NEWBORN - NExt generation high poWer fuel cells for airBORNe applications

WP12 – Project Management

D12.18 Impact Monitoring – Reference, KPIs, Targets, and TRL

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REVISION HISTORY

Revision	Date	Revision summary
00	2023-06-30	Initial issue

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

REFERENCES

ID	Reference	Title	Revision
1	GA101101967	NEWBORN project Grant Agreement	2022-12-31
2	NS-WP01-SE-NO-DEL-100001	Aircraft-level requirements summary	01
3	NS-WP01-SE-NO-DEL-100002	Regional and Commuter aircraft integration concepts description	00
4	NF-WP04-SE-NO-DEL-400003	Preliminary stack specification	00
5	NE-WP08-PU-NO-DEL-800001	D8.27 Propulsion motor and inverter trade study summary	00
6	NS-WP01-SE-NO-DEL-100004	D1.4 Paralleling provisions requirements	00
7	NE-WP08-SE-NO-DEL-800001	D8.1 Electrical architecture & topology report	00
48	ND-WP08-IN-NO-DEL-800002	D8.278 Motor, Inverter and Control PDR	Draft
9	NT-WP05-SE-NO-DEL-000001	D5.2 TMS Architecture Studies Report	Draft
10	NT-WP05-SE-NO-DEL-500003-00	D5.3 Aircraft-level thermal management analysis report	Draft
11	Lefebvre, A.H., Ballal, D.R.: Gas turbine combustion, CRC press, 2010	Gas turbine combustion	N/A
12	Textron Aviation Inc., "Type Certificate Data Sheet No. A00016WI - Model 408," Department of Transportation - Federal Aviation Administration, Wichita, Kansas, March 2022.	TCDS No. A00016WI	00
13	UNIFIER19, "D3.3.: Conceptual design report including LCA - open," Clean Sky 2 Joint Undertaking, September 2022.	UNIFIER19-D3.3	00
14	https://cessna.txtav.com/en/lp/skycourier-splash-lp	Cessna SkyCourier data	00

15	**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.**	**Emission Indexes**	**00**
16	**Gierens, K. (2021). Theory of contrail formation for fuel cells. Aerospace, 8(6), 164.**	**Fuel cell contrails**	**00**
17	https://web.archive.org/web/20181106021310/http://www.geocities.jp/nomonomo2007/AircraftDatabase/AWdata/AviationWeekPages/GTEnginesAWJan2008.pdf	**Engine data**	**00**
18	**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
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
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

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

[1] Other than SMR ACAP and HERA

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 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

[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).

- 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.

This template document aims at providing guidelines to ensure a homogeneous collection of data in view of supporting the performance assessment of aircraft concepts under investigation and the achievement of the High Level Objectives of the Clean Aviation Programme.

2 AIRCRAFT CONCEPT LEVEL – HERA-UCA

2.1 Concept HERA-UCA

This aircraft concept will be 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
- Fuel cell power source integrated within the fuselage, powered by the LH2 tank located in the tailcone
- 1.0 - 1.1 MW of peak electric propulsive power per engine
- Ceiling altitude of FL250

2.2 Reference aircraft definition

The reference aircraft will be detailed by HERA project.

2.3 Typical Mission for Impact Monitoring

Typical mission for the reference aircraft will be detailed by the HERA project.

2.4 Aircraft Concept

The description of the HERA UCA concept will be provided by the HERA project.

3 AIRCRAFT CONCEPT LEVEL – HERA-UCB

3.1 Concept HERA-UCA

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
- Fuel cell power source integrated within the fuselage, powered by the LH2 tank located in the tailcone
- 1.0 - 1.1 MW of peak electric propulsive power per side of the aircraft
- Ceiling altitude of FL250

3.2 Reference aircraft definition

The reference aircraft will be detailed by HERA project.

3.3 Typical Mission for Impact Monitoring

Typical mission for the reference aircraft will be detailed by the HERA project.

3.4 Aircraft Concept

The description of the HERA UCB concept will be provided by the HERA project.

4 AIRCRAFT CONCEPT LEVEL – MINILINER

4.1 Concept Pipistrel Miniliner

1.1.1 Reference aircraft definition

The passenger version of the Cessna SkyCourier [12] [14], 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.

1.1.1.1 TLARs

Table 3 – TLARs of the reference aircraft. Sources: [12] [14].

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
Max Payload [tons]	2.268
Full fuel Payload [tons]	0.780
Cruise speed [Mach]	M = 0.35 (210 ktas @ 7620 m)
Design weights	MTOW = 8618 kg MLW = 8437 kg Maximum fuel weight = 2189 kg Maximum fuel volume = 2725 liters MZFW = 6429 kg MWE = 5591 kg
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

1.1.1.2 Emissions of the Reference Aircraft

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 [12]. The data for this engine is not publicly available in the ICAO Aircraft Engine Emissions Databank. For this reason, the average Emission Index values reported by Lee et al. [13] 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 4 – Emissions of reference aircraft. Sources: [13] [17]

Title	Value	Comments
SFC [kg/kW*h]	Not publicly available	0.326 kg/kW*h is sfc from P&W Canada PT6A-65B[3] [17]
CO_2 [kg/pax/nm]	0.446	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 as fuel weight used for reference mission. EI=3.16 kg CO2/kg fuel
NOx [kg/pax/nm]	1.98E-3	Same mission as above. EI=0.014 kg NOx/kg fuel
H2O [kg/pax/nm]	0.175	Same mission as above. EI=1.24 kg H2O/kg fuel
NvPM [kg/pax/nm]	3.53E-6	Same mission as above. EI=2.5E-5 kg soot/kg fuel
SO2 [kg/pax/nm]	1.13E-4	Same mission as above. EI=8E-4 kg SO2/kg fuel
Contrails[5]	Quantification is very uncertain.	

[3] Data for PT6A-65SC not available, considered PT6A-65B as closest.
[4] From payload-range diagram (Figure 2), 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).

1.1.1.3 Noise emissions of the Reference Aircraft

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. 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 [13] on the acoustic emission assessment of a conventional twin-prop aircraft are used. The described configuration is similar to the 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.

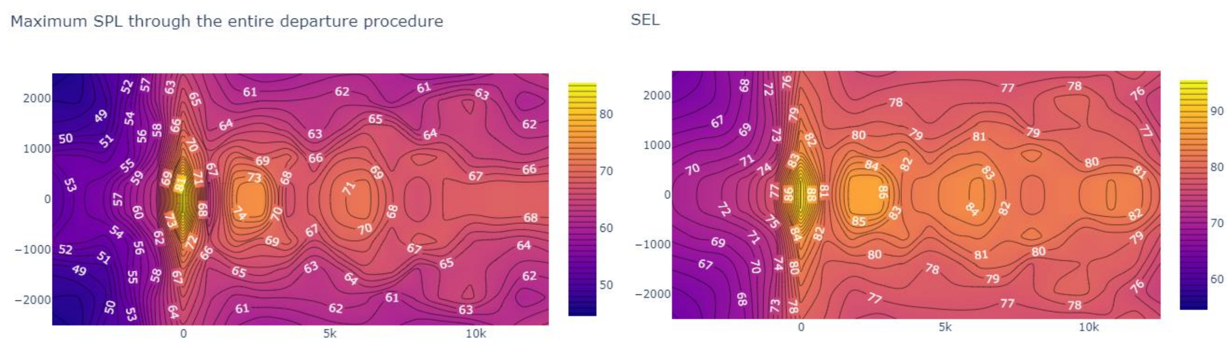

Figure 1 – Left: Maximum Sound Pressure Levels [dB] for reference aircraft (UNI19-CO) on the ground through the entire departure procedure. Right: Sound Exposure Levels on the ground for the entire departure procedure for conventional twin turbo-prop aircraft. Source: UNIFIER19 D3.3[13].

1.1.2 Typical Mission for Impact Monitoring

The reference mission of the Cessna SkyCourier (Passenger version) is considered as 386 nm range, flying at FL100 with 19 passengers, with 100 nm IFR reserve. The payload-range diagram of the Cessna SkyCourier (Passenger version) is shown in Figure 2.

