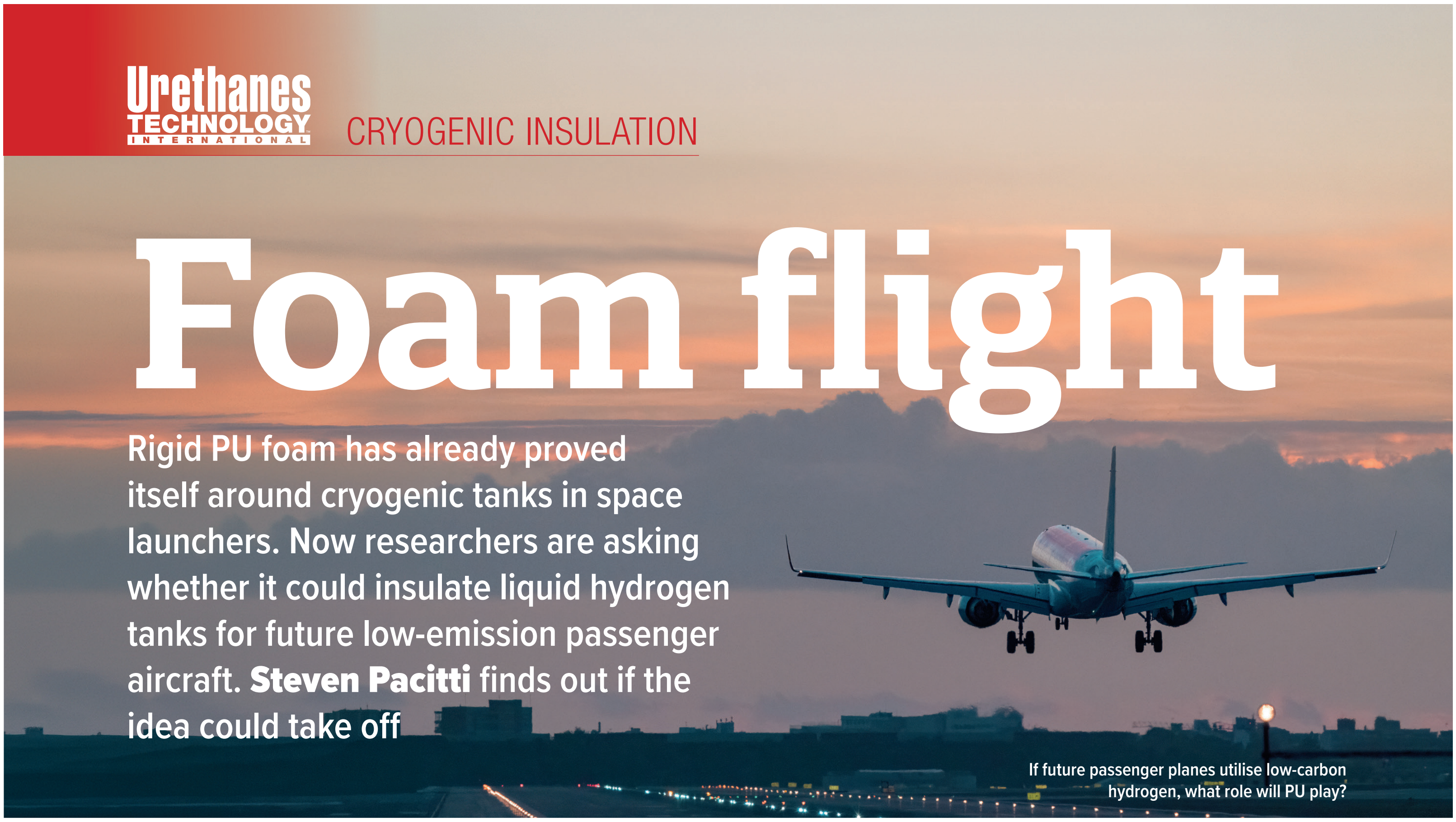


Foam flight

Rigid PU foam has already proved itself around cryogenic tanks in space launchers. Now researchers are asking whether it could insulate liquid hydrogen tanks for future low-emission passenger aircraft. **Steven Pacitti** finds out if the idea could take off

If future passenger planes utilise low-carbon hydrogen, what role will PU play?

Getty Images

For polyurethane, hydrogen aviation is a tantalising question. Liquid hydrogen promises high gravimetric energy density and, when used in a fuel cell or combustion system with low-carbon hydrogen, a route to dramatically lower in-flight carbon emissions. But, before any future passenger aircraft can fly routinely on LH_2, some important questions might be answered. How do you keep hydrogen at around -253°C in a tank light enough for aviation, safe enough for passengers and durable enough for years of repeated service?

