to adopt the scale in 2010.

The baseline definition for TRLs for Horizon Europe projects is inherited from Horizon 2020, where a general definition of TRL is provided as part of the Part 19 – Commission Decision C(2017)7124 Annex G.

G. Technology readiness levels (TRL)

Where a topic description refers to a TRL, the following definitions apply, unless otherwise specified:

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

The sections below propose generic and non-prescriptive guidance based on the original TRL process definition and cross industry best practices identified. They are intended to achieve alignment on key concepts to homogenize the definition across the different Clean Aviation projects.

1. Technology readiness level applicability

Ideally, TRL assessment should be formally performed by an independent team, as a way of avoiding potential conflicts of interest between the team responsible for the development of the technology and the team performing.

TRL method should be used to estimate the maturity of a component, sub-system or aircraft, whenever a "critical" technology (CT) is being acquired.

A technology is "critical" if the component, sub-system or aircraft depends on this technology element to meet operational requirements (within acceptable cost and schedule limits) and if the technology element or its application is either new or novel or in an area that poses major technological risk during detailed design or demonstration.

2. Key concepts definition

When assessing a TRL level, certain concepts need to be clearly understood. The table below provides a summary of key terms utilized as part of the TRL level definition:

Term	Definition
Breadboard	Integrated components that provide a representation of a system/subsystem and that can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.
High Fidelity	Addresses form, fit, and function. A high-fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.
Low Fidelity	A representative of the component or system that has limited ability to provide anything but first-order information about the end product. Low-fidelity assessments are used to provide trend analysis.
Model	A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.
Operational Environment	Environment that addresses all the operational requirements and specifications required of the final system to include platform/packaging.
Prototype	A physical or virtual model used to evaluate the technical or manufacturing feasibility or military utility of a particular technology or process, concept, end item, or system.
Relevant Environment	Testing environment that simulates both the most important and most stressing aspects of the operational environment.
Simulated Operational Environment	Either (1) a real environment that can simulate all the operational requirements and specifications required of the final system or (2) a simulated environment that allows for testing of a virtual prototype. Used in either case to determine whether a developmental system meets the operational requirements and specifications of the final system.

Ref Technology Readiness Assessment (TRA) Deskbook; US Department of Defense

The definition of Relevant Environment (TRL5-6) and Operational Environment (TRL7-8) is a common source of discussion when assessing a technology readiness level and hence, further clarification should be provided.

As such, a technology that is demonstrated in a relevant environment should demonstrate that either

(1) Shows that the CT satisfies the required functionality across the full spectrum of **intended operational employments**

or

(2) Shows that the CT satisfies the functional need for some important, intended operational employment(s) and then uses accepted analytical techniques to extend confidence in

supporting the required functionality over all the required, **intended operational employments**.

A technology that is demonstrated in an operational environment should demonstrate that either

(1) Shows that the CT satisfies the required functionality across the full spectrum of **operational employments**

or

(2) Shows that the CT satisfies the functional need for important, operational employment(s) and then uses accepted analytical techniques to extend confidence in supporting the required functionality over all the required **operational employments**.

3. TRL Description and supporting information

The table below proposed by the US DoD, provides additional description and supporting information to the TRL definition. The TRL assessment should consider these when defining the evidence and rationale for the TRL level definition:

Hardware TRL Definitions, Descriptions, and Supporting Information		
TRL Definition	**Description**	**Supporting Information**
1 *Basic principles observed and reported.*	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2 *Technology concept and/or application formulated.*	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3 *Analytical and experimental critical function and/or characteristic proof of concept.*	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4 *Component and/or breadboard validation in a laboratory environment.*	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5 *Component and/ or breadboard validation in a relevant environment.*	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?
6 *System/subsystem model or prototype demonstration in a relevant environment.*	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7 *System prototype demonstration in an operational environment.*	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8 *Actual system completed and qualified through test and demonstration.*	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9 *Actual system proven through successful mission operations.*	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

Ref: Technology Readiness Assessment (TRA) Deskbook;US Department of Defense

4. Alternative TRL definition

The project uses an EU directive definition of the TRL, complemented by the US DoD definition. The specific detailed interpretation of the levels is further provided with main clarifications highlighted.

- TRL1: Basic principles observed.
    - Technology basic principles formulated.
- TRL2: Technology concept formulated.
    - Analytical studies confirm the technology concept feasibility in first principles.
- TRL3: Experimental proof of concept.
    - Demonstrates main principles of the technology, and feasibility of achieving the desired performance without change of the Critical Technology.
    - Physical demonstration
    - **Technology components are not required to be integrated into the target higher level architecture. The demonstration focuses on isolated validation of the technology with simulated interfaces.**
    - May use Breadboards.
        - Breadboard denotes a set of integrated components providing a representation of the technological element used to determine the concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble the final system in function only.
- TRL4: Technology validated in laboratory environment.
    - **Demonstrates proper function when integrated with interfacing systems or their functionally representative surrogates.**
    - **Technology components integrated to establish they perform the intended functions together.**
    - May be Low Fidelity **but must be representative for the key parameters of the technology.**
        - Low Fidelity denotes a representative of the component or system that has limited ability to provide anything but first-order information about the end product.
- TRL5: Technology validated in relevant environment.
    - Relevant environment simulates both the most important and most stressing aspects of the operational environment.
    - **Relevant environment validation demonstrates that technology satisfies functional needs for the important environmental conditions (corner points) and may use analytical techniques to interpolate the coverage across the whole operating envelope.**
    - **May use representative Models, as long as the results can be extrapolated to the intended final form of the technology/system.**
        - Model denotes a functional form of a system, generally reduced in scale, near or at operational specification. Models are sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.
    - The basic technological components are integrated together with reasonably realistic supporting elements to allow for testing in Simulated Environment.
        - Simulated environment denotes and environment representing all the operational requirements required from the target environment.

        - Simulated environment at TRL5 doesn't necessitate demonstration in simultaneous combination of the environmental aspects unless such combination is explicitly defined as critical for the technology.
    - Should use High Fidelity components or their Models.
        - High Fidelity addresses form, fit, and function.
    - Uses environmentally representative packaging for critical technology elements.
    - **May use substitute components with representative functions, where their individual technology has been demonstrated at or above TRL5.**
- TRL6: Technology demonstrated in relevant environment.
    - Relevant environment simulates both the most important and most stressing aspects of the operational environment.
    - **Relevant environment demonstration confirms that technology satisfies functional needs for the important environmental conditions (corner points) and may use analytical techniques to interpolate the coverage across the whole operating envelope.**
    - **At or near the design configuration in terms of performance, weight, and volume. Technological components meeting requirements for experimental aircraft demonstration.**
    - **Typically, ready for experimental aircraft installation.**
- TRL7: System prototype demonstration in operational environment
    - Prototype denotes a physical or virtual model used to evaluate the technical or manufacturing feasibility and utility of the technology.
    - **Typically, passed flight demonstrations.**
- TRL8: System complete and qualified
    - Final design verification tests complete
- TRL9: Actual system proven in operational environment.
    - System deployed in practice in target operating conditions.