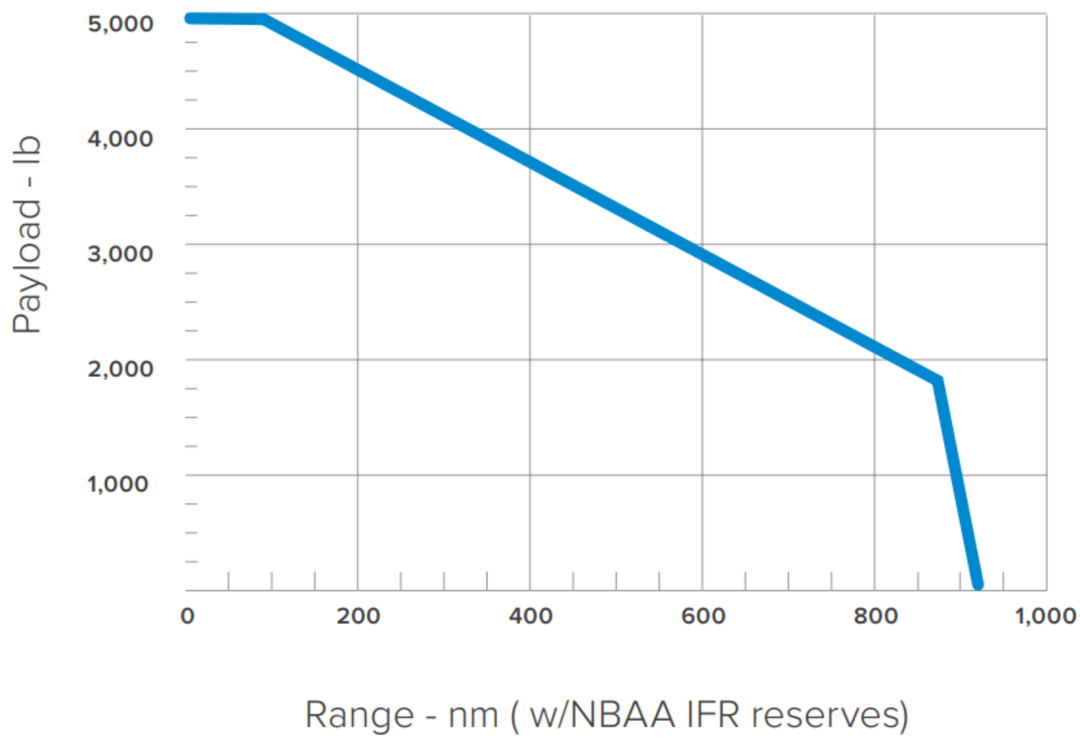

Figure 2 – Payload-range diagram of the Cessna SkyCourier (Passenger Version). Source: [14]

Cruise at 4000 ft and 150 kt cruise speed is considered. The 5-hop version is selected for Impact Monitoring, as it shows the best performance while keeping weight under CS-23 limit. The reference mission of the concept aircraft (Miniliner passenger version) is shown in Figure 3.

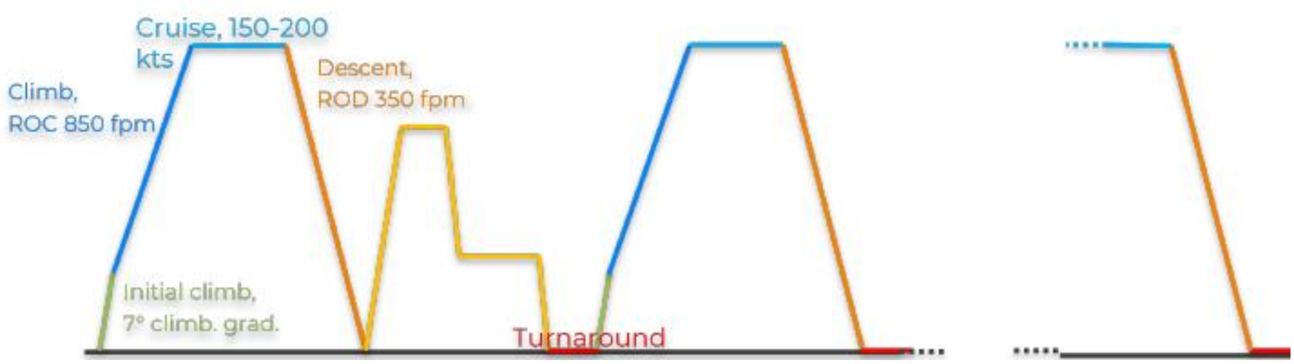

Figure 3 – 5-hop mission profile of the Pipistrel Miniliner. Source: UNIFIER19 project.

1.1.3 Aircraft Concept:

1.1.3.1 Aircraft concept definition

The Miniliner concept defined in the UNIFIER19 project is used as aircraft concept herein. This concept is depicted in Figure 4.

Figure 4 – Pipistrel Miniliner concept. This concept is illustrative; high-level aircraft concept definition can change with future developments and studies.

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

Table 5 – TLARs of the concept aircraft. Source: UNIFIER19 project [13]

CONCEPT NAME	Miniliner-UNIFIER19– 5 hops version
TLARs	
Fuel type(s) (Jet-A1, SAF, Elec., H2)	Liquid hydrogen
Design Range [nm] (max) - typical	(865 nm for 5 hops) – 173 nm per hop
# 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

fLHYing tank deliverables:

- D1.1 – Reference, KPIs, Targets and TRL.
- D1.2 – Report on safety studies.
- D1.3 – Report on system architecture tradeoff studies, flight test instrumentation layout and flight test requirements. Confidential annex on system requirements.

[6] 100 kg per pax + carry-on baggage; 20 kg per checked luggage; 19 passengers. Assumptions from UNIFIER19 D3.3 [13]

Table 6 – Key subsystems of the concept aircraft. Source: UNIFIER19 project [13].

Key Sub-Systems		
Sub-system	Description	CA project
Propulsion	H2-fuelled fuel cell system connected to propellers providing main thrust, and to Distributed Electric Propulsion propellers. Considerations are being made on the use of a tail propeller. Main propulsion layout TBD.	NEWBORN, HyPoTraDe
Fuselage & Empennage	Single aisle, 2x1 seats configuration, high-wing with DEP propellers, V-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)

- 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.

1.1.3.2 Aircraft level key performance metrics

Environmental and performance KPIs

Table 7 – Environmental KPIs of concept aircraft. Sources: [13] [16]

Environmental KPIs @ A/C level				
Title	**Target**	**Status**	**% vs reference**	**Comments**
GHG emission reduction	100%	>0%	-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	0.446	-100%	No carbon dioxide from use of hydrogen.
NOx [kg/pax/nm]	0.0	1.98E-3	-100%	No NOx from use of fuel cells.
H2O [kg/pax/nm]	0.162	0.175	-7%	$EI_{H2} = 9.0 \frac{kgH2O}{kgH2}$ $EI_{JetA} = 1.237 \frac{kg\ H2O}{kgJet\ A}$.
NvPM [mass & number]	0.0	3.53E-6	-100%	No NvPM from use of hydrogen.
SO2 [kg/pax/nm]	0.0	1.13E-4	-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]

[8] For detailed explanation, the authors suggest the reader refers to state-of-the-art scientific literature (e.g., Gierens [16]). State-of-the-art literature is still mainly qualitative, or quantitative with very high uncertainty range. Hence, only a qualitative indication is provided.

Table 8 – Energy consumption of concept aircraft. Source: Own elaboration (PVS).

Energy Consumption @ A/C level				
Title	**Target (Miniliner 5-hop version)**	**Status (SkyCourier)**	**% vs reference**	**Comments**
Hydrogen consumption [kg/pax/nm]	0.018 kg H2/pax/nm 270-300 kg LH2	N/A	N/A	Engineering estimate.
Battery energy consumption [Wh/pax/nm]	480-560 kg battery 250 Wh/kg, depleted to 30% 84-98 kWh	N/A	N/A	Engineering estimate. Battery is sized for power, not for energy.
Total Energy Consumption [Wh/pax/nm] or [MJ/pax/nm]	10,000 kWh for 19 pax, 865 nm 608 Wh/pax/nm	12390 kWh for 19 pax, 386 nm[9] 1689 Wh/pax/nm	~36%	Engineering estimate. Cessna SkyCourier reference mission. Difference in energy consumption can be related to difference in flight speed.

