The Future of Cooling is Solid-State - New Market Research on Solid State Cooling 2024-2044

Tuesday 5 September, 2023

The market for solid state cooling will more than triple to over $100 billion by 2044, providing many ways to create a billion-dollar business in this sector. Uniquely, the Zhar Research report, "Solid State Cooling Markets 2024-2044" (326 pages) has the full analysis, fully up-to-date. Older reports are useless because this subject is advancing rapidly.

Future cooling will increasingly be solid-state. Imagine multi-mode and multi-functional materials using multilayered solids and structural electronics like your mobile phone and much of your electric car. This will mainly be a world of benign, affordable materials such as silicone, silica, boron nitride, alumina, titania and polyethylene variants but often in sophisticated forms such as aerogels, nanocomposites, photonics and metamaterials. Complex chemistry too – a major opportunity for your skills, with less risk of commoditisation. Just as your phone replaces many things, solid-state cooling may reverse as heating or provide sensing, electricity, electronic drape function and more. Increasingly it will vanish into your roof, window, car body etc. Learn how some versions are even transparent, enabling invisible retrofit and use in glass buildings. Mostly, they will cause less or no undesirable heating of your city because they will be more efficient or unpowered "passive". There will be very little to go wrong in contrast to so much cooling today that relies on plumbing, liquids and gases including undesirable refrigerants.

Some of the new insights and data in the report include:

- Maturity curves 4
- New infograms 25
- Background forecasts 3
- New SWOT appraisals 11
- Acquisition opportunities over 6
- Companies mentioned 121+ worldwide
- Partnership opportunities and best research
- Ongoing updates so you get the latest developments
- New solid-state cooling forecasts 2024-2044 in 24 lines
- Detailed roadmaps 2024-2044 in two lines and two pages
- Data and insights for you to create a billion-dollar business
- Many promising applications and gaps in the market identified
- Detailed appraisal of research pipeline with much further reading
- PhD level analysis revealing winners, losers, main materials of interest
- Emphasis on research and company progress is particularly 2023 onwards

The "Executive summary and conclusions" at 39 pages is sufficient for those with limited time as it uses prolific new graphics, SWOT appraisals, infograms to reveal the market and technology dynamics, potential acquisitions and partnerships and the detailed road ahead 2024-2044 in many forecasts and a roadmap by year. The emphasis is commercial, particularly focussing on opportunities for added-value materials and devices but with many of latest research reports recommended for further reading throughout the report.

Chapter 2 Introduction takes 25 pages to introduce how cooling needs will increase for many reasons, growing problems and new solutions when cooling buildings and how problems are becoming severe with traditional cooling inadequate. It gives the overview of solid-state passive cooling for buildings and cooling windows and greenhouses. Learn air conditioner alternatives that are lower power, greener, more affordable and see comparison of traditional and emerging refrigeration technologies with NEOM smart city The Line in Saudi Arabia as an emerging example.

Understand the major new cooling opportunities in electronics and ICT with new SWOT appraisal of 6G Communications thermal material opportunities. See how cooling various forms of solar power: solar panels, photovoltaic cladding etc. and large battery thermal management become important plus electric vehicles land, water and air creating major new needs for thermal management.

The fins on your electronics and your car radiator cool mainly by forced and natural convection not radiation. However, paradoxically, reinvented radiative cooling is one of the most significant new trends. Chapter 3 puts all that together with a full 50 pages of, "Radiative and heat sink radiative/ convective cooling, passive liquid cooling: emerging materials and devices toolkit 2023-2043" given its huge

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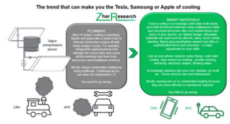

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potential. A maturity curve of radiative cooling technologies give technology readiness of each. This chapter explains the future of heat sinks and radiators and traditional and emerging radiative cooling. A major focus is Passive Daytime Radiative Cooling PDRC with its startup, massive research pipeline, materials opportunities and SWOT. See the fundamental and addressable limitations because this is data-based analysis not evangelism. The rest of the chapter analyses other emerging forms of radiative cooling, including tailorable-emittance coatings, paints, tapes, thermal louvers and ,particularly, tuned radiative cooling using both sides by Janus emitter JET. Then comes self-adaptive radiative cooling based on phase change materials and a SWOT appraisal of passive radiative cooling in general.

Chapter 4 (45 pages) is “Thermal Interface Materials and other emerging materials and devices for conductive cooling”. It spans the familiar world of thermal conductors at interfaces and for spreading and removing heat. The TIM analysis is thorough, embracing manufacturer lists and initiatives, next materials, formats, morphologies micro to industrial. See the explanation of why there is a modest trend away from filling large gaps so thermal film and adhesives come to the fore but many other forms have a future. Seven current options are compared against nine parameters. The silicone SWOT explains why there is some trend to more use of advanced graphite, graphene and sophisticated thermally-conducting polymers as thermal conductors but silicones have a great future. Indeed, silicone-based solid-state cooling, in its huge variety of forms, dominates the research pipeline and company initiatives taken together in the report as a whole. In this chapter, both electrically-conducting and electrically insulating thermal conductors are in the frame. A large section addresses important considerations when solving thermal challenges with conductive materials. Thermally conductive carbon-based polymers are appraised against targetted features and applications and there is more.

Chapter 5. “Solid-state caloric cooling” is considered by Zhar Research to be very promising so it takes a full 57 pages to make sense of the frenzy of new research, the start of commercialisation and the potential applications. Three SWOT appraisals and sections on electrocaloric, magnetocaloric, elastocaloric and barocaloric options with a nod to the less-important twistocalorics. The multicaloric option follows. See why some of the options are non-starters on basic principles and other could be improved to the point of appearing in vast areas on buildings and maybe vehicles, despite being affected by weather. How does the best shape up against the older technology called thermoelectrics? Both are part of the strong trend from plumbing, liquids and gases to smart materials that is also seen with electricity production and batteries.

Could you have greenhouse glass that cools? Could you have a lens that concentrates sunlight not to set fire to something but to cool? Researchers say you can and Chapter 6. “Metamaterial and other advanced photonic cooling: emerging materials and devices” takes 32 pages to explain how this magic can mean big business. What materials, applications, timescales, best research papers, commercial initiatives, lessons of success and failure, three SWOT appraisals? It is all here, including metafabrics with such radiative and reflective cooling and a close look at why Anti-Stokes fluorescence is newly commercialised with considerable potential.

Thermoelectric cooling is solid-state but after a very long time it is still unusual to find someone selling $100 million yearly of it. Why bother to discuss it in this report? Well, it is being reinvented to escape rare toxic materials and become affordable and suitable for large areas. How about thermal locking by ferrons or spin-driven thermoelectrics? Metal organic framework thermoelectrics? Already, thermoelectrics can be lower cost than alternatives where precise temperature control is vital or strong cooling of small areas is needed, as required by the 1kW microprocessors expected soon. The 31 pages of Chapter7. “Thermoelectric cooling reinvented” explain, give a SWOT and predictions.

You cannot read this report without realising that is not just your car window that is multi-purpose (block the sun, antenna, demister). Cooling is firmly headed the same way, including car windows that also cool using several physical principles. Chapter 8. “Multi–mode and multi-purpose integrated cooling involving solid-state” closes the report with many examples to come. Expect solid-state cooling that desalinates water, captures useful amounts from the air. What startup offers solid-state reflective and radiative cooling smart material for aircon and refrigeration? There is load-bearing thermal insulation and active cooling material and a great deal more on the horizon. The report emphasises clarity with a glossary and terms explained in the text.

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