



## 1.5 Concept Generation

Concept generation is an important tool to use for finding a solution to a problem. Our team utilized multiple concept generation techniques to generate one hundred concepts. An abundance of concepts makes it more likely that we have looked at all possible ideas and the best concept can be selected during concept selection. The list of all 100 concepts is shown in appendix D. From our list of 100 concepts 5 were chosen to be medium fidelity concepts, meaning that they could be suitable solutions for our project and 3 concepts were chosen as high fidelity concepts which means they have the prospect to fulfill a majority of the needs of our design.

**1.5.1 Concept Generation Tools**

Generating the one hundred concepts required the use of numerous techniques including: brainstorming, crap shoot, and biomimicry. General brainstorming resulted in approximately forty percent of the total concepts. In brainstorming, we wrote whatever came to mind, both orthodox and unorthodox methods were welcomed. The next method was crap shoot, here we investigated entirely improbable designs but could possibly yield valuable solutions. This method did not result in many concepts but made it interesting to look at our problem with an open mind. Another method that our group used to generate concepts was the anti-problem. With this method we focused on existing module cooling designs and analyzed the problems that those designs had. We then came up with solutions to those problems and created concepts that addressed those problems. An example of this is concept number 2. Concept 2 is reconfiguring the coolant channels in cold plates to reduce pressure drop. One problem with existing cooling methods is the pressure drop through the cooling plates is high, so the coolant pump uses a lot of energy to pump the fluid around. Concept 2 reduces would focus on reducing pressure drop by optimizing coolant channels. The last method we used was biomimicry, we searched keywords like cooling and found examples of cooling in nature. One example of biomimicry is concept number 48 which entails drilling holes in the module walls to increase air flow within the module. This idea came from research that we found about how termites drill holes in their nest to increase cooling. Another example of biomimicry that we used as inspiration was sweat. Sweat is how mammals cool themselves by releasing water which carries heat out of the body. This inspired concept number 15 which is using a salt hydrate-based phase change material to cool the cell. As the cell heats up the phase change of the material occurs which absorbs the heat and moves it outside of the cell.

**1.5.2 Medium Fidelity Concepts**

After completing our list of 100 concepts our team went through the list and picked out ideas that we felt were medium fidelity concepts. This included ideas that we felt offered solutions to aspects of our project that can be useful design but did not encapsulate all the functions that our design needs to have. Table 4 shows the list of medium fidelity ideas we produced.

*Table 4: Medium Fidelity Concepts*

|  |  |
| --- | --- |
| **Concept Number** | **Description**  |
| 12 | Cooling plates sandwiched between modules with coolant flowing between them. |
| 15 |  Using salt hydrate phase change materials to absorb heat and remove it from inside of the module. |
| 45 | Coolant channel that starts at the top of the module and snakes between all the cells and outputs to a heat sink at the bottom of the module.  |
| 53 | Cabinet based holding for pouch cells with gap in between each cell to allow for coolant flow. |
| **55** | Angle slits on the battery pack to increase the amount of airflow into the modules |

**1.5.3 High Fidelity Concepts**

From the list of 100 concepts three were chosen as high fidelity concepts. These concepts are shown in Table 5. These concepts have many of the functions that our design will need to meet our targets.

*Table 5: High Fidelity Concepts*

|  |  |
| --- | --- |
| **Concept Number**  | **Description** |
| 22 | Route liquid cooling pipes around the inner shell of module wall with aluminum plates between cells to transfer heat to pipes. |
| 44 | Create thermal paste packs that increase contact area between cells and module walls. |
| 54 | Layer highly thermally conductive tape between cells to transfer heat to the side of the module to which the coolant channels are connected. |

Concept 22 is routing liquid cooling pipes around the inner shell of the module walls with aluminum plates between the cells to transfer heat to the coolant pipes. This concept takes advantage of liquid cooling to provide more heat transfer within the cell. The specific heat of fluids such as water are much higher than air. Also, routing the cooling pipes around the module gives the pipes more space which will allow them to have a larger diameter which will reduce the pressure drop within the pipes. The use of the aluminum plates will allow the heat from each cell to transfer in multiple directions to reach a pipe, keeping the temperature gradient across the cell constant. If higher heat transfer is needed the fluid flow rate can be increased to improve heat transfer within the module.

Concept 44 uses thermal paste packs to increase contact area between the cells and module walls. The more surface area there is between the cells and the cooling medium allows for more heat to be transferred within the cell. Thermal pastes have a high thermal conductivity which will efficiently remove heat from the module. Thermal paste will be able to maximize the empty spaces within the module that would normally be filled with air.

Concept 54 uses thermally conductive tape between cells to transfer heat to the sides of the module. Thermally conductive tape is used in electronics such computers to remove heat. This design will utilize this thermally conductive tape to efficiently transfer heat from the cells to a coolant channel. One advantage of this concept is the tape is very light and has a high thermally conductivity. It also allows the design to significantly reduce pressure drop from coolant channels because the tape limits the need for coolant channels within the module.