Table 9 – Noise performance of concept aircraft. Source: UNIFIER19 project (UNIFIER19, September 2022)

Noise performance @ A/C level				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Noise performance	See Figure 10	See Figure 1	-15 dB (SPL at ICAO noise assessment procedure point).	From UNIFIER19 D3.3 results (UNIFIER19, September 2022).

[9] Cessna SkyCourier reference mission (386 nm range, flying at FL100 with 19 passengers). Assuming 43.1 MJ/kg for Jet A.

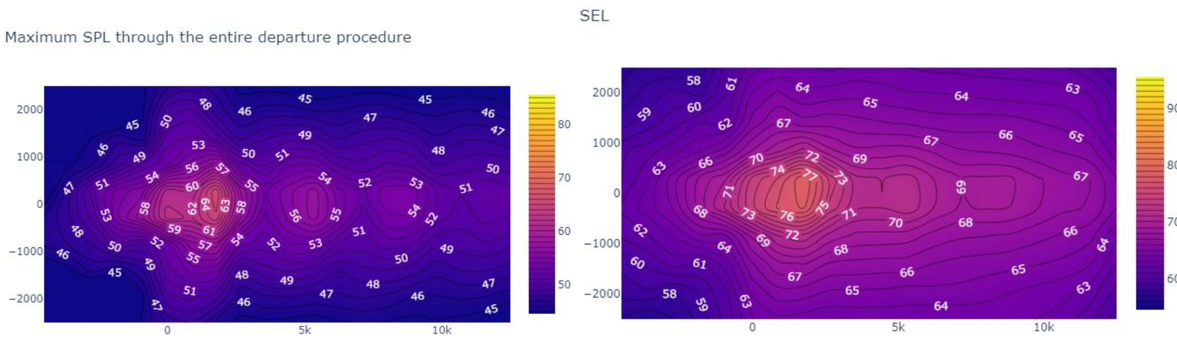

Figure 5 – Left: Maximum Sound Pressure Levels [dB] for C7A-HARW aircraft on the ground through the entire departure procedure. Right: Sound Exposure Levels on the ground for the entire departure procedure for C7A-HARW aircraft. Source: UNIFIER19 D3.3 [13].

TRL Level

Table 10 – TRL evolution of concept aircraft.

Technology Readiness Level (using US DoD definitions)					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2024-2025[10]	2024-2025[11]	2025-2026[12]	2028[13]
Year Achieved	2022[14]	-	-	-	-

Additional metrics

Table 11 – Additional KPIs of concept aircraft.

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[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/)

Additional KPIs / Other Quantified Performance Targets at project end and beyond				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Industrial readiness	TRL9	TRL2	N/A	TRL2 reached with UNIFIER19 project [13]
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 [13]
Reliability	DEP and independent power provision lines improve system reliability.			From UNIFIER19 D3.3 results [13]
Cost effectiveness	€0.322 cost per available seat km	€0.352 cost per available seat km	-8.5%	From UNIFIER19 D3.3 results [13]. Considering Single Pilot Operations.
LCA	Refer to UNIFIER19 D3.3 results (UNIFIER19, September 2022).			From UNIFIER19 D3.3 results [13]
Market acceptance	Potential 40,000 customers for Venice (VCE) airport.			From UNIFIER19 D1.2 results [18]
Operability	Conversion of small airfields into transport nodes	Limited to use of commercial airports	50% EU airfields have >800 m runway.	From UNIFIER19 D1.2 results [18]

Table 12 – 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.

5 AIRCRAFT CONCEPT LEVEL – FUEL CELL FULLY-ELECTRIC 80-PASSENGER REGIONAL AIRCRAFT

5.1 Concept FC80pax

While the NEWBORN system technology is scalable across various classes of aircraft, the concept discussed herein covers the high end of the spectrum – a 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 either 2 or 4 propulsors, depending on the availability of electric motors with sufficient power rating.

5.2 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.

5.3 Typical Mission for Impact Monitoring

The typical mission is very similar of identical to the HERA UCA mission in section 3.3. For the detailed analyses internal to the project, the following mission was however assumed.

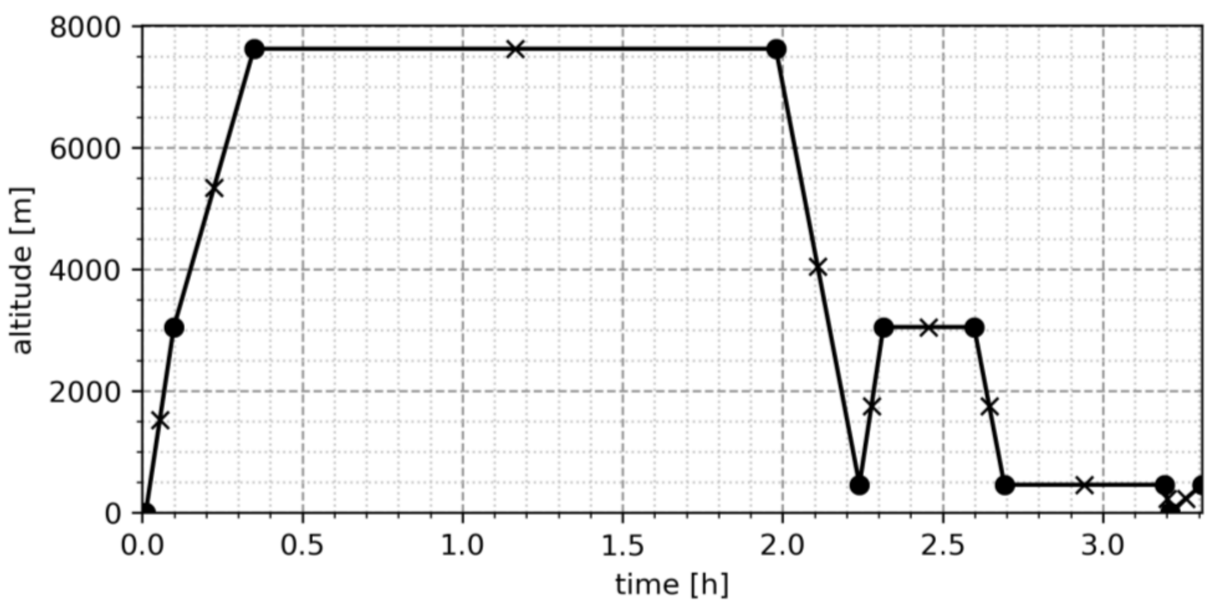


Figure 6: Assumed mission of the Fuel cell fully electric 80-pax aircraft

The details of the mission are then included in Table 13 below.

Table 13: 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	1900	0	10000	120.0
Slow climb	1000	10000	25000	160.0
Cruise	/	25000	25000	195.0
Descent	1500	25000	0	220.0

5.4 Aircraft Concept

5.4.1 Aircraft concept definition

Please describe the main Top Aircraft Level Requirements (TLARs) for the aircraft concepts under consideration. This should include any other additional a/c level characteristics/design choices which may be relevant for high level Aircraft concept definition such as: engine type and configuration (turbofan, open fan, turboprop), propulsion integration (underwing-mounted, rear-mounted, distributed propulsion, etc.), wing type and configuration (high wing, low wing, dry wing, wet wing, aspect ratio), etc.

N.B: As a general principle, the projects should provide sufficient content to clearly identify the aircraft concept. Reference to relevant deliverables should be provided.

The table below is provided for reference, any other relevant A/C characteristics for Impact Monitoring should also be added.