Rigid PU foam is not a new cryogenic material, having heritage as insulation in space launchers and ground cryogenic storage. Researchers at the Latvian State Institute of Wood Chemistry (LSIWC) have spent years developing rigid PU foams for liquefied gas storage, renewable polyols and cryogenic applications. Uģis Cābulis, vice-director for scientific activities and leading researcher at LSIWC, lists PU chemistry, rigid PU thermal insulation, renewable raw materials and PU foams for cryogenic storage among his core research areas.

And the case for aviation is compelling. The International Civil Aviation Organisation has adopted a long-term global aspirational goal of net-zero carbon emissions from international aviation by 2050, while the EU's ReFuelEU Aviation framework allows renewable hydrogen for aviation and certain low-carbon hydrogen routes to contribute to compliance. Airbus, meanwhile, has revised its ZEROe roadmap but continues to pursue hydrogen-powered flight, saying in 2025 that it had down-selected a fully electric fuel-cell concept supplied by two liquid hydrogen tanks. Fokker Next Gen is also designing an aircraft able to operate on liquid hydrogen, SAF and kerosene, with its public roadmap still pointing to entry into service in 2035.

Yet Cābulis is cautious about timelines. "I think that planes that will fly with liquefied H_2 are quite a distant future," he said. "Because one big problem is the LH_2 tank." Conventional aviation fuel can be carried in wing tanks of varied geometry and needs no cryogenic insulation. Liquid hydrogen, by contrast, needs a tank with maximum volume and minimum surface area closer to a sphere or cylinder, and that changes the aircraft architecture. "Such a cylinder will take up space in the current passenger cabin," he said.

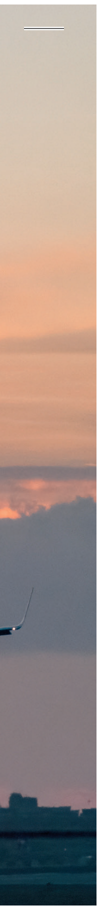
The project description for PUR4LH2, "Rigid Polyurethane Foams as Cryogenic Insulation for Future Zero-Emission Commercial Aircrafts", notes that liquid hydrogen's volume penalty makes gaseous hydrogen impractical for aviation, while storage at -253°C brings the need for highly specific tank systems and insulation. It also highlights a key difference between space and civil aviation: a commercial aircraft tank may need to endure around 20,000 take-offs and landings and keep LH_2 liquid for much longer than a launch vehicle tank.

Aerogels and multilayer insulation can be extremely effective, but they are not automatically suited to every aircraft tank surface or maintenance regime. "Aerogels are used in multilayer insulation (MLI), covering them on all sides with an air and moisture-proof foil," said Cābulis. "MLI materials are usually used on flat or slightly curved surfaces, but more complex surfaces are insulated with PU, because it can be sprayed onto surfaces of a wide variety of configurations." He also points to impact tolerance: "A small physical impact on the PU material will only cause a small dent, but the MLI will be broken and problems will begin."

That makes rigid PU foam a credible candidate for future LH_2 aircraft tanks, especially where complex geometry, adhesion and repairability are concerned, but this is not construction foam or refrigerator foam repurposed for flight. "The most critical moment after cryo-shocks is the cracking and delamination of the material from the surface of the tank," Cābulis said. "Air moisture can be cryo-pumped through the cracks, thereby deteriorating the thermal insulation properties."

For aviation, he added, the formulation must withstand repeated filling and emptying, and "retain some elasticity at cryogenic temperatures, which is not the case for PU used in construction or refrigerator manufacturing."

LSIWC's rigid PU foams for Ariane-6 cryogenic tanks won recognition at the 2025 Plastics Industry Awards, after work with ArianeGroup, ESA, ESTEC and MT Aerospace took the material and process from lab concept through qualification to TRL 9. The foam was used to insulate Ariane-6 upper-stage tanks, which must perform at around 20K, or -253°C, under severe thermal shock. But a launcher is not an airliner, and a space vehicle faces extreme ascent loads and, in some cases, external heating from atmospheric flight; an aircraft faces routine maintenance, certification, refuelling cycles, passenger safety requirements and long service life.



