

# Development of a Multifunctional Snow Production Unit for Granåsen Arena

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## Preface

This project report was carried out at the Department of Mechanical and Industrial Engineering (MTP, Institutt for maskinteknikk og produksjon) at NTNU during the autumn 2017. The project was given by the Centre for Sport Facilities and Technology (SIAT, Senter for idrettsanlegg og teknologi). The project is a part of the development process of a multifunctional snow production unit for Granåsen Arena.



Figure 1: First design idea for the combined light mast and snow lance. Photo: Gudrun Reikvam (2016)

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- Supervisor at SIAT: Bernhard Vagle
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## Summary

In this project, the preliminary work in the product development process of a multifunctional snow production unit for Granåsen Arena has been carried out. This involves formulation of a vision statement and analysis of technology and user needs. A literature survey on existing technology has been conducted. Customer needs have been analyzed through observations and interviews with Trondheim Bydrift in Granåsen. The main outcome of the report is the user requirements and product requirements specifications.

It is assumed that the infrastructure needed for snow production will be developed, and the focus has therefore been on the isolated unit and the conditions above ground. There has been discovered some conflicts between lighting and snow production. The height of the lance is important to let the water freeze before it reaches the ground. However, too high lances will make snow production more fragile in windy areas, as the the snow can be blown away from the tracks. Light masts should ideally be taller than lances. With sufficient height, the luminaire surface can be parallel to the ground, which will reduce stray light on the surrounding nature. Another conflict is the heat from the lights. When designing the lighting armature and housing, the heat from the lights must be distributed in such a way that it does not affect the snow production.

The skiing resorts will require more artificial snow during the winter seasons in the future in order to stay open. This increase of production will perhaps not be possible in Granåsen with the system that exists there today. A system of evenly distributed stationary lances that can automatically change settings according to local conditions and predefined parameters is the desired solution. This will save time, energy and cost in operation.

None of the results presented in this report suggest that the development of a combined unit will not be possible. The results should therefore be the basis for a master thesis, where the development process will continue.

## Acronyms

**CRI** Color Rendering Index

**CAD** Computer Aided Design

**FEA** Finite Element Analysis

**GHG** Greenhouse Gas

**IPM** Institutt for Produktutvikling og Materialer

**kWh** Kilo Watt Hour

**MPH** Miles Per Hour

**MTP** Institutt for Maskinteknikk og Produksjon

**PCB** Printed Circuit Board

**SIAT** Senter for Idrettsanlegg og Teknologi

# Contents

<b>Preface</b>	<b>i</b>
<b>Summary</b>	<b>ii</b>
<b>Acronyms</b>	<b>iii</b>
<b>1 Introduction</b>	<b>2</b>
1.1 Background . . . . .	3
1.2 Objectives . . . . .	3
1.3 Approach . . . . .	4
<b>2 The Product Development Process</b>	<b>5</b>
2.1 Vision and Project Plan . . . . .	5
2.2 Needs- and Technology Analysis . . . . .	5
2.3 Concept Development . . . . .	6
2.4 Structure, Design and Production Ramp-up . . . . .	7
2.5 Prototyping . . . . .	7
<b>3 Vision</b>	<b>9</b>
<b>4 Snow Theory</b>	<b>10</b>
4.1 Natural Snow . . . . .	10
4.2 Artificial Snow . . . . .	11
4.3 Snow Production . . . . .	14
<b>5 Customer needs analysis</b>	<b>17</b>
5.1 Snow Production in Granåsen . . . . .	17
5.2 Climatic Conditions . . . . .	19
5.3 Users and Stakeholders . . . . .	22
5.4 User Requirements . . . . .	27
<b>6 Technology Analysis</b>	<b>28</b>
6.1 Lance Technology . . . . .	28

<i>CONTENTS</i>	1
6.2 Lighting . . . . .	35
6.3 Product Requirements . . . . .	43
<b>7 Summary, Conclusions and Further Work</b>	<b>44</b>
7.1 Summary . . . . .	44
7.2 Conclusion . . . . .	45
7.3 Limitations . . . . .	46
7.4 Further Work . . . . .	47
<b>A Appendix</b>	<b>48</b>
A.1 Data for Calculations on Solar Cell Energy Output . . . . .	48
A.2 Project Plan . . . . .	49
<b>References</b>	<b>50</b>

## 1 Introduction

Skiing has been a part of Norwegian identity for hundreds of years, and could be considered an important Norwegian value. In sports, skiing disciplines are where Norway as a nation traditionally reach the best international results. Moreover, skiing is a popular form of exercise among the average population, and is therefore important to public health. For these reasons, skiing is considered to be the Norwegian national sport. It is therefore important to secure skiing conditions that are both of high quality, available and appealing to people.

Through the last decades, climate changes have affected the winters in Norway. The implication of these climate changes are shorter winter seasons with increased temperatures, which makes snow production more relevant than ever before. Ski resorts are dependent on artificial snow production when the natural snow is absent. The Norwegian Ski Federation has an executive goal that skiing should be the national sport in Norway also in the future, despite the climate changes. They have recognized that ski resorts that can provide artificial snow is necessary to reach this goal (Kulturdepartementet (2014)). As a result, many skiing resorts are putting large amounts of resources into improving their snow production and snow storages.



Figure 2: Worlds championships in Granåsen, 1997 (Nilsen (2014))

A development of Granåsen arena is planned whether Trondheim gets to arrange the world championships in Nordic disciplines in 2023 or not. To function as a modern area for recre-

ational and elite sports, new and innovative solutions are needed. Trondheim Municipality has decided to spend 980 MNOK to develop Granåsen Arena (Trondheim Municipality (2017)). Highly prioritized focus areas for the development plans are reduction of Greenhouse Gas (GHG) emissions and energy consumption (Langedal (2017)). One of the means to address these issues is to develop a combined snow production unit and light mast. With a such solution, the snow production can be distributed around the tracks without having to move mobile snow production units.

## 1.1 Background

So far, little has been done on the development of the new snow production unit. One student assignment was started but not finished. However, snow production is very relevant, considering the global climate changes, and the field of research is therefore expanding. The conditions in Granåsen has been researched due to the upcoming rollout of the arena.

The idea of a combined snow production unit and lamppost is interesting because such a solution would reduce the time needed to start snow production when the right conditions are present. It would remove the need to transport mobile units around the course, because there would be a network of automated, stationary units. To produce snow directly around the track will also reduce operating cost of transporting snow from big piles to the track. A combined solution could also reduce investment cost compared to a solution with new lampposts and snow lances separated.

### Problem Formulation

Which conditions, constraints and user needs have to be considered when developing a combined light mast and snow lance for Granåsen Arena?

## 1.2 Objectives

The overall objective of this report is to facilitate the development process of the snow production unit. This involves:



1. To become familiar with the conditions and technology that influence snow production. (Section 4 and 6.1-6.2)
2. To become familiar with the challenges of today's arena in Granåsen and to know the local conditions and constraints that will affect the design and implementation of the new unit. (Section 5.1-5.2)
3. To evaluate some relevant product development methodologies for this project and further work. (Section 2)
4. To map the users and stakeholders. (Section 5.2-5.3)
5. To create an initial requirement specification. (Section 5.4)

The last objective, initial requirement specification, should be derived from the other objectives.

### 1.3 Approach

Through this project the product development model of IPM (Institutt for Produktutvikling og Materialer) has served as a foundation, with some input from the model of (Ulrich and Eppinger (2012)). The IPM-model is structured with intermediate objectives and it is simple to follow.

The development model is divided into five phases. Between each phase there is a milestone. This project considers the two first phases, as an initiation of the master thesis. The first phase involves planning and formulation of the problem statement and vision. The next step is to gain knowledge about the subject, referring to the three first objectives. A literature review on relevant technology has been performed to gain insight. This involved searching the literature and reviewing reports produced by SIAT, Trondheim Municipality and other involved institutions.

Customer needs has been investigated through existing literature on snow production in Granåsen and also through meetings and observations of employees at Trondheim Bydrift. The requirements has been prioritized according to importance and complexity. These requirements are initial, and will be evaluated and possibly changed as the project proceeds.