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	2 or 4 fully electric propulsion systems (2x4 MW_{peak} or 4x2 MW_{peak})
Powertrain configuration	Fuel cell + battery hybrid, batteries sized for emergency case Either 4 or 6 independent fuel cell power sources
Maximum fuel cell power	8.4 MW desired, 8 MW acceptable

<table>
<tr><td>Battery power</td><td>3.5 MW (emergency use)</td></tr>
<tr><td>Typical takeoff power</td><td>7.8 MW</td></tr>
<tr><td>Typical cruise power</td><td>6.1 MW</td></tr>
<tr><td>Design Range [nm]

(max) - typical</td><td>600</td></tr>
<tr><td># PAX

(max) - typical</td><td>80</td></tr>
<tr><td>Max Payload [tons]</td><td>8.2</td></tr>
<tr><td>Cruise speed [Mach]</td><td>0.48 (195 KCAS@25000ft)</td></tr>
<tr><td>Take-Off Field Length (@sea level, ISA conditions, MTOW)</td><td>1315 m</td></tr>
<tr><td>Approach speed [Kts]</td><td>Final approach speed: 125 KCAS,
stall speed in landing configuration: 92 KCAS</td></tr>
<tr><td>Operating altitude ceiling</td><td>FL250</td></tr>
<tr><td>Typical cruise altitude</td><td>20000 ft</td></tr>
<tr><td>Time to climb
[min to FLxxx]</td><td><table>
<tr><th>Mission Phase</th><th>Time [min]</th><th>Range [Nm]</th><th>Altitude [ft]</th></tr>
<tr><td>Take-Off</td><td>0.36</td><td>0.39</td><td>0 - 35</td></tr>
<tr><td>Take-Off to Climb</td><td>5.84</td><td>15.50</td><td>0 -10000</td></tr>
<tr><td>Climb</td><td>7.95</td><td>26.92</td><td>10000 - 20000</td></tr>
</table></td></tr>
<tr><td>Airport category</td><td>3C</td></tr>
</table>

- ☐ Further data provided in
  - ☐ [2] NEWBORN D1.1 rev 01, 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 2 or 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 2 or 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	Load-bearing, conformal, high gravimetric index liquid hydrogen cryogenic tank with redundancy. The aircraft concept assumes a gravimetric index of >0.6.	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.

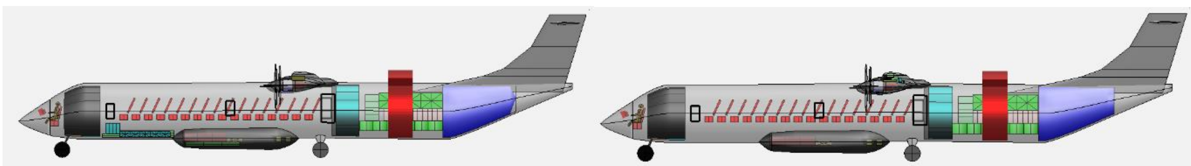


Figure 7: Conceptual fuel cell full-electric regional aircraft with fuel cell integrated near the tailcone

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

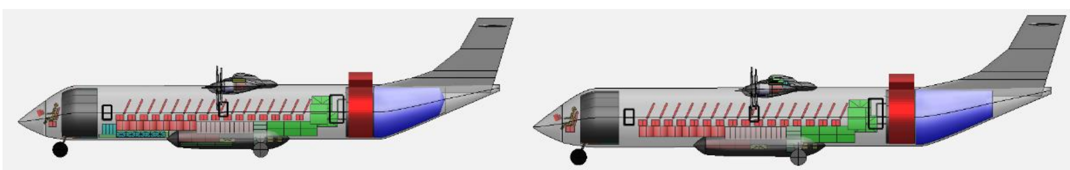


Figure 8: Conceptual fuel cell full-electric regional aircraft with fuel cell integrated below the floor

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.

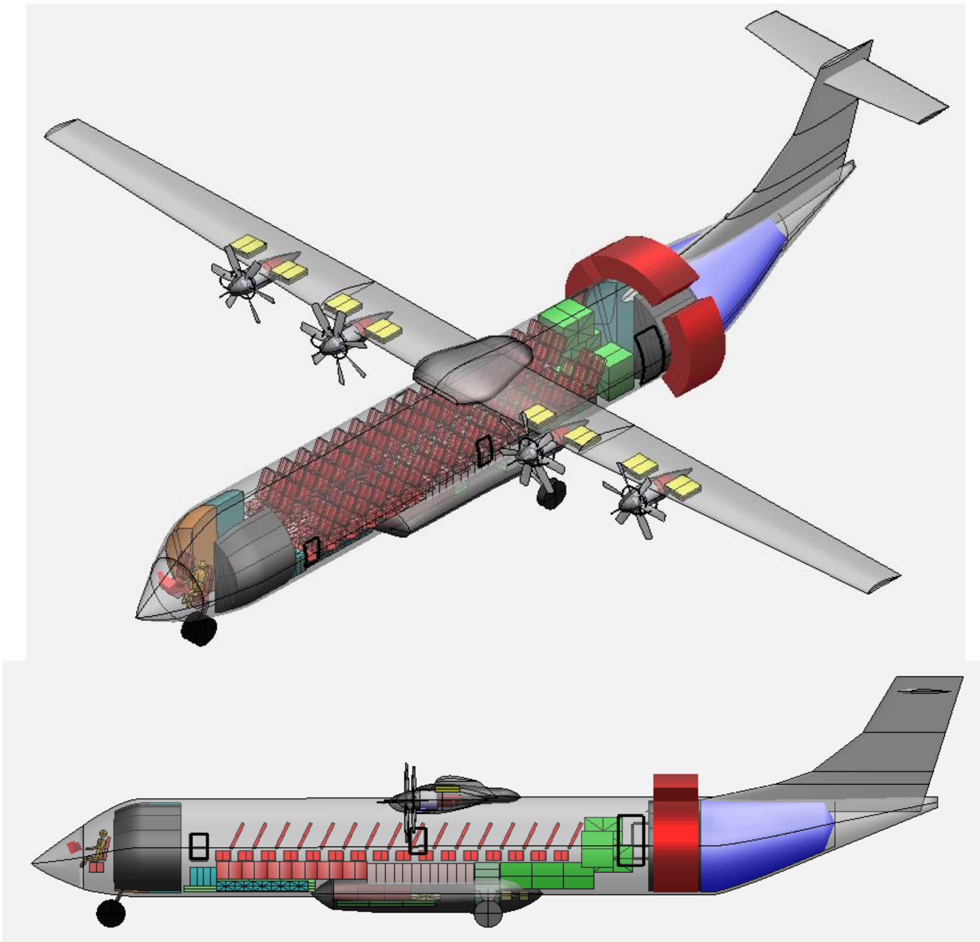


Figure 9: Conceptual fuel cell fully electric 80-pax regional aircraft

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

Table 14: Assumed power profiles of the fuel cell fully electric regional aircraft

	Time [min]	Power [kW]
Take-off / **Initial climb**	0.7	1942
Fast climb	5.3	1835
Slow climb	15.0	1713
Cruise	97.8	1520
Fast descent / **Slow descent**	15.7	512
Emergency battery climb	6.0	795

5.4.2 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**	**Status**	**% vs reference**	**Comments**
GHG emission reduction excl. contrails				
CO_2 [kg/pax/nm]	0	0.142	-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}	-100%	From source [15]
H2O [kg/pax/nm]	0.171	0.066	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}	-100%	From source [15]
SO2 [kg/pax/nm]	0	6×10^{-3} max	-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**	**Status**	**% vs reference**	**Comments**
Kerosene/SAF consumption [kg/pax/nm]	0	0.046 (recalculation for 80pax)	-100%	ATR 72 kerosene consumption of 0.040 kg/pax/NM
Hydrogen consumption [kg/pax/nm]	0.019 (0.023)	0	+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	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/kg	+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**	**Status**	**% vs reference**	**Comments**
Noise performance	See Figure 10	See Figure 1	-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

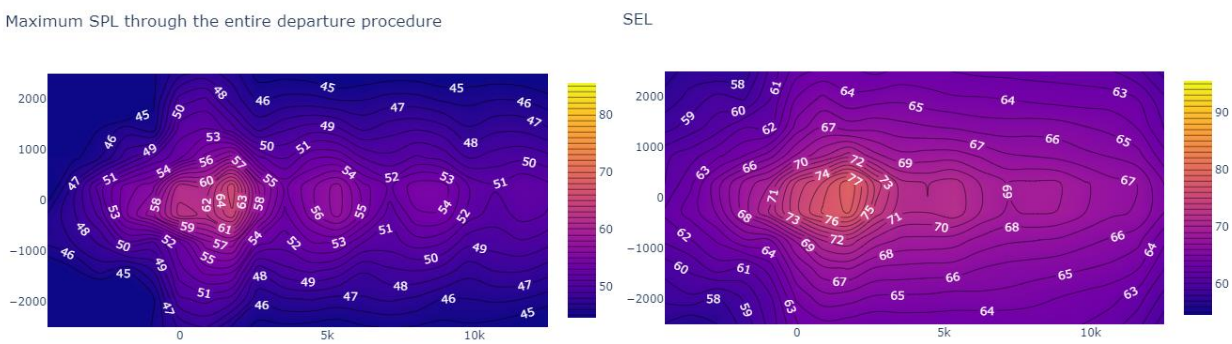


Figure 10: Left: Maximum Sound Pressure Levels [dB] for C7A-HARW aircraft on the ground through the entire departure procedure. Right: Sound Exposure Levels on the ground for the entire departure procedure for C7A-HARW aircraft. Source: UNIFIER19 D3.3 [12].