Uģis Cābulis (second from right) pictured here with his team at a recent conference for green chemistry and nanotechnologies in polymeric materials in Spain

Latvian State Institute of Wood Chemistry

> The perfect stability of the raw materials is essential for cryogenic insulation, because the macromolecular structure must be very precise”
> **Uģis Cābulis, Latvian State Institute of Wood Chemistry**

The Space Shuttle Columbia disaster in 2003 remains the sobering example whenever external cryogenic insulation is discussed. Here, foam from the shuttle’s external tank struck the orbiter. NASA’s Columbia Accident Investigation Board said management practices were “as much a cause of the accident as the foam that struck the left wing”, underlining that materials performance, inspection and system-level risk culture cannot be separated.

For aircraft, Cābulis sees density as one of the likely differences from space applications. “In the aerospace industry, the goal is 35-45, max 50kg/m^3. In aviation, it can be up to around 70kg/m^3, because every kilogram counts there too, but the durability of the insulated container, multiple use, is much more important,” he said. A denser foam would carry a weight penalty but may improve mechanical robustness and service life.

Then there’s the substate. Aluminium, steel, titanium and composite tanks all pose different thermal expansion and adhesion questions. “The main principle is that there must be balanced thermal expansion coefficients between the surface material and the insulation,” said Cābulis. For composite tanks, he warned, “the PU insulation must be modified, and all qualification tests have to be started from scratch. The material is not transferable from aluminium to composite.”

Inspection and repair would therefore be central to any aviation use case. Cābulis said routine service would require non-destructive testing methods such as thermography, ultrasonic testing and X-ray techniques to detect cracks, delamination and voids within the insulation. For small open defects, he said, repair technologies using pouring compositions have been developed.

Fire performance is another unavoidable barrier. “All polymer materials used in aviation must be non-flammable or self-extinguishing,” Cābulis said. “So, flame retardants must be used in the formulation.” That requirement arrives just as European chemical regulation continues to narrow the range of available flame retardants, adding another formulation constraint to cryogenic elasticity, adhesion, density, cell morphology and ageing.

The sustainability side is also part of PUR4LH2. The project aims to combine LSIWC’s experience in renewable-resource PU with rigid PU cryogenic insulation. Cābulis said the team is using tall oil, a by-product of cellulose production that does not compete with food or feed raw materials, to synthesise polyols by esterification, amidisation and epoxidation routes.

However, Cābulis is careful not to oversell renewable feedstocks for such a demanding application. “Petrochemical polyols have a more stable and constant structure,” he said. Renewable raw materials can vary with tree species, weather, location and harvesting season, while cryogenic insulation requires very high consistency: “The perfect stability of the raw materials is essential for cryogenic insulation, because the macromolecular structure must be very precise.”

Blowing agents are another factor. “For about five years now we have been working only with fourth-generation foaming agents,” said Cābulis, naming Solstice LBA, Opteon 1100 and Methylal among the materials tested. “It must be admitted that Solstice LBA is the most effective – it produces the highest-quality foam, even better than with the third-generation foaming agent, Solkane 365/227.”

End-of-life may be less exotic than the operating temperature. Cābulis said cryogenic PU foam has no fundamentally different chemical structure from conventional PU foams and can be degraded by known chemical recycling routes such as glycolysis. The practical problem is collection and transport to depolymerisation reactors. LSIWC is also working on another project, RecPur, using tall oil esters as depolymerisation reagents instead of diethylene glycol, increasing renewable content in the recovered polyol product.

The remaining question is commercial timing. If a hydrogen aircraft were to enter service in the mid-2030s, Cābulis estimates insulation materials would need to be qualified around 2032. But he doubts the sector will move that quickly. “I personally do not believe that it will be possible by 2035,” he said, arguing that aviation currently appears more focused on SAF, which can be used in existing aircraft without completely new airframes. That caution is consistent with Airbus’ own 2025 language, which refers to an adjusted ZEROe roadmap and a longer-term role for hydrogen alongside SAF.

So, could PU foams be used for cryogenic insulation in future low-emission passenger aircraft? The answer is yes – plausibly, and perhaps importantly – but only if the material is treated as a certified aviation system rather than an insulation commodity. It would need to adhere to the tank through thermal cycling, resist cracking and delamination, avoid moisture cryo-pumping, meet aircraft fire requirements, tolerate inspection and repair, and survive several decades of refuelling and service.

If liquid-hydrogen aircraft do emerge, said Cābulis, “PU will definitely be one of the main insulation solutions”. But he leaves room for another outcome: “Maybe it will be concluded that vacuum insulation is better, even though it is heavier, and any defect completely destroys the insulation.”

Hydrogen aviation could become a high-value niche for advanced rigid PU systems, but it will reward only those formulations that can combine cryogenic performance, durability, sustainability, application control and certifiable safety. At -253°C, foam is no longer just insulation. It becomes part of the aircraft’s fuel system.