## 2 The Product Development Process

This section gives an introduction the product development model of IPM and Ulrich and Eppinger (2012). The model of Ulrich and Eppinger (2012) provides a step-by-step approach as seen in Figure 3. This gives an easily understandable overview of the project and process. In this project the model is used as a supplement to the IPM model. Ulrich and Eppinger (2012) define product development as the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product.

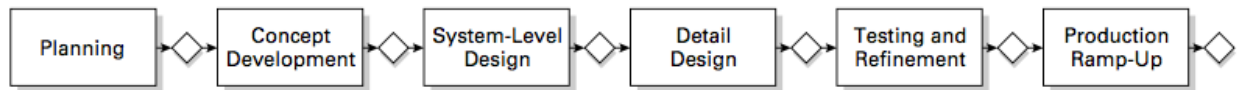


Figure 3: Product Development Model by Ulrich and Eppinger (2012)

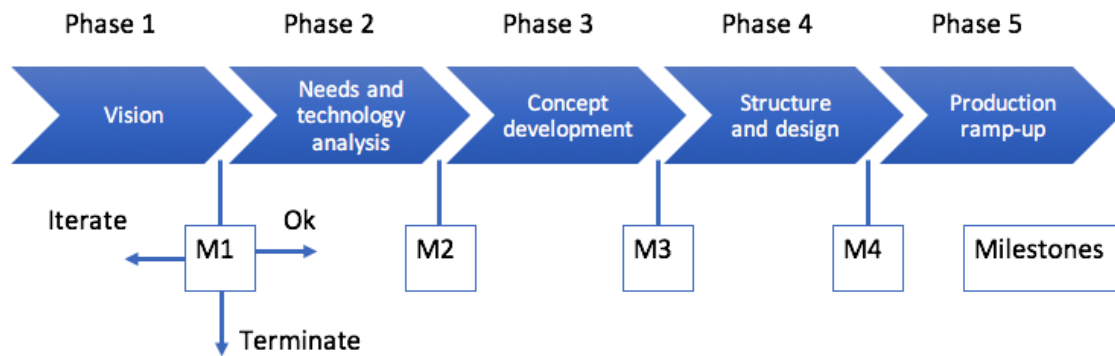


Figure 4: The IPM process model. The milestones represent deliveries. One should evaluate if the project should go to the next phase, be terminated or if iterations are necessary (Hildre (2004))

### 2.1 Vision and Project Plan

The vision should describe the basic idea of the project. A project plan should also be made to define milestones and time schedule.

### 2.2 Needs- and Technology Analysis

This step should make the development team understand the customers needs and technology constraints. After one have gained more insight to the users/marked one can search for tech-

nology possibilities. This should again lead to a product requirement specification.

## 2.3 Concept Development

The concept development is a front-end process, which contains many interrelated activities. In practice, the front-end activities may be overlapped in time and iteration is often necessary. At almost any stage, new information may become available or results learned that can cause the team to step back to repeat an earlier activity before proceeding.

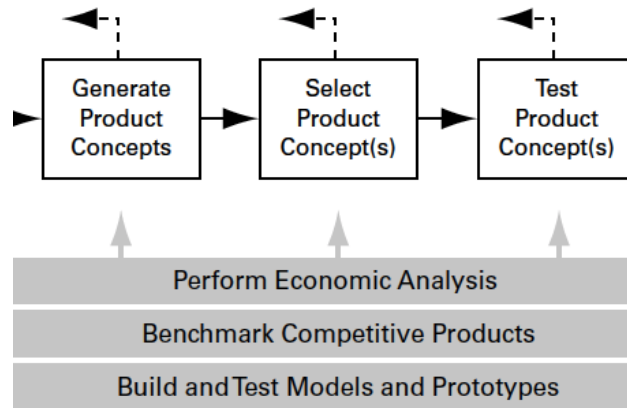


Figure 5: Concept Development Process (Ulrich and Eppinger (2012))

The steps of concept development are shown in Figure 5. An explanation of the three steps are given below:

**Concept generation** begins with a set of customer needs and target specifications. This results in a set of product concepts from which the team will make a final selection. A product concept is an approximate description of the technology, working principles, and form of the product.

**Concept selection** is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development. Both stages, concept screening and concept scoring, follow a six-step process that leads the team through the concept selection activity.

**Concept testing** to see if the artifact meets the customer needs and verify the design.

## 2.4 Structure, Design and Production Ramp-up

The end result of this activity is an approximate geometric layout of the product, descriptions of the major chunks, and documentation of the key interactions among the chunks. A detailed design should include computer drawings of design describing geometry of each part. Material selection, production cost and performance should be estimated. In this phase the product is made using the intended production system. Production methods used for production should be explained.

## 2.5 Prototyping

A common practice is to use prototypes to represent different parts of the design and explore different options. This is done to validate and verify assumptions, calculations and decisions during the development. A prototype can also reduce the risk of unnecessary iterations. These iterations will cost time and money, depending on how far in the development process you have gotten.

Ulrich and Eppinger (2012) claims prototypes are used for learning, communication, integration and milestones:

**Learning:** Prototypes used for learning should answer how well it meets the customers needs.

The question "Will it work?" should be answered. Various designs could be tested to learn if it works or not.

**Communication:** It is often important to communicate through prototypes with people outside the development team. A three-dimensional representation is much easier to understand than a verbal description or a sketch (Ulrich and Eppinger (2012)). When the customer understands the concept, it is easier for him to give better feedback.

**Integration:** By integration of different components in a prototype, one can test if the product works as expected. Sub functions can work alone, but if the combination interferes with the overall function, an evaluation and re-design is needed. Physical integration in a comprehensive prototype is a good method to detect eventual problems (Ulrich and Eppinger (2012)).

**Milestones:** Testing to see if the product has achieved desired functionality is often done by milestone prototypes. Milestones prototypes provide tangible goals and demonstrate progress. Sometimes milestones are used to show required functions to the customer before allowing the project to proceed.

### 3 Vision

The problem was given by SIAT at NTNU. They have a good relationship with Trondheim Bydrift who runs Granåsen Arena. Considering the new development plan in Granåsen, it is possible to develop new solutions for more efficient snow production. As a result, the idea of a combined light and snow production unit emerged. Below, the vision and mission statements are presented. In Table 1, the most important business goals, markets and stakeholders are presented.

**Vision:** To develop a concept and design for combining snow production and light armature into one unit, which will make snow production more efficient and reduce GHG emissions in both manufacturing and in operation.

**Mission:** To conduct a product development process during project and master thesis, where the user needs are the foundation of all decisions.

Table 1: This table summarizes the directions to be followed for the product development of the multifunctional snow production unit.

<b>Product description</b>	Fully automated unit for snow production and lighting to be distributed along a cross country skiing track
<b>Key business goals</b>	Make snow production more efficient, Contribute to Granåsen Arena's goal of snow guarantee, Reduce start-up time for production, Reduce investment cost compared to standard solutions, Reduce GHG emissions.
<b>Primary market</b>	Customized solution for Granåsen Arena is the first priority, Cross country skiing tracks.
<b>Primary Stakeholders</b>	Trondheim Municipality and Trondheim Bydrift Users of Granåsen Arena (including elite athletes, families, recreational sports, etc.), Potential industrial partners, SIAT.

## 4 Snow Theory

This chapter contains a literature study of snow theory. Knowledge of snow, both natural and artificial, is very important in order to understand the snow production process and some of the technical requirements that will affect the design. Snow, both natural and artificial, consist of clusters of ice crystals. The formed ice crystals can take different shapes depending on temperature and humidity in the atmosphere where the snow is created. The most known shape being the six-armed crystal, known as dendrite.