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**	**Status**	**% vs reference**	**Comments**
Industrial readiness timeframe	2035+	N/A	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

6 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. The view of the subsystems from the aircraft perspective and the project perspective is slightly different, the Table 15 below defines the mapping of the grant agreement definition of subsystems and the aircraft view of the subsystems.

Table 15: 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

6.1 Reference sub-systems definition

Reference Sub-system (State of the art) - Fuel cell power source (automotive systems, adapted for low-altitude flight demonstrations)	
Key characteristics	Value or description
General fit for purpose	Only demonstrators using various automotive 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 not meeting the requirements
System efficiency at ground altitude	Varies, ~45%
System efficiency at cruise altitude	Unable to reach desired altitude
System output voltage	Varies
System lifetime	Significant immediate degradation at target altitude
Power scalability	Blocks by ~100 kW (gross power, not usable 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.

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 (various prototypes of aircraft electric propulsion motors and inverters)	
Key characteristics	Value or description
Propeller speed	Optimized for classical propeller speeds
Maximum peak power	~300 kW
Maximum continuous power	~300 kW
Power density – motor	5 kW/kg
Power density – inverter	5 kW/kg
Power density – integrated system (incl. gearbox, thermal management, lubrication, ..)	~1 kW/kg (est.)
Efficiency – motor	~95% depending on the operating point

Efficiency – inverter	~95% depending on the operating point
Scalability to MW levels	Questionable, not possible for many prototypes
Partial discharge immunity to HV at altitude	Undisclosed, assumed not solved

Rationale for the selection of the reference sub-system: There is no single best solution but variety of dissimilar technologies.

Reference Sub-system (State of the art) - Liquid hydrogen storage (space technology and Linde unpublished prototype)	
Key characteristics	Value or description
Conceptual technology	Vacuum insulated tank (Dewar)
Load bearing	No
Conformal	No
Gravimetric index	~0.20 (for 500 kg LH2)
Incorporation of the hydrogen treatment equipment	Partial, not optimal

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.

6.2 Sub-system Concept 1 – Fuel cell power source

6.2.1 Sub-system concept definition

The high-level description of the fuel cell power source developed in NEWBORN is the following:

- Altitude ceiling of FL250
- Assumed integration in non-pressurized, non-climatized environment, except from specific elements (control system electronics, for cost reasons – technology for adaptation to non-controlled environment is available at TRL9).
- Primarily assuming fuselage installation
- Close integration with the other subsystems, especially liquid hydrogen tank and battery
- Increased operating temperature to improve cooling temperature gradients

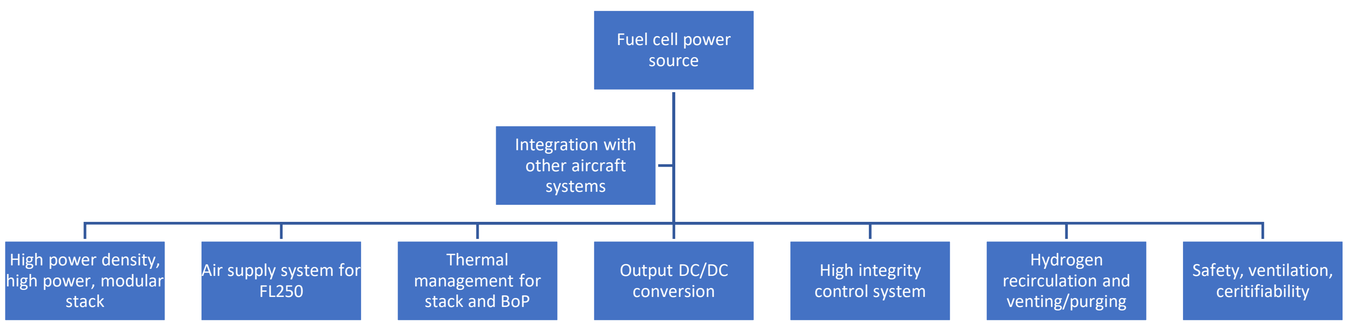


Figure 11: Composition of the fuel cell power source technology demonstrated in NEWBORN

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 11. The main components include:

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

Sub-system Concept definition: Scalable fuel cell power source	
Key characteristics	Value or description
High efficiency	>50% at system level
High power density	>1.2 kW/kg at level of the power source as shown
Scalable in power	1 MW demonstrated, architecture for up to 4 MW per aircraft side
Altitude ceiling (propulsion use case)	FL250
Altitude ceiling (SPU spinoff use case)	FL450
Scalable to lower powers	Scalable directly down to ~250 kW of net output power Scalable further down with stack downscaling (easy, no technology development needed)
High power density converters	>20 kW/kg for non-isolating DC/DC converters >2 kW/kg for isolating DC/DC converters >18 kW/kg for compressor inverters
Fuel cells operating temperature	>105 °C (hotspot temperature) Architecture readiness for high temperature PEM fuel cells

6.2.2 Aircraft concept applicability

The subsystem is applicable for wide range of aircraft classes, ranging from small general aviation aircraft, up to fully fuel cell electric regional aircraft. The realistic targetable aircraft classes are with the number of passengers ranging from 4 to 80. The concept is usable for both hybrid-electric and fuel cell electric aircraft.

6.2.3 Sub-system Level Key Performance Metrics

The consortium should use this section to define sub-system key performance metrics and indicators suitable for Impact Monitoring in accordance with the Clean Aviation program objectives.

Please refer to section 3 for guidance on how to define the KPIs.

Title	Target	Status	% vs reference	Comments
GHG emission reduction				
CO_2 [kg/pax/nm]	0	Varies	-100%	
NOx [kg/pax/nm]	0	Varies	-100%	
H2O [kg/pax/nm]	0.171 0.162	0.066 0.175	259% -7%[15]	+259% based on the estimation for 80-passenger fully-electric aircraft -7% for 19-seater
NvPM [mass & number]	0	Varies	-100%	
SO2 [kg/pax/nm]	0	Varies	-100%	
Contrails	Cannot estimate at this time			

[15] Note that the Target (UNIFIER19 results) and Status (Cessna Skycourier) data are not directly comparable and that the UNIFIER19 has an overall lower energy consumption per nautical mile. The difference between the two aircraft classes is a result of combination of two effects: a) the Miniliner concept is much more energy efficient compered to reference aircraft b) the overall energy efficiency of regional kerosene turbine-based reference aircraft is much higher than smaller reference ones.

Energy Consumption @ Sub-system level (before integration)				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	>50%	~45%	+5 pp	The caveat is that 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.

