

Project details and results (Section 1 in the portal)

Project result for Vinnova to be assessed

- **Project conclusion – Result (0-1500 characters)**

Carrar demonstrated its superior technology both on the performance test, and the safety test. Carrar designed and built two prototypes according to project requirements and tested them for aggressive and continuous drive cycles and for thermal propagation. The two-phase pool-boiling principal advantage is the high heat transfer coefficient at low heat and high heat flux which enables temperature uniformity across the module and can dissipate the generated heat from the cells during fast charging and discharging, and thermal runaway events. Carrar's advantage is kept also in large modules, showing temperature uniformity and steady temperature during both performance and safety tests. The test results, both for safety and performance, showed the advantage of Carrar's battery module. In the performance testing, the average temperature variation between the cells was 1.65°C, and along the cell was 0.6°C. The maximal module temperature variation was less than 3°C for almost 94% of the test time. The safety test was repeated twice; in both cases, the heat dissipation ascended the cell heat generation, and therefore the thermal propagation was eliminated. The highest temperature observed on the triggered cell was ~83°C, while the surrounding cells were kept below 25°C.

- **Goal for the project – achievement fulfillment (0-1500 characters)**

The Volvo Group and Carrar initiated a project to deliver and evaluate a high-performance Thermal Management Solution (TMS) for battery packs, and an overall high-power solution for Volvo Group applications. As part of it, Carrar designed and built two battery modules for heavy-duty, long-haul applications. The modules tested for performance and safety. Success criteria:

- Demonstrate high C-rate ≥ 1.2
- Uniform temperature:
 - ΔT between cells $< 3^\circ\text{C}$ @ any C-rate* (charging /discharging rate)
 - ΔT on cell $< 3^\circ\text{C}$ @ any C-rate* (charging /discharging rate)
- Cell temperature $< 40^\circ\text{C}$
- 24h drive cycle test shall result in improved cooling compared to bottom plate cooling and give an improved lifetime according to Volvo aging simulations
- Higher energy density [Wh/kg] (pack level) - comparable to the energy density in the current Volvo module
- Thermal runaway test with significantly improved result compared with bottom cooling plate

In the performance test, the module was cycled at room temperature at a pre-defined drive cycle. The safety test consisted of the same module design, in which one cell was triggered by overcharging at 2.7C. In the safety test, Carrar's thermal management system was completely passive, allowing free flow of refrigerant to the condenser and back to the module.

The project objective and success criteria were met, showing Carrar module can handle extreme drive cycles and prevent thermal runaway and thermal propagation successfully.

Project summaries for publication (Section 2 in the portal)

Project summaries for publication at www.vinnova.se as a part of open data policies. I hereby admit that I am aware that the following information will be published after being audited and contingent edited by Vinnovna.

- Purpose and aim – fulfillments (0-500 characters) (Swedish)
- Purpose and aim – fulfillments (0-500 characters) (English)

The Volvo Group and Carrar initiated a project to deliver and evaluate a high-performance Thermal Management Solution (TMS) for battery packs, and an overall high-power solution for Volvo Group

applications. As part of it, Carrar designed and built two battery modules for heavy-duty, long-haul applications that were tested for performance and safety.

- Result and expected effects - outcome (0-500 characters) (Swedish)
- Result and expected effects - outcome (0-500 characters) (English)

In the performance testing, the average temperature variation between the cells was 1.65°C, and along the cell was 0.6°C. The temperature uniformity contributes to the cells' health and can result in longer battery lifetime. In the safety test, the thermal propagation was eliminated as a result of higher heat dissipation than the cell heat generation. The highest temperature observed on the triggered cell was ~83°C, while the surrounding cells were kept below 25°C.

- Arrangement and implementation - analysis (0-500 characters) (Swedish)
- Arrangement and implementation - analysis (0-500 characters) (English)

Supplementary questions (Section 5 in the portal)

- How well does the outcome of the project align with the expectations at the start of the project (1-10)? - 8
- How user-friendly has the Vinnova portal been (1-10)?
- How well has Vinnova's counseling and support worked during the project. (1-10)?
- How satisfied are you with Vinnova as an authority (1-10)?
- Other questions? (0-500 characters)?
- How big share of the project has been performed by men (answer in %)? 73%

Follow-up questions (section 7 in the portal)

1. The FFI program is aiming for the participating institutions to have the mix of skills, both from academia and industry, that they need to carry out their projects. What are the skills, education, professional categories or equivalent of the people who have or have had their main funding from the FFI project (broken down by women and men)?

| | Number of women | Number of men |
|---|-----------------|---------------|
| Postdoctoral researcher | | |
| MSC in Engineering | | 2 |
| Research Scientist | | |
| Professors | | |
| Additional participants from the industry | 3 | 6 |
| Additional participants from the universities | | |

2. The FFI program is aiming that the organizations participating in the project disseminate and make the expertise built up in the project available. In what ways has your project contributed to the dissemination of skills?

- By participating in construction of courses at universities
- By participating as councilors or lecturer e.g., at universities.
- By internal competence developing program within participating organizations
- Other

Choose at least 1 alternative (multiple choices possible)

3. Has the project resulted in new recruitments?

- Yes, the project has resulted in new recruitments within the project.
- Yes, the project has resulted in new recruitments outside the project.
- No, no new recruitments have been made.
- Don't know

Choose at least one alternative (multiple choices are possible)

4. Engagement around the project can be done in various ways, for instance by a new or existing research environment. Does the project take place in a completely new and/or existing research environment or is it carried out in another way?

- In a new, purpose-built research environment
- In an already existing environment
- In other ways

Choose at least one alternative

5. Has the project led to new or developed collaborations relevant to R&D and innovation activities?

- Yes
- No

6. State the number of research degrees and degree projects taken or completed within the framework of the project, broken down by women and men. Indicate only those persons who have been mainly financed by the FFI project.

| | Number of women | Number of men |
|--------------------|-----------------|---------------|
| Doctoral degrees | | |
| Licentiate degrees | | |
| Diploma thesis | | |

7. Has the project resulted in licentiate and doctoral theses, scientific articles or conference papers?

- Yes
- No

8. Has the project led to any other publications?

- Yes
- No

9. Has the project led to knowledge and information sharing in other ways than publications?

- Yes
- No

10. Has the project contributed to applications – or already approved – patents or intellectual property rights?

- Yes
- No

11. Has the project produced results that have increased knowledge, been transferred to different development projects, introduced to the market or used in other ways?

- Yes
- No

Please note that the question also include early development stages before a product or service is ready to launch

12. Has the project resulted in or contributed to new or significant improved products, services, technical processes, or production processes

- Yes
 No

13. Has the project resulted in new or significant improved business processes or made the organization more efficient

- Yes
 No

14. Has the project resulted in new or significant improved business models or strategies?

- Yes
 No

15. Has the project led to increased R&D or other innovation investments?

- Yes
 No

16. Has the project resulted in any incomes

- Yes, the project has resulted in incomes for one or multiple project partners
 No, and it has never been the goal
 No, not yet

17. Has the project resulted in the development of policies, regulations or methods in public activities or politics?

- Yes
 No

18. Has or will the project lead to follow-on projects?

- Yes
 No

19. Eventual additional comments or reflections (0-500 characters)