### 4.1 Natural Snow

Snow crystals are formed when water vapor in the atmosphere, usually in clouds, sublimates directly into solid ice without going through the liquid phase, and the ice crystals cling together. Looking at the phase-diagram of water in Figure 6, this transformation happens along the sublimation line where both temperature and pressure are low. The phase transformation consist of two phases: *nucleation* and *growth*. Nucleation of a given material involves the appearance of very small particles, or nuclei of the new phase (often consisting of only a few hundred atoms), which are capable of growing. During the growth stage, these particles increase in size until the equilibrium fraction of the phases is reached (Callister and Rethwisch (2007)). One of the necessary conditions for a solidification transformation is that the temperature is below the equilibrium solidification temperature, however, this is not sufficient for the phase transformation to happen. When water is divided into small drops, the statistical probability that it will freeze at a given temperature becomes smaller since there are fewer water molecules available to form a nuclei that is capable of growth (Curry and Webster (1998)). Snow is made when water vapor is solidified onto the nucleus. If a nucleus grow to become a big enough particle, it will start falling through the air.

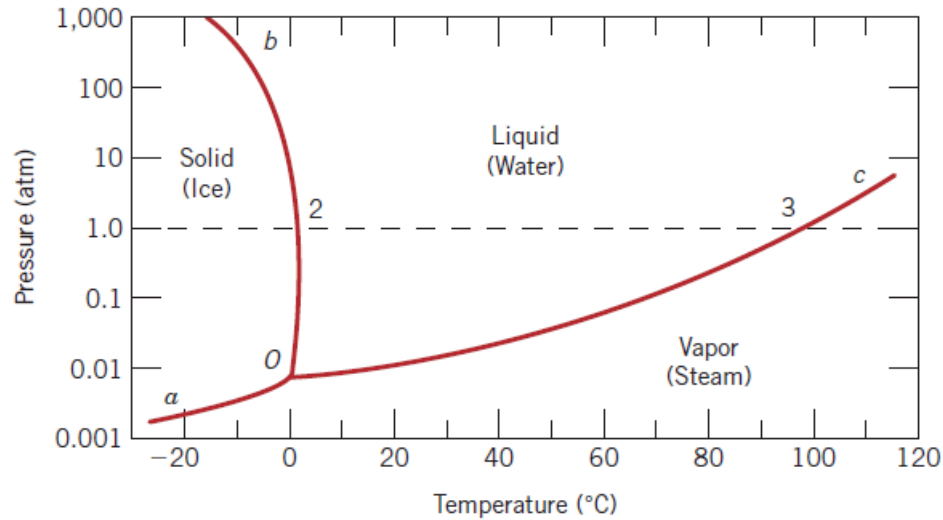


Figure 6: Pressure-temperature phase diagram for  $H_2O$ . Intersection of the dashed horizontal line at 1 atm pressure with the solid-liquid phase boundary (point 2) corresponds to the melting point at this pressure ( $T = 0^\circ C$ ). Similarly, point 3, the intersection with the liquid-vapor boundary, represents the boiling point ( $T = 100^\circ C$ ). The sublimation line is the boundary curve from  $a$  to the tripple point,  $O$ . (Callister and Rethwisch (2007))

## 4.2 Artificial Snow

Artificial snow production consist of two main stages: Generating water droplets and freezing of the droplets. The first stage is done by disbursing water into fine droplets. This can happen when water and air at high pressure are mixed and atomized through a nozzle. The pressure difference from the water to the atmospheric air cause turbulence that brakes the water jet and creates droplets. The smaller the droplets are, the greater the surface to volume ratio is.

For the water to freeze in the air, certain conditions must be present: Air temperature; humidity; distance from nozzle to ground; and nuclei that can catalyze the phase transformation of the droplets. The droplets will freeze from the outside and inwards. This is what causes the structural difference between natural snow and artificial snow. In general three factors control the freezing of droplets (Kulturdepartementet (2014)):

1. **Thermal balance.** The ration between low wet-bulb temperature and volume of water that should freeze.
2. Sufficient amounts of **nuclei** in the water, to start the solidification process of the water



droplets.

3. The water droplets need adequate **air time** to be able to freeze.

These points are reflected in Figure 7.

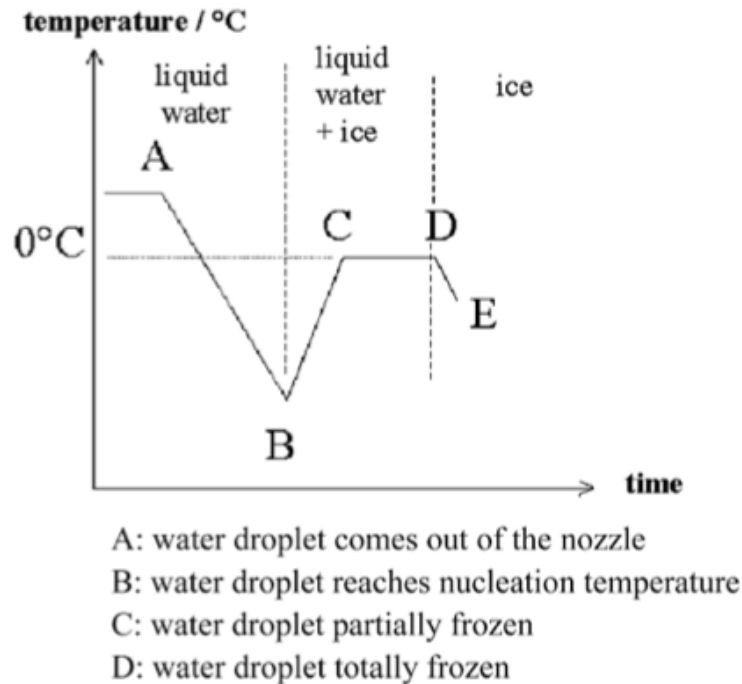


Figure 7: Temperature of water droplet during snow production. (Fauve and Rhyner (2004))

Artificial snow has the advantage of withstanding longer periods of warm weather. The round grains of machine-made snow gives a structure which is close-packed and in general denser than natural snow, which accordingly results in a higher density compared to natural snow (Linzén (2016)). A report from Kulturdepartementet (2014) claims that  $10\text{cm}^3$  of artificial snow equals  $40\text{cm}^3$  of natural snow.

#### 4.2.1 Thermal Balance

*Wet-bulb* temperature is dependent on relative humidity and conventional air temperature (dry-bulb), that explains the relationship between temperature, humidity and snow production. Relative humidity is a measure of the amount of water vapour in the air, expressed as a percentage of the total amount contained in saturated air at a given temperature and pressure. More specifically, wet-bulb is "the temperature a parcel of air would have if it were cooled adiabatically (at

constant pressure) to saturation by the evaporation of water into it, with the latent heat being supplied by the parcel" (Dunlop (2008)).

To let go of the heat some water need to evaporate from the surface of the water droplets. When the humidity is high, the water on the droplets surface are not able to evaporate. In principle, snow can be produced at higher temperatures when the humidity is low.

Figure 8 shows wet-bulb temperature for corresponding humidity and temperature. The different colors shows how the specified wet-bulb temperature affects the snow quality.