Additional KPIs

KPIs				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Scalability in power [kW]	300 – 4000 kW per aircraft side	100-1000	400%	
Altitude ceiling	FL250	<FL100	N/A	The systems publicly demonstrated so far don't have sufficient performance to operate at requested altitudes
Entry into service – CS-23	2030	N/A	N/A	
Entry into service – CS-25 (HERA)	2035	N/A	N/A	
Overall system efficiency	>50%	~45%	5 pp.	The caveat is that 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.
System power density [kW/kg]	>1.2	~0.5	240%	
Stack power density [kW/kg]	>5	<4.7	+6 pp	
System availability	>99% proposed. Targeting 1e-4 for the demonstrator.	>99%	10 000%	
System life	>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.
Power density – stack bus-tie DC/DC converters [kW/kg]	>20 technology 15 kW/kg in the demonstrator application	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.
Power density – battery DC/DC converters [kW/kg]	>20 technology 18 kW/kg in the demonstrator application	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.
Power density – isolated DC/DC converters [kW/kg]	>2	~1	200%	
Demonstrated stack paralleling	Up to 9 fuel cell modules; 3 fuel cell modules demonstrated	N/A	N/A	

TRL Level

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

Technology Readiness Level – sub-technologies (plan/achieved)					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Modular high-power, higher-temperature stack	<2022	2023	2024	2025	2028
Altitude-scalable air supply subsystem	2022	2025	2026	2027	2028
High-reliability lightweight humidity management	<2022	2023	2025	2027	2028
Air compressor inverter for non-pressurized environment	<2022	2023	2025	2026	2028
DC/DC converters	<2022	2023	2025	2026	2028
Stack paralleling	2022	2023	2025	2027	2028
High-availability control system architecture	<2022	<2022	2023	2026	2028
HV immunity to partial discharge at altitude	<2022	2023	2025	2026	2028

Next generation microtube heat exchangers	<2022	2023	2025	2026	2028
Independent safety/health monitoring system	<2022	2023	2026	2027	2028

The TRL levels reflect the EU directive definition of the Technology Readiness Level.

Additional KPIs / Other Quantified Performance Targets at project end and beyond				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Safety – critical hazard probability	10^{-10}	N/A	N/A	

Potential Barriers
Certifiability

6.3 Sub-system Concept 2 – Battery

6.3.1 Sub-system concept definition

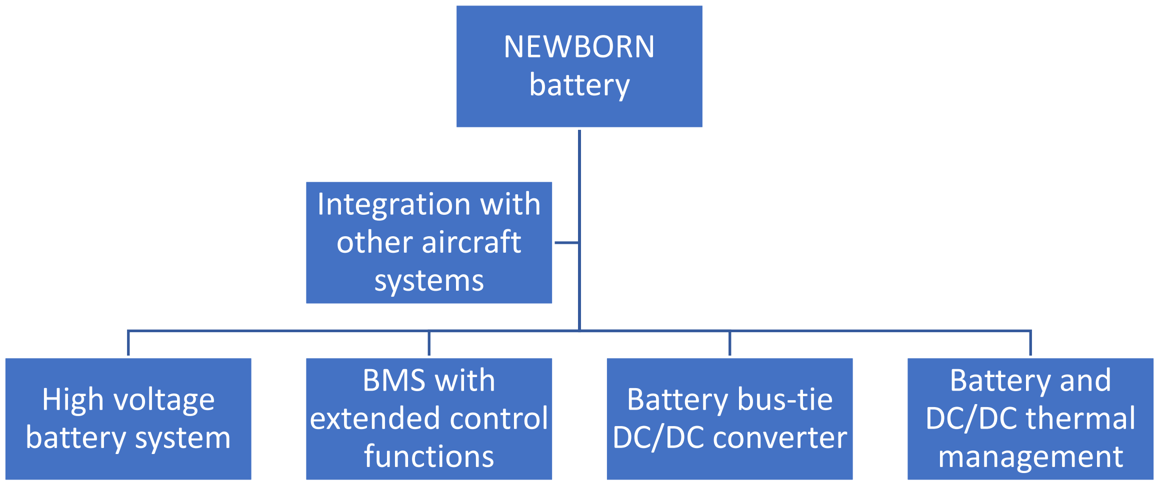


Figure 12: Composition of the battery technology demonstrated in NEWBORN

Sub-system Concept definition:	
Key characteristics	Value or description
Battery pack energy density	230 Wh/kg, lower TRL with higher energy density
Battery pack power density	1.28 kW/kg (~1.75 kW/kg achievable with custom capacity optimized cells – demo battery will have more capacity than needed for the power)
Volumetric energy density	~200 Wh/l
Nominal voltage	DC/DC converter stabilized output voltage (design-time selectable, nominal 825V demonstrated)

Maximum charge / discharge C rates	Max charge: ~580 A (~3C rate) Max discharge (for Battery system ~100 kWh): 1374A (~7.15 C rate)

More information on the developed battery is available in D8.1 and will become available in D8.18 Battery prototype design description document.

6.3.2 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 two 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.

We therefore conclude that the technology is applicable to all fuel cell powered aircraft including hybrids.

6.3.3 Sub-system Level Key Performance Metrics

Note that the battery itself during use is completely emission free. Hence, the below table shows zero emissions as the target on this subsystem level. Emissions incurred during production of the battery are not accounted here.

Title	**Target**	**Status**	**% vs reference**	**Comments**
GHG emission reduction				
CO_2 [kg/pax/nm]	0	N/A	N/A	The battery is a critical enabler of the fuel cell based aircraft, leading to zero emissions except water. The battery itself has no operating emissions.
NOx [kg/pax/nm]	0	N/A	N/A	
H2O [kg/pax/nm]	0	N/A	N/A	
NvPM [mass & number]	0	N/A	N/A	
SO2 [kg/pax/nm]	0	N/A	N/A	
Contrails	0	N/A	N/A	

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

Each additional quantitative KPI should be defined along with its unit, and each qualitative KPI should be properly stated.

KPIs				
Title	**Target (NEWBORN)**	**Status (Velis Electro)**	**% vs reference**	**Comments**
Battery pack energy density	230 Wh/kg, lower TRL with higher energy density	161 Wh/kg	143%	Improvement against SoA battery on the EASA certified Velis Electro. Some numbers are hard to estimate, but the best possible estimate was performed.
Battery pack power density	1.28 kW/kg (~1.75 kW/kg achievable with custom capacity optimized cells – demo battery will have more capacity than needed for the power)	0.56 kW/kg	228%	
Volumetric energy density	~200 Wh/l	206 Wh/l	~0%	
Nominal voltage	DC/DC converter stabilized output voltage (design-time selectable, 825V demonstrated)	Variable output voltage, nominal 345 V	~200%	

Maximum charge / discharge C rates	Max charge: ~580 A (~3C rate) Max discharge (for Battery system ~100 kWh): 1374A (~7.15 C rate)	Max charge: 40A (~ 1.21C rate) Max discharge: 120A (3.64C rate)	~1000% for the currents ~200% for the C-rates	

TRL Level

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2025	2027
Year Achieved	2022	2023			

Additional metrics

Additional KPIs / Other Qualitative Performance Targets at project end and beyond				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Resistant to thermal runaway of full module	To be resistant	In progress	Not quantifiable	As part of safety

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.

6.4 Sub-system Concept 3 – Electric propulsion

6.4.1 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.

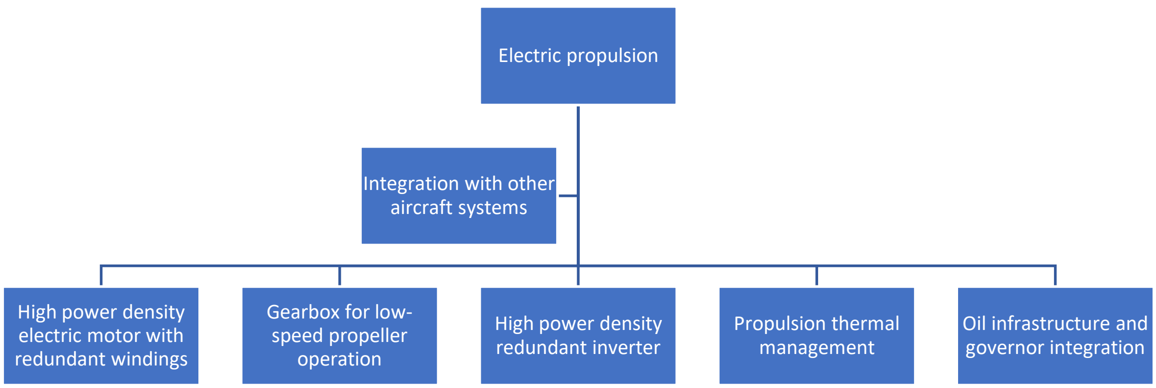


Figure 13: Composition of the electric propulsion technology demonstrated in NEWBORN

Sub-system Concept definition: High power density propulsion system	
Key characteristics	**Value or description**
Propeller speed	Optimized for varying propeller speeds including low-speed propellers (e.g., 1200 RPM)
Maximum peak power	1200 kW (TBD)
Maximum continuous power	1047 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 %
Efficiency – inverter	>98 %
Scalability to MW levels	4 MW machine demonstrated by the project partner on external linked project. Inverter scalable by paralleling, 4 MW achievable.
Partial discharge immunity to HV at altitude	Ensured.