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**Appendix D: Concept List**

1. Use peltier device within module to help generate electricity without raising temperature
2. Change layout of cooling channels to reduce losses
3. Make use of copper's high conductivity to take away more heat
4. Make use aluminums high conductivity to take away more heat
5. Reduce the distance between plates to increase the heat rate
6. Add fans to induce airflow into the module to increase the heat taken out
7. Add more cooling plates to the module
8. Add fins to the cooling plates with induced airflow to increase heat taken out
9. Increase the amount of cooling channels to increase heat taken out
10. Increase the area of the cooling plate to increase heat taken out
11. Decrease the thickness of the cooling plates to increase heat taken out
12. Cooling plates in between modules with coolant flowing between them
13. Add holes/slits in battery pack to allow for increased airflow
14. Increase the convection heat transfer coefficient (h)
15. Using salt hydrate phase change materials (PCM) to absorb heat
16. Using paraffin PCM to absorb heat
17. Heat pipe design with an air-cooled end
18. Heat pipe design coupled with coolant flow
19. Submerge the cells in coolant Batter
20. Submerge module in ice pack
21. Put batteries inside the vehicle and place them in a refrigerator
22. Route liquid cooling pipes around the inner shell of module wall.
23. Add carbon fiber plates between cells to increase conduction from cells.
24. Add cooling plates between each cell and run coolant through the plates.
25. Pump antifreeze over the modules when they overheat
26. Coolant is run through a fan cooled radiator
27. Use lightweight material so less energy is required to operate the vehicle
28. Use evaporative cooling method
29. Use aluminum foil sheets to increase the contact area of cooling
30. Use heat sink to force heat out
31. Spray coolant onto cells onto cells and cooling plates
32. Add AC system to battery pack
33. Tilt batteries and spray coolant, allow for coolant to run down modules and fall to bottom of pack, pump waste out
34. Spray coolant on batteries intermittently and let coolant pool on bottom, add cooling element to the pooled coolant and slowly pump it out
35. Placing pack on cooling/heating pad
36. Submerge module in coolant, constantly pumping in cool coolant while pumping out hot coolant
37. Submerge module in coolant while constantly cooling the pool
38. Serpentine pipes between modules
39. Insert dry ice into modules before each use
40. Have a bunch of tiny fans blowing
41. Single cooling pipe that goes around module with aluminum plates to transfer heat to the fluid
42. Cold plates with dimples inside induce turbulence on flow to increase conduction
43. Thermally conductive tape between cells used in electronics to transfer heat
44. Create thermal paste packs that increase contact area between cells and module walls
45. Coolant channel that snakes between the cells and outputs to a heat sink
46. Cooling plate with entire plate filled with coolant instead of using pipes
47. Energy is pulled from other sources when the batteries overheat
48. Drilling holes in the module walls to increase natural convection
49. Plate heat exchanger that has the cells fitted between it and fluid flows through it
50. Diamond plated heat exchanger
51. Gold plated heat exchanger
52. Cabinet based holding for pouch cells with gap in between each cell to allow for air flow
53. Cabinet based holding for pouch cells with gap in between each cell to allow for coolant flow
54. Layer highly thermally conductive tape between cells to transfer heat to the side of the module to which the coolant channels are connected
55. Angle slits on the battery pack to increase the amount of airflow into the modules
56. Using AC pump to provide cold air to the modules, similar to building hvac
57. Use insulation to conserve cool air, then extract hot air through holes in the top
58. Air compressor on vehicle compresses air and as air is released into the module and the drop in pressure reduces temperature in air going into module
59. Add scoops to battery pack to increase the amount of airflow
60. Use silver plates between the cells to transfer heat at a higher thermal conductivity
61. Use a hydrogel of a polyacrylamide framework infused with water and specific ions. When hydrogel is heated, electricity is produced creating less strain on the batteries.
62. Decrease the surface roughness of cooling channels to minimize losses
63. Cells are immersed in a dielectric fluid and the fluid absorbs the heat as the battery cells heat up
64. Increase the diameter of the cooling channels to reduce losses
65. Switching the side of the tabs of the cell so they are on opposite ends of the battery module.
66. Use liquid nitrogen heat exchanger to cool battery
67. Use liquid helium for better efficiency and to cool the battery
68. Bring outside airflow into a radiator inside the battery pack
69. Intermittently drop dry ice into pack during operation
70. Use cooling plates with modules submerged in a cold pool of liquid
71. Route heat from cooling plates to battery pack and have outside airflow cool battery
72. Add fins to battery pack
73. Submerge battery pack in coolant
74. Spray coolant on battery pack
75. Use regular cooling plates and spray extra cold coolant into the network when heat is too extreme
76. Use a fan to blow evaporated liquid nitrogen into the module
77. Have a rotating cold plate, as one plate gets hot rotate in one that has been precooled
78. Focus cooling on one part of the cell so that it overall doesn’t overheat
79. Connect cooling channels to fins on the battery pack and route them into the cooling plates in the module
80. Use shell and tube heat exchanger to help direct air and coolant flow to effectively cool cells
81. Submerge battery pack in cold pool and insulate the pool, have hot liquid circulated out and cooled using outside airflow and bring it back into the pool
82. Use barbed pipes to increase the surface area of the pipes and increase the amount of heat taken out
83. Periodically pour coolant onto cells
84. Put cells on rotating piece that dumps them into coolant as the piece rotates
85. Put cells on rotating piece that dumps them into coolant as the piece rotates and spray coolant onto the cells at the top of the rotation
86. Use baffles to prevent the cooling channels from vibrating and losing energy
87. Spread cells out with one cooling plate per cell
88. Decrease the length of cooling channels but increase the number of passes
89. Use smoother cooling channels to decrease losses
90. Have sliding piece in module that goes to each cell spraying coolant
91. Pour coolant onto cells, have it pool at the bottom, as it gets hot pump it out and recool It
92. Use smoother channels with higher damping on the battery to decrease losses
93. Have coolant injectors on a rail in the module that intermittently spray coolant
94. Use a sprinkler type system that can spray the whole module with coolant
95. Use a system similar to a building’s fire suppression system that can spray coolant in the module
96. Use system that can constantly pull-out hot cells and dunk them in a coolant reservoir
97. Tilt cells and have coolant run over them and out of a slit on the other side
98. Have fan pointed on cells and oscillate the cells to have even distribution of airflow
99. Use thermal paste to improve the contact area of cooling
100. Use compressor, evaporator and helium as the heat transfer fluid to have large heat transfer rate.