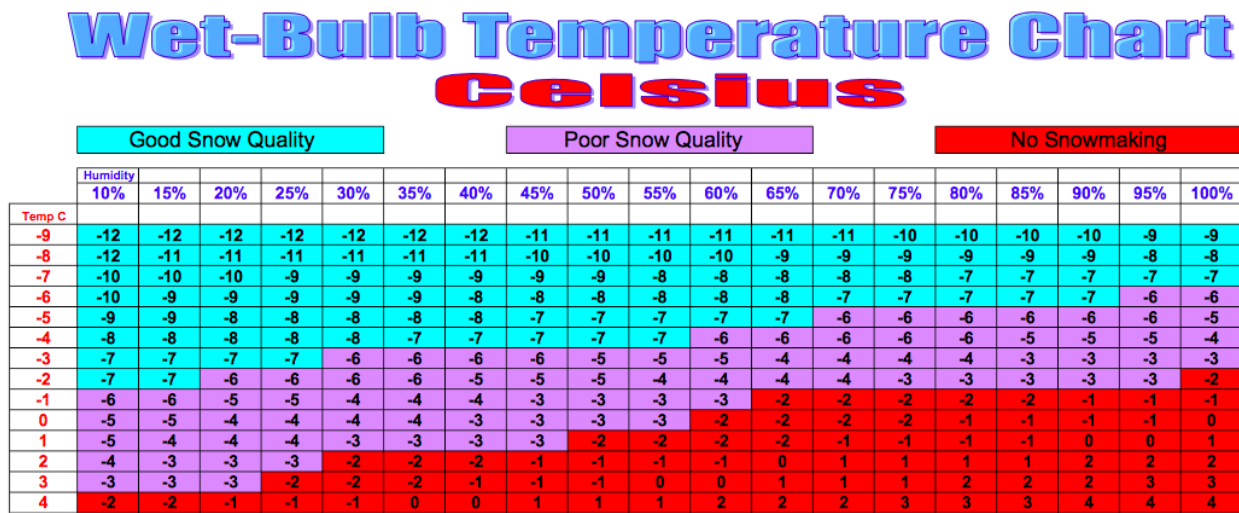


Figure 8: Shows wet-bulb temperature for corresponding humidity and temperature. By plotting the current temperature at the left column and the current humidity at the top column the wet-bulb temperature is shown in where they meet. The chart illustrates how the snow quality varies with different wet-bulb temperature. Below  $-7^{\circ}\text{C}$  wet bulb temperature gives good snow quality. This means nice and dry snow.  $-3^{\circ}\text{C}$  to  $-6^{\circ}\text{C}$  gives poor snow quality, which means that the snow is very wet. (Snowathome (2017))

#### 4.2.2 Nuclei

As illustrated in Figure 7 the water need to reach nucleation temperature to start the freezing process. Freezing nuclei are ice particles, or other solid particles, in the water. Distilled water start to freeze at  $-40^{\circ}\text{C}$ , while water containing other particles (e.g. added proteins or "dirt" from the water source) can freeze at  $-3^{\circ}\text{C}$  (Kulturdepartementet (2014)). When the nucleation temperature is reached the droplets start to freeze and release heat. The temperature then increases before the whole droplet is frozen, and the temperature decreases again (Fauve and

Rhyner (2004)).

### 4.3 Snow Production

The decision of type of snow guns, and when and where to produce snow are influenced by many factors: local conditions; snow demand; economy; and experience. Moreover, the snow production does not only depend on the type of snow gun, but also the infrastructure around the guns.

One common practice is to produce a sturdy ground layer of snow to be covered by natural snow, and then produce more snow for selected parts of the course/slope to maintain snow depth and quality. Vulnerable areas where the snow require extra maintenance could be: Tracks that are frequently exposed to the sun; at the top of steep hills (or in the hills) where skiers slow down using snowploughing technique; areas exposed to wind; etc. Sometimes, it could also be beneficial to produce snow in piles when the conditions are present, that may be distributed later on.

Today there are two main types of snow making machines on the market. These are fan based machines (fan guns) and high-pressure tower based machines (lances). They both follow the principles of snowmaking that were presented in section 4.2. Comparison of lances and fan gun can be seen in table 2.

Table 2: Comparison of lances and fan guns. (Rogstam and Dahlberg (2011) and Sufag (2017))

	Lance	Snow gun
Capacity (m <sup>3</sup> /h)	20 - 65	55 - 95
Power consumption (kWh/m <sup>3</sup> )	0,58 - 0,72	0,97 - 1,94
Optimal reach (meters)	10-20	40
Water use (l/s)	25 - 30	11 - 44
Mobility	Easier to move, but are often placed stationary on strategic points	Hard to move, high weight
Maintenance	Low	High, over time
Adjustment for snow quality	Few adjustment steps	Several adjustment steps
Sources to operate	Water and high pressure air	Water and electrical power

### Fan Guns

Fan guns use a fan to blow the water-air mix up to 60 meters . This leads to high production rates and makes them less sensitive to wind. High pressure air is made on the unit by a compressor. Therefore, proximity to a direct power outlet is necessary. Because of the high production rate snow guns are often used to produce snow in big piles, which is then transported into the tracks. More adjustment possibilities can also lead to snow production at marginal temperatures. Because of the large number of parts, fan guns need more maintenance over time than lances.



Figure 9: Fan gun (Technoalpin (2017))

### Lances

Lances use high pressure air to atomize the water into fine droplets in the nozzle. The height of the lance is important to let the water be able to freeze before it reaches the ground. This again makes snow from lances more fragile in windy areas, as it can be blown away from the tracks. Lances need to be connected to a piping system of high pressure water and air. The high pressure air could be produced by local compressors or by pipe lines from a stationary compressor unit. When installing such a piping system, there are several options as to how they can be installed along the tracks. They can either be placed above the ground, at frost-free depth, or somewhere between. This decision is often made based on economic concerns. The lances are often placed stationary to produce snow at strategic spots along the tracks. Because of the low weight, they are easier to move. Lances often involve lower investment costs compared to fan guns (Aas and Vagle (2017)).



Figure 10: Snow lance (Cogle (2011))

## 5 Customer needs analysis

### 5.1 Snow Production in Granåsen

The following objectives are set for the snow production facility (Aas and Vagle (2017)):

- To guarantee snow from 1st of December each year with at least 2,5km tracks.
- Skiing conditions from 1st of December to 1st of April.
- To satisfy course requirements for world cup and national competitions in February/March.
- Snow production should be effective, in terms of energy efficiency, costs and time.
- Granåsen Arena should be an inspiration for other sports arenas.

#### 5.1.1 Challenges of Today's Arena

Today the snow production system at Granåsen must be operated manually. Each snow production unit needs to be transported to desired location. Then the units have to be connected to electrical power and water. While someone has to start the feed pumps and regulate it. This gives multiple challenges like:

- It takes six hours with four workers to start the snow production.
- The workers have a hard time starting up the snow production within the time window where production temperature is present. In practise, this means that a weather forecast with at least  $-4^{\circ}\text{C}$  for two days or more is needed before snow production is prepared.
- Since there is a demand for many workers, snow production at night times are sometimes not prioritized. This is unfortunate because the best conditions often occur during the night hours.
- The workers have to control the snow guns, water and air hoses manually approximately once per hour.

### 5.1.2 Development Plans

The development of Granåsen Arena is divided into three phases. This report will focus on Phase 2, in which a skiing track for cross country skiing and roller skiing is planned on the east side of Smistadvegen. This can be seen in Figure 11. Infrastructure for snow production is planned for these tracks.



Figure 11: Map for the planned development for Phase 2 (Aas and Vagle (2017)).

The tracks that are being developed are 5 km long. Snow production along these tracks should be automated (Aas and Vagle (2017)). This would give multiple benefits like:

- The production can start once the right conditions are present.
- It will be easier to control how much snow to produce with an automated system. One can avoid overproduction and thereby save energy, time and cost.
- It will be easier to adjust the production after temperature differences and wind.

- It will be easier to expose errors on the equipment. As a result, maintenance can happen before a crisis occurs.
- Reduced need for manning will make it less inconvenient to produce snow at night time, when the conditions often are best.

Aas and Vagle (2017) present two suggestions for the snow production development: one with fan guns and one with lances. Some of the main take aways from the lance solution are summarized below:

- Stationary lances requires higher investment costs, because one would need more lances than fan guns to cover the track.
- Operating cost are lower since the need of moving fans are not present.
- The time it takes to open the tracks is almost 1/3 when the conditions are marginal, compared to a solution with mobile fan guns.
- Better distribution of snow along the tracks.
- The need of new light post are present. why not combine with snow production? This will reduce the total investment cost

## **5.2 Climatic Conditions**

This section presents the climatic conditions in Trondheim and the local conditions in Granåsen Arena.

### **5.2.1 Climatic Conditions in Trondheim, Sør-Trøndelag**

The climate in Sør-Trøndelag varies from warm and wet in the coastal areas to continental climate in the inner areas. Granåsen and Trondheim belongs in the first category. In the period 1971 to 2000 Trondheim had an average temperature of  $5^{\circ}\text{C}$  and average precipitation amount of  $950\text{mm}$  pr. year (Norsk Klimaservicesenter (2017)). The average temperature in Trøndelag during the winter months in the latest three decades has been around  $-4^{\circ}\text{C}$ . This can be seen



in Figure 12. A more detailed overview of the temperatures in Trøndelag over the last 20 years is given in Figure 13. Since Trondheim is placed in one of the warmer areas of Trøndelag. This suggests that snow production in Granåsen should be optimized for marginal conditions.