Please include as a reference, any project deliverables that support the detailed definition of the sub-system concept under consideration.

Define the boundary of the sub-system and key technologies identified for this sub-system (e.g. are the installed systems included in the metrics, are the interfaces included or not?)

6.4.2 Aircraft concept applicability

The electric propulsion subsystem in NEWBORN is primarily focused on integration with:

- CS-23 19-passenger aircraft as primary propulsion system (2 per aircraft)
- CS-25 hybrid-electric regional aircraft (thermal engine & fuel cell + battery), matching the 80-seater requirements for electric propulsor

In addition, it can be used for other aircraft classes with re-scaling to lower power levels, or paralleling through gearbox to achieve 2 MW power levels. Up-scaling of the technology to double the power would enable its scaling even to fully-electric 80-passenger aircraft with 2 propellers.

6.4.3 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.

Title	**Target**	**Status**	**% vs reference**	**Comments**
GHG emission reduction				
CO_2 [kg/pax/nm]	Varies depending on the aircraft concept	Varies	N/A	The electric propulsion subsystem serves as a critical enabler of the new aircraft concepts, and by itself it doesn't contribute to the reduction of the emissions.
NOx [kg/pax/nm]	Varies depending on the aircraft concept	Varies	N/A	
H2O [kg/pax/nm]	Varies depending on the aircraft concept	Varies	N/A	
NvPM [mass & number]	Varies depending on the aircraft concept	Varies	N/A	
SO2 [kg/pax/nm]	Varies depending on the aircraft concept	Varies	N/A	
Contrails	Varies depending on the aircraft concept	Varies	N/A	

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

Quantitative KPIs

KPIs				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Power density – motor [kW/kg]	15 proposed, 18 current estimate 18	5-8	225-360%	
Power density – inverter [kW/kg]	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	-	-	-	-

The TRL levels follow the EU directive definition.

Potential Barriers
N/A

6.5 Sub-system Concept 4 – Liquid hydrogen storage

6.5.1 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 technology demonstrator is developed as a single tank with auxiliary equipment shown below in Figure 14. 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.

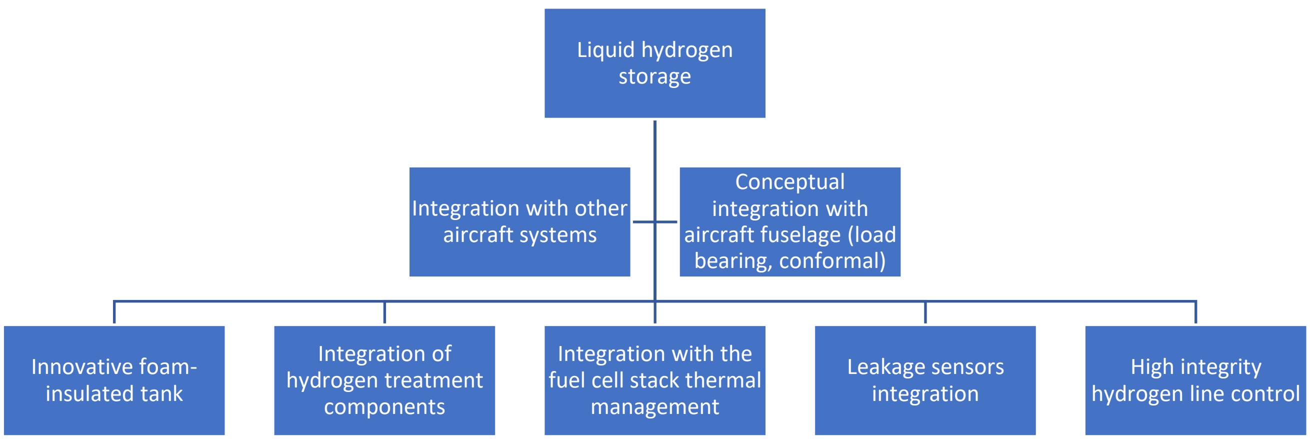


Figure 14: Composition of the liquid hydrogen storage technology demonstrated in NEWBORN

Sub-system Concept definition: Liquid hydrogen storage	
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	Yes, external tank structure is the airframe (in principle, but not limiting to, within the rear fuselage section).
Conformal	Yes, external tank structure is the airframe (in principle, within the rear fuselage section).
Gravimetric index – Isolated tank (excluding aircraft structure) *	Single tank: 0.43 @ 230 kg (LH_2), 0.56 @ 620 kg, 0.57 @ 800kg, 0.60 @ 1.200 kg Dual tank with redundancy: 0.39 @ 230 kg, 0.53 @ 620 kg, 0.56 @ 800kg, 0.59 @ 1.200 kg
Gravimetric index – tank including hydrogen preconditioning and venting equipment (excluding aircraft structure) *	Single tank: 0.41 @ 230 kg, 0.54 @ 620 kg, 0.56 @ 800kg, 0.59 @ 1.200 kg Dual tank with redundancy: 0.37 @ 230 kg, 0.51 @ 620 kg, 0.54 @ 800kg, 0.58 @ 1.200 kg
Incorporation of the hydrogen treatment equipment	Yes, in an insulated equipment bay

*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.

Please include as a reference, any project deliverables that support the detailed definition of the sub-system concept under consideration.

Define the boundary of the sub-system and key technologies identified for this sub-system (e.g. are the installed systems included in the metrics, are the interfaces included or not?)

6.5.2 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.

6.5.3 Sub-system Level Key Performance Metrics

Title	**Target**	**Status**	**% vs reference**	**Comments**
GHG emission reduction	Critical enabler for both fuel cell and hydrogen burning aircraft	N/A	N/A	No cryogenic tank today
CO_2 [kg/pax/nm]	0%	Varies	Up to -100%	N/A
NOx [kg/pax/nm]	0%	Varies	Up to -100%	N/A
H2O [kg/pax/nm]	N/A	Varies	0-259%	Depending on the hybridization level and the aircraft class
NvPM [mass & number]	0%	Varies	Up to -100%	N/A
SO2 [kg/pax/nm]	0%	Varies	Up to -100%	N/A
Low LH2 leakage	Low leakage: leaking fuel which leads to a fuel concentration in a fuel/air mixture below 25% of the Lower Flammability Level (LFL) (1% volumetric H2 concentration)	N/A	N/A	Reference target taken from safety point of view, Value not to exceed, should be reviewed (reduce it) considering climate impacts. (TBC, discussion if considering other reference)
Contrails	N/A	N/A	N/A	N/A

Energy Consumption @ Sub-system level (before integration)				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Total Energy Efficiency [%]	N/A	N/A	N/A	N/A

Additional KPIs:

KPIs				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Gravimetric Index (for 150 kg LH2)	>35%	20% for 500 kg of LH2	N/A	Current DEWAR technology reaches even lower GI values for greater capacity. (It has not been found a direct comparable case)
Gravimetric Index (for 800 kg LH2)	>57%	20% for 500 kg of LH2	N/A	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	N/A	N/A	No comparable technology.

<u>TRL Level</u>

Please provide the technology readiness level achieved and forecast for the aircraft concept.

N.B. It is acknowledged that some concepts will not be pursued up to TRL6 and a down selection will be performed at the end of Clean Aviation Phase 1.

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

The TRL levels definition follows the EU directive

Additional KPIs / Other Quantified Performance Targets at project end and beyond				
Title	**Target**	**Status**	**% vs reference**	**Comments**
Certification approach and acceptable means of compliance reviewed by EASA	To be issued by the end of H2ELIOS Task 1.4	On going	N/A	Highly dependent on EASA's feedback
Functional validated Digital Twin representative of the tank structural and thermal behavior	To be issued by the end of H2ELIOS Task 5.6	On-going	N/A	Highly dependent on availability of information regarding properties, and experimental results
Completion of sequential testing of 4 operational scenarios including filling/refilling, without impacting current turn-around operations (service levels) and with 0% recurrent leaks	Further detail to be defined within H2ELIOS T1.6 in the deliverable D1.9	On going	N/A	
environmental impact emissions proven via LCA ≥20% vs. current technology proven by LCA	≥20% environmental impact emissions	On going	N/A	
≥80% recyclability of the tanks	≥80% recyclability	On going	N/A	
LCCA of the LH2 storage solution, targeting costs reduction of ≥ 20%, compared to current materials	≥ 20% cost reduction	On going	N/A	

increased durability targeting between 50,000 and 100,000 hours of expected service life, aligned with a/c expected life	Service life between 50,000 and 100,000 hours	On going	N/A	

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.