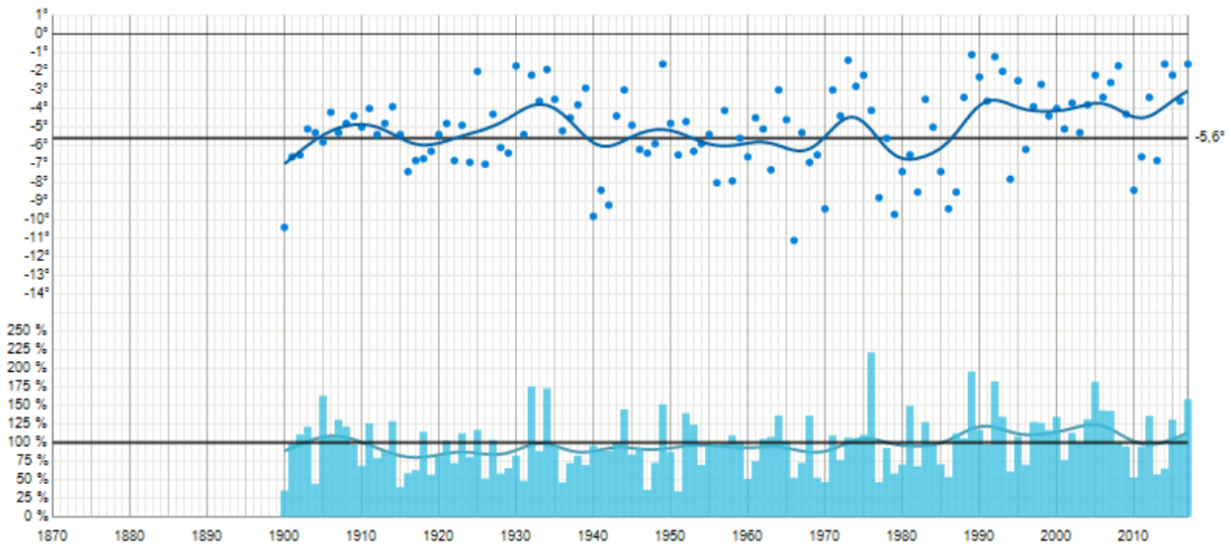


Figure 12: Statistics for temperature and precipitation in Trøndelag pr. winter (December, January and February). The thick grey lines denote the average temperature and precipitation in the winter seasons in the years between 1961 and 1990. The dots show the yearly average temperature for each winter season. The blue columns show precipitation as percentage of the normal amount of precipitation in the winter season, marked by the grey line (Meteorologisk Institutt and NRK (2017)).

### 5.2.2 Climate Change

Norsk Klimaservicesenter (2017) suggests a climate scenario with a temperature increase of  $4^{\circ}\text{C}$  in Sør-Trøndelag by the end of this century. The biggest increase will be during the winter. The scenario also includes an increase in precipitation by 20%, however this increase will be smaller during the winter. As a consequence, there is expected a significant reduction in snow coverage. These changes will also make snow production in Granåsen more difficult.

Tabellvisning for temperatur/nedbør vinter

År	Temperatur				Nedbør
	Maks	Min	Gjennomsnitt	Normalavvik	Nedbør
2017			-1,6°	3,9°	158,8 %
2016			-3,6°	1,9°	108,4 %
2015			-2,2°	3,2°	131,2 %
2014			-1,6°	3,9°	65,6 %
2013			-6,8°	-1,3°	57,8 %
2012			-3,4°	2,2°	136,1 %
2011			-6,6°	-1,1°	94,5 %
2010			-8,4°	-2,9°	53,5 %
2009			-4,3°	1,2°	94,8 %
2008			-1,7°	3,9°	99,5 %
2007			-2,6°	3,0°	143,0 %
2006			-3,4°	2,2°	143,7 %
2005			-2,2°	3,4°	182,1 %
2004			-3,8°	1,8°	131,6 %
2003			-5,3°	0,3°	99,9 %
2002			-3,7°	1,9°	113,3 %
2001			-5,1°	0,5°	76,8 %
2000			-4,0°	1,6°	135,1 %
1999			-4,4°	1,2°	117,0 %
1998			-2,7°	2,8°	126,9 %
1997			-3,9°	1,7°	128,0 %

Figure 13: Table showing average temperature during the winter over the last 20 years (Meteo-  
nologisk Institutt and NRK (2017)).

### 5.2.3 Local Conditions in Granåsen Arena

Granåsen arena have three weather stations with live feed to MetNet<sup>1</sup>. These measure temperature, wind and humidity. These stations show that the temperature at the stadium is often 2°C lower than further up in the tracks and in the ski jumping hill. During an observation period between the middle of November until the middle of December, the humidity was between 90% to 95% most days. This level of humidity makes snow production difficult, as it increases the wet-bulb temperature. The wind conditions in the same period were marginal, with wind slower than 1  $\frac{m}{s}$  most days.

Local variations in altitude, vegetation, orientation, etc. cause local variation in temperature and precipitation. This again makes manual snow production a difficult task. Therefore an automated system that could be controlled after local climate stations (temperature, wind, hu-

<sup>1</sup>Utviklet av MUSTASJ, TMV-kaia 1, 7042 Trondheim. Available at: <https://embed.metnet.no/?dash=otItgiNuM5%20>

midity) would make the production way more effective, both in terms of energy consumption and snow quality.

### 5.3 Users and Stakeholders

This section will present relevant users and stakeholders of the project. User Profiles, Personas and Scenarios are used to gain knowledge of the users, stakeholders and their needs. These are initial - as user requirement activities are conducted these will be developed further. A description of User Profiles, Personas and Scenarios are presented in Table 4.

Table 3: Classification of users and stakeholders.

<b>Users</b>	Trondheim Bydrift employees, 5.3.1
<b>Indirect users</b>	Elite Athletes, 5.3.2 Young Athletes, 5.3.3 Everyday users, recreational sports, 5.3.4 Other users, 5.3.5
<b>Stakeholders</b>	Trondheim Municipality The Norwegian Ski Federation Potential industrial partners and/or sponsors

Table 4: Descriptions of User Profiles, Personas and Scenarios.

	<b>Description</b>	<b>Purpose</b>	<b>Content</b>
<b>User Profile</b>	Detailed description of the user's attributes.	Knowing who the product is developed for.	Demographic data, skills, education, occupation.
<b>Persona</b>	A fictional person that is based on one or more user profiles.	Represents the user during design discussions.	Identity, status, skill set, relationships, goals, requirements, expectations.
<b>Scenario</b>	A short story which describes how a persona completes a task, interacts with a product or behaves in a given situation.	Brings the users to life, make it clear whether or not the product meets the user needs, develop artifacts for usability activities.	Setting, actors, objectives, sequence of event, result.

**5.3.1 Trondheim Municipality, Trondheim Bydrift Employees**

Trondheim Bydrift has employees that work on operating Granåsen Arena. These are responsible for managing the tracks during the winter season, involving driving out snow from the snow storage, producing snow, dosing snow and preparing the tracks. Employees of Trondheim Bydrift are the only direct users of the snow production system, as they are the only ones who should interact with it.

Table 5: Results from field trip

Description	Field trip to Granåsen 30. November
Setting	One lance and one fan gun were producing snow in the upper parts of the tracks. Two fan guns were producing snow directly onto the snow storage. It was snowing at the time, which made it possible to compare the artificial snow to the natural snow.
Temperature	$-7^{\circ}C$
Wind	$0.2 \frac{m}{s}$
Humidity	Ca. 95%
Notes made from observations	<p>The artificial snow was wet and very compact compared to the natural snow. It was also more yellow than the natural snow.</p> <p>Both the fan gun and the lance made a lot of noise</p> <p>Both the fan gun and the lance produced snow in piles on the side of the cross country track, while people were skiing there.</p> <p>There were drained water coming from the snow storage.</p>
Notes made from conversations with the workers	<p>The workers have to control the producing units approximately once per hour. The hoses with air and water also have to be controlled, as they lay above ground. The water hoses have to be moved sometimes to ensure continuous flow (prevent freezing). It takes two workers to lift these. This means that at least two people have to be there both day and night while producing.</p> <p>The produced snow should drain for at least one day before it is dosed. Ideally for two days. This is because the snow usually is very wet. Under very cold and dry conditions, it is possible to produce snow that is less wet. Such conditions are rare in Granåsen. Once the snow is drained, it is no problem for the snowmobile to dose big piles of snow.</p> <p>They believed it would be best to close the whole arena for some days to produce all the necessary snow at once and give it time to drain. Their experience was that producing in only some parts of the track at the time led to more conflicts with the users of the tracks.</p> <p>Vassfjellet has a snow system which is more automated and controllable by computers. They have stationary lances that are 7,5 meters tall, which are automated based on data from weather stations. This system is older than the manual system they use in Granåsen. The workers did not seem very happy about this.</p> <p>Some skiers, both amateurs and elite, are very eager to train. Sometimes they will be skiing right behind the snowmobiles at 05:00, before the tracks are completely ready.</p> <p>They believed stationary lances would be great for Granåsen. However, TV producers do not "like" lances. The stationary lances in the jumping hill need to be moved before jumping events on TV.</p>

## Personas

Table 6: Persona 1

Attribute	Description
Name	Trond
Age	46 years
Occupation and skills	Employee in Trondheim Bydrift, operating Granåsen Arena. Has worked with snow management and snow production for 11 years, with different technologies.
Relationships	Married with two children
Goals	It is very important to Trond that Granåsen Arena manages to deliver snow for the tracks in the winter season. It is also important to him to have as much predictability in his work hours as possible, because he likes to spend time with his family.

## Scenarios

**Scenario 1:** The temperature is  $-8^{\circ}\text{C}$  at 22:00PM in Granåsen Arena and there is need for more snow in parts of the tracks. Trond should be able to chose which snow production units to turn on, register approximately how big area that needs to be covered with new snow, and start the lances simultaneously within 15 minutes. The lances should automatically use the best suitable settings for the present conditions, and stop when enough snow is produced.

**Scenario 2:** The temperature conditions along the tracks are suitable for producing snow of high quiality, however, the wind conditions are varying along the tracks, and Trond suspects that there will be a lot of drift from the tracks if he starts snow production in certain areas. He should be get advice from the controlling system on where to start production and where not to.

### **5.3.2 Elite Athletes**

Granåsen Arena is used by elite athletes from all cross country skiing, ski-jumping, Nordic combined and biathlon. Olympiatoppen Midt-Norge is housed in Granåsen Arena, and world cup arrangements take place there every year. These users have high demands of the quality of the arena, including high demands of snow and lighting quality.

### **5.3.3 Young Athletes**

Young athletes might not have the same demands for high quality as an elite athlete, but they require steady conditions over longer periods of time. They do not have the same opportunity to travel as the elite athletes, so the local arena is very important for their development. Bad conditions can lead to a lower sense of achievements, which again can lead to more young athletes quitting skiing.

### **5.3.4 Everyday Amateur Skiers, Recreational sports**

Most of the users of the arena is there for recreational sports and activities. These users are very important, as Granåsen Arena should be available for everyday activities and recreational sports almost all the time. This includes good skiing conditions for as many days as possible during the winter season.

Some of these users have been using the arena for a very long time and have very strong opinions of how the arena should be. They might see the new units as a risk for the nature experience, and might be scared that the snow production unit is dangerous.

### **5.3.5 Other Activities in Granåsen Arena**

Beside skiing in the winter, Granåsen Arena is widely used for a number of activities throughout the year. In the summer, the roller ski course is much used. The arena is also a base for other sports, such as cross country running and MTB. It is also used as concert arena.

## 5.4 User Requirements

Table 7 presents the initial user requirements. These are separated into "Required" and "Should" requirements, and presented with a value where this is relevant.

Table 7: User Requirements.

Requirement description	Required	Should	(Value)
<b>1 Operational Requirements</b>			
1.1 Easy to maintain	x		
1.2 Evenly distributed snow production	x		
1.3 Require less start-up time	x		Maximum 30 minutes
1.4 Require less people to start the production	x		
1.5 Enable snow production at marginal temperatures	x		
1.5 Minimize the amount of snow entering the ground outside the tracks (when this is expedient)		x	
1.6 The units should be automated	x		
1.7 Remote starting of the production	x		
1.8 The light from the units should satisfy requirements for international competitions	x		
<b>2 Design requirements</b>			
2.1 Nice design (approved by TV producers)	x		
2.2 Discreet (blend in with the nature)		x	
2.3 Look modern		x	
Designed to minimize stray light		x	
<b>3 Usability Requirements</b>			
3.1 Should be easy to operate	x		
3.2 Employees should be able to operate the units after one day of training		x	
3.3 Include advising system based on weather data		x	
3.4 Degree of manual control can be changed	x		



## 6 Technology Analysis

This section takes a closer look on the existing technology in snowmaking.

### 6.1 Lance Technology

The lance frame consists of a steel pipe ranging from 3 to 10 meters, with internal channels for high pressure water and air. They are usually placed stationary on a standpipe or some kind of support mechanism. The whole unit can usually be turned 360° and lowered by 45° for assembly and maintenance. This is illustrated in Figure 14.