7 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

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

7.1.1 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)
Operating temperature	>105 °C (hotspot 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

7.1.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Power density	5 kW/kg	<4.7 kW/kg	+6 pp.	Highest known power density automotive stack
Power per single module	300 kW gross	100-130 kW	300%	Parallelizable
Operating temperature	105 °C	85 °C	See comment	20 degrees increase of operating temperature means reduction of thermal management heat exchanges to by 25%

<u>TRL Level</u>

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

The TRL definitions follow the EU directive

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

7.2.1 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	

7.2.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Ceiling altitude	FL250	<FL100	Meets requirement	
Scalability to high altitude	DL450	<FL100	Meets requirement	
Compatibility with high temp fuel cells	100 °C	85 °C	See comment	20 degrees increase of stack operating temperature means reduction of thermal management heat exchanges to by 25%

TRL Level

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

The TRL definitions follow the EU directive

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

7.3.1 Key Technology Concept Definition

Key technology definition: Self-regulated, load bearing, conformal LH2 tank	
Key characteristics	Value or description
Gravimetric Index	*Weight of LH2 with respect LH2 storage function dedicated elements [%] (for a reference LH2 amount)*
Volumetric Index	*Volume of LH2 with respect LH2 storage function dedicated elements [%] (for a reference LH2 amount)*
Boil-Off (venting)	*Typical rate of LH2 venting outside the tank [%/day]*
Dormancy with zero venting at mission end	*Time until it is needed to start venting with a 20% (TBC with OEMs) capacity [hours]*
Dormancy until discharge	*Time until complete discharge from a 20% (TBC with OEMs) capacity [hours]*
Refueling / discharge times	*[l/min], [kg/min]*

7.3.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Gravimetric Index (for 150 kg LH2 - demonstrator)	>35%	20% for 500 kg of LH2	Not comparable	Current DEWAR technology reaches even lower GI values for greater capacity. (It has not been found a direct comparable case)

Gravimetric Index (for 800 kg LH2)	>57%	20% for 500 kg of LH2	Not comparable	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	N/A	No comparable technology.

TRL Level

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

The TRL definitions follow the EU directive

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

7.4.1 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

7.4.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Motor power density	18 kW/kg	5-8 kW/kg	225-360%	
Motor efficiency	>98%	~95%	40% of losses +3 pp.	
Inverter power density	18 kW/kg	5-10 kW/kg	180-360%	
Inverter efficiency	>98%	~95%	40% of losses +3 pp.	

TRL Level

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

The TRL definitions follow the EU directive

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

7.5.1 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 high efficiency, scalable by parallelization to multi-MW levels
Battery DC/DC converter	Battery high voltage DC/DC converter with high efficiency

7.5.2 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**	**% 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	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%	95-96%	2-3 pp.	
Power density – battery DC/DC	>20 technology	2-5	400-1000%	The power density of the DC/DC converter in the application depends on

converters [kW/kg]	18 kW/kg in the demonstrator application			the details of their use, especially in this case the range of input voltage.
Efficiency – battery DC/DC converters [%]	>98%	95-96%	2-3pp.	

TRL Level

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

The TRL definitions follow the EU directive

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

7.6.1 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

7.6.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Weight	20% weight reduction with respect to SoA	SoA	-20%	The heat exchangers are very specific and no SoA can be easily quantified.

TRL Level

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

The TRL definitions follow the EU directive

7.7 Key technology 7 – High voltage battery pack

7.7.1 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

7.7.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Nominal voltage	800 V	400 V	200%	Pipistrel Velis Electro
Energy capacity	>100 kWh	10 kWh	1000%	Pipistrel Velis Electro
Power	>350 kW	47 kW	744%	Pipistrel Velis Electro

<u>TRL Level</u>

Technology Readiness Level					
TRL	TRL2	TRL3	TRL4	TRL5	TRL6
Year Planned	2022	2023	2024	2025	2027
Year Achieved	2022	2023			

The TRL definitions follow the EU directive

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

7.8.1 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

7.8.2 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**	**% vs. Reference**	**Comments – Values for a SoA component/technology**
Efficiency	>98.5	~96	+ 2.5 pp	
Power density	20 kW/kg	~3 kW/kg	666%	Existing aerospace designs

<u>TRL Level</u>

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

The TRL definitions follow the EU directive

5. 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:

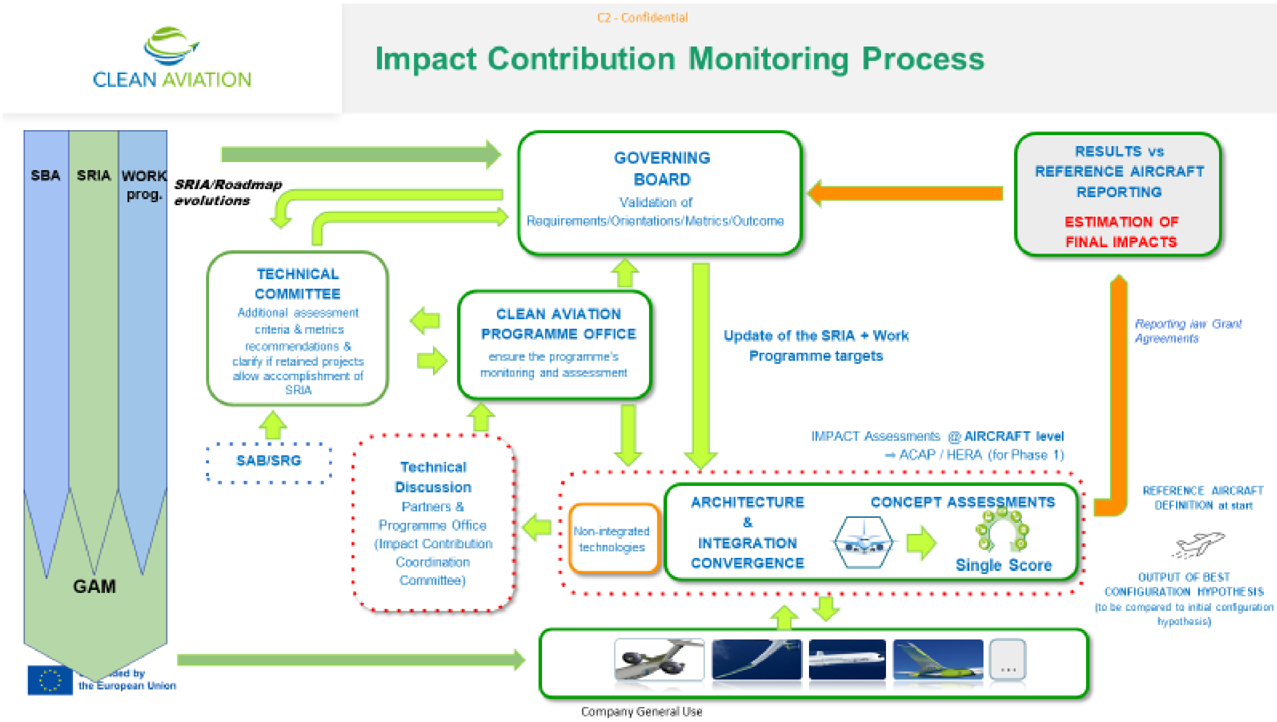
- ✓ Impact Contribution to be monitored through the SMR & HER pillars.
- ✓ It is assumed that the projects selected following the open calls and independent evaluations will enable the achievement of the high level impact objectives at aircraft level. *Clarification required to determine if the projects 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.

Co-funded by

Company General Use


C2 - Confidential
CLEAN AVIATION
Impact Contribution Monitoring Process
SBA
SRIA
WORK prog.
GAM
the European Union
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)
...
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 and doesn't define alternative TRLs.