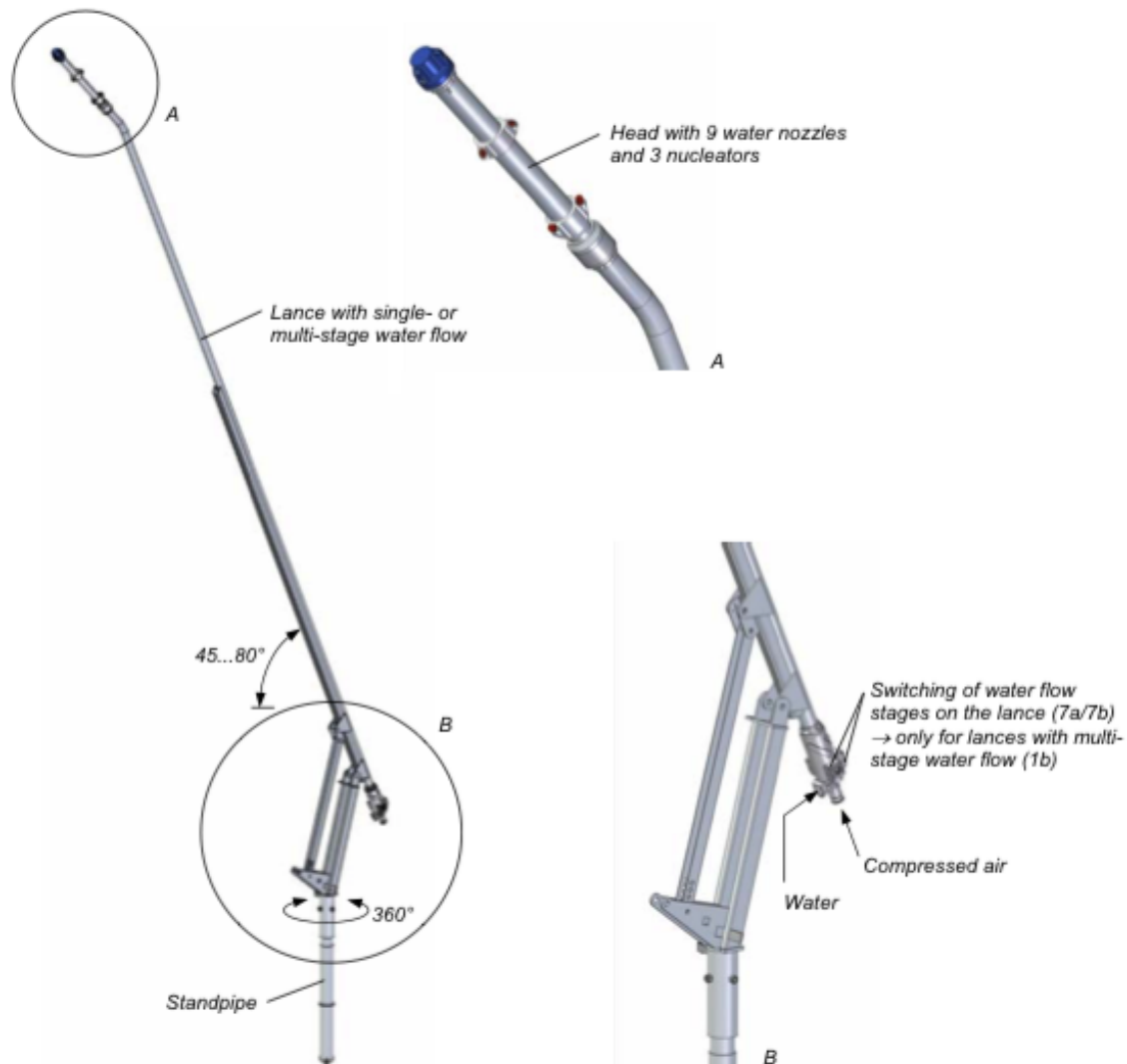


Figure 14: Main parts and functions of a lance. (Bachler (2017))

The lance units today usually have these functions:

- Have a way to be lowered/dismantled to enable maintenance.
- Have intake and internal pipes for pressurized air and water.
- Have sufficient height for the water to freeze.
- Adjustment to compensate for wind.
- Several steps of water flow to adjust after temperature.
- Sensors (or separate weather stations) that measure different physical parameters.

#### **6.1.1 Nozzle Technology**

The intention of the nozzle is to atomize water into small droplets. Optimal snow production sets requirements for the nozzles. The most important requirements are: (Snowathome (2017)).

1. Form the correct droplet size.
2. Create the correct spray pattern.
3. Allow proper distance between droplets.
4. Allow proper cloud density.
5. Ensure proper water turbulence.

Today nozzles for snowmaking use compressed air to help divide the water stream into finer droplets. This is necessary for making the droplets small enough to freeze before they hit the ground. Shea (1999) claims that effective snowmaking without compressed air can not take place before the wet-bulb drop below  $-12^{\circ}\text{C}$ .

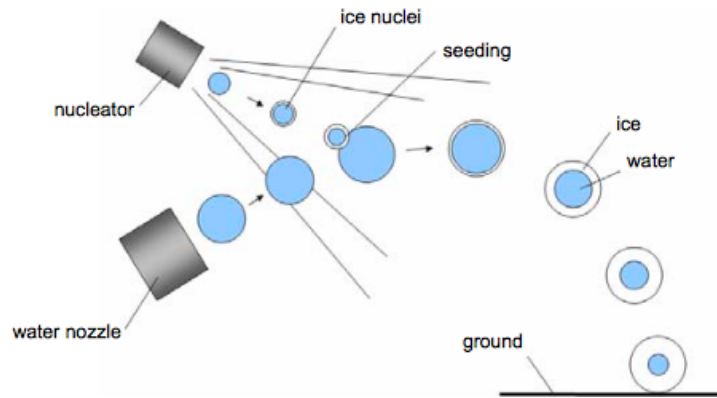


Figure 15: Theoretic model of nozzle setup. Showing how the water droplets from the nozzle are nucleated by the nucleator nozzle. (Bachler (2017))

The nozzle design in lances often consists of a nucleator nozzle together with a water nozzle, as shown in Figure 15. The nucleator produces small frozen particles. These particles become the nuclei for the larger droplets from the water nozzles (Bete (2017)).

The nucleator nozzles are usually either internal mix or external mix. Internal mix set-up mixes liquid and air within the nozzle as shown in Figure 16. The streams are not independent, meaning that a change in air flow will affect the liquid flow. This makes it harder to measure the liquid flow than with an external mix set-up. Internal mix is again able to produce finer atomized droplets (Bete (2017)).

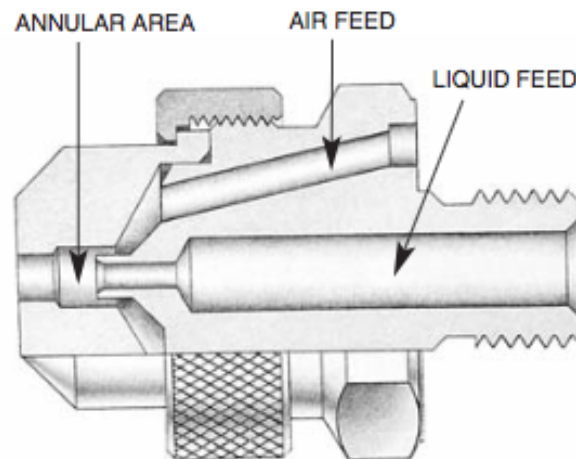


Figure 16: Nozzle with internal mix set-up. Water and air are mixed in the annular area in the front (Bete (2017)).

When the air and liquid exit the nozzle independently and mix outside as shown in figure 17,

it is called external mix set-up. In this solution the air and liquid flow can be controlled independently. This makes precise metering of the liquid possible. The adjustable air flow controls the atomization of the water and thus the size of the droplets.

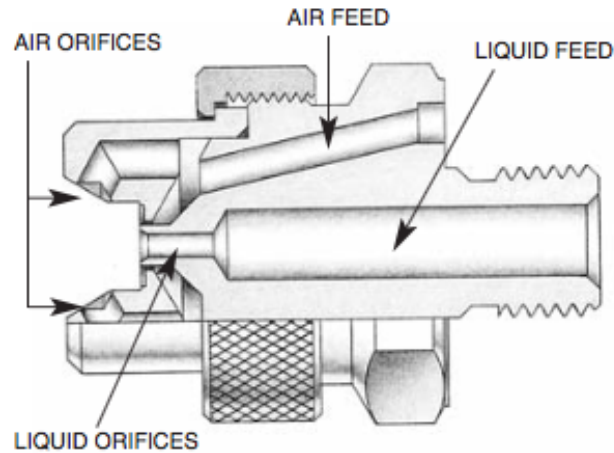


Figure 17: Nozzle with external mix set-up. The air is blown "into" the water jet from the water orifices (Bete (2017)).

## Droplet Size

The size of the nozzle outlet and the water pressure are the main parameters controlling the droplet size. The height of the path and the break up of the water stream will be controlled by the nozzle type. Smaller droplets will freeze faster. However, they will have less momentum leaving the nozzle, causing decreased throw length. Another factor concerning the droplet size is the amount of drift. Ideally all of the produced snow should land within the tracks. Larger drops will be less affected by the wind then smaller drops. Figure 18 shows the lateral movement of different droplet sizes in 1MPH wind ( $\approx 0,45 \frac{m}{s}$ ). This amount of wind would be considered as good wind conditions for snow production. With a fall of six meters a droplet of  $200\mu m$  will drift approximately three meters. Droplets of  $120\mu m$  or smaller will disappear.

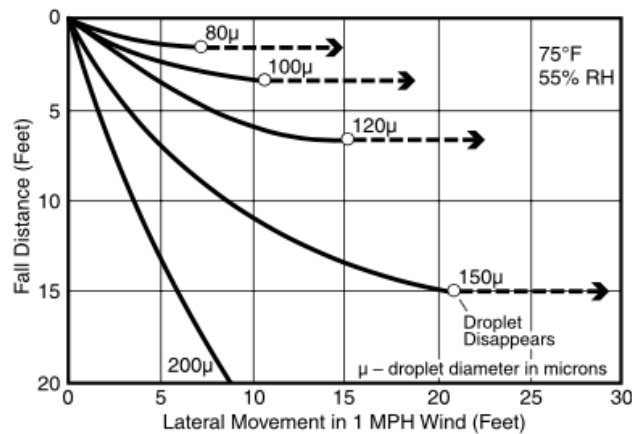


Figure 18: Chart showing how the lateral movement of droplets depends on fall distance and size of water droplets in 1MPH wind (Hoffman and Solseng (2014)).

## Spray Pattern

Spray pattern considers the spray angle and spray shape. The angle usually varies from 65 to 120 degrees. Spray angle is the angle formed between the edges of the spray from a single nozzle, as shown in Figure 19. Nozzles with wide spray angles will produce a thinner sheet of spray solution with smaller droplets, compared to nozzles with narrower spray angle (Hoffman and Solseng (2014)). In a narrow cross country track a small angle would be preferred to minimize snow loss. However, smaller angle will produce larger droplets that will use longer time to freeze. That again would require higher lances.

The most common shape pattern for nucleator nozzles is hollow cone. Hollow cone nozzles provide a good interface between air and droplet surface. For water nozzles, on the other hand, it is most common to use a flat fan pattern. The flat fan pattern provides a uniform coverage across the impact area (Bete (2017)). These patterns can be seen in Figure 19.

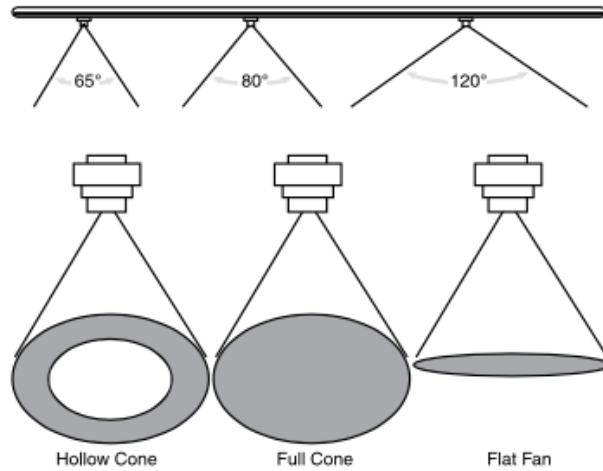


Figure 19: Example of nozzle spray angle and patterns (Hoffman and Solseng (2014))

### Throw length

The throw length depends on air and water pressure, height and spray angle. However, height will increase the drift in windy conditions.

Rogstam and Dahlberg (2011) performed several tests on different snow lances and measured the "hit rate" of the snow. The "hit rate" is the depth of snow covering the ground at a specific point near the lance. The lances in the test are from different manufactures and have different heights. A general picture of the projection area can be drawn from this test. The main projection area can be assumed to be 15 meters forward and 10 meters in width, as figure 20 illustrates.

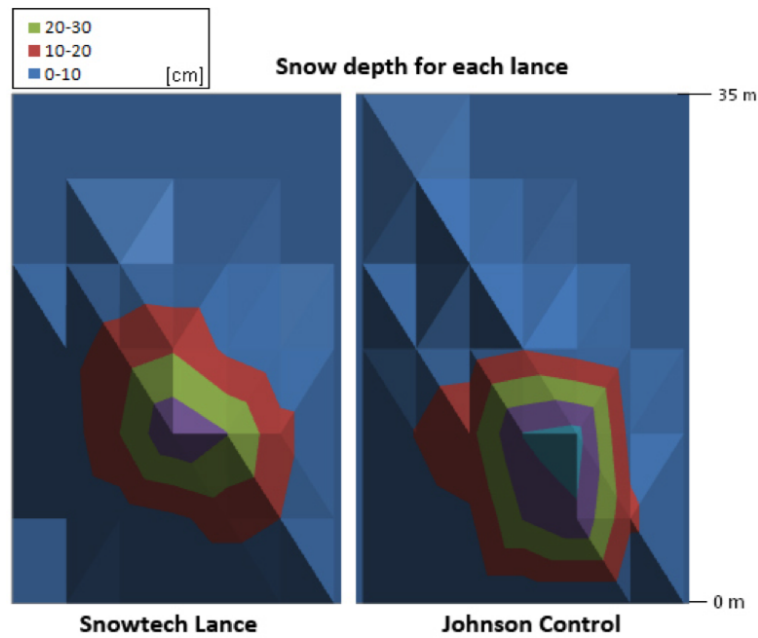


Figure 20: Figure showing the "hit rate" of the snow for two different lances. The left one for a lance at 9 meters, and the right for a lance at 6 meters. One can note that most of the snow are in a pile at 5-15 meters, with some small drift up to 30 meters. The main pile also have a width of 10 meters. (Rogstam and Dahlberg (2011))

## 6.2 Lighting

Over the last decade, Light Emitting Diode (LED) Technology has developed rapidly. LED lighting are energy efficient and have good lighting quality compared to other light sources.

Table 8: Typical properties for relevant light sources.

	Price	Life time	Color Rendering	Lumen	Operating Economy
Fluorescent Lamps	Medium	Long	Medium	Low	Good
Sodium-vapor Lamps	Low	Medium	Bad	High	Good
Metal-halide Lamps	Medium	Short	Good	High	Bad
LED	High	Long	Medium	Medium	Good



Figure 21: Fluorescent lamps (Parsley (2015))



Figure 22: Sodium-vapor lamps (Nunuk (2015))

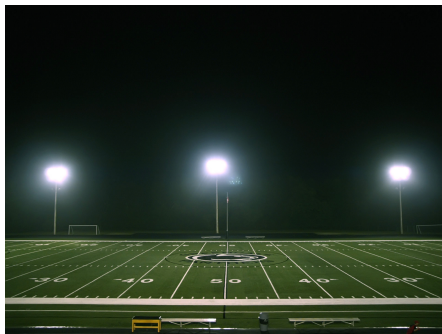


Figure 23: Metal-halide lamps



Figure 24: LED street lights (Antonelli (2016))

When discussing lighting for sporting activities, there are many light properties that are important. Some of these are presented in Table 9.



Table 9: Light Properties (SI units)

Property name	Symbol	Description	Unit	Unit symbol
Luminous Flux	$\phi_v$	The luminous energy emitted	Lumen	$lm$
Luminous Intensity	$i_v$	The luminous flux per unit solid angle	Candela	$cd = \frac{lm}{sr}$
Luminance	$L_v$	Luminous flux per unit solid angle per unit projected source area	Candela per square meter	$\frac{cd}{m^2}$
Illuminance	$E_v$	The luminous flux incident on a surface	Lux, Lumen per square meter	$lx = \frac{lm}{m^2}$
Luminous Emittance	$M_v$	The luminous flux emitted from a surface	Lux	$lx$
Luminous Efficacy	$\eta$	A measure of how well a light source produces light	Lumen per Watt	$\frac{lm}{W}$

Color Rendering and Color Temperature are also important light properties. Color Rendering Index (CRI) tells us about the ability of a light source to reveal the true colors of various objects in comparison with a natural light source. The color temperature of a light source says something about the color of the light. The color of "white" light can vary from reddish/orange via yellow to more or less white, to blueish white. Here, color temperatures over 5000K are bluish white, whereas color temperatures below 2700–3000K are yellowish to orange.

### 6.2.1 LED Lights for Outdoor Lighting

Over the past ten years, LED lighting has been taken in use to light parks, streets, facades and other outdoor objects and venues. LED lights have the following advantages:

- The LED lights can be dimmed from 100% of maximum light value and down to 0%. This makes creating smart lighting systems possible, which again will lead to energy saving and more optimal lighting conditions depending on the external factors.
- The expected lifetime of LED components is about 50 000 hours ( $\approx 12$  years), versus 3-5 years for conventional light sources (Khan et al. (2014)).
- White LED street luminaires with Color Rendering Index (CRI) values in the range of 65-85

have as good (or even better) color rendering quality as conventional light. Thus, objects in the area can be easily detected (Khan et al. (2014)).

- The wall-plug efficiency - the optical power out divided by electrical power in, of LED packages is typically in the region of 5-40%, which means that somewhere between 60 and 95% of the input electrical power is lost as heat. These numbers are better for LED lights than for many other light sources (Whitaker (2005)).

Moreover, the development in LED technology is evolving fast. The development is said to follow Hatiz's law, which states that LED flux per package has doubled every 18-24 months for more than 30 years (Steigerwald et al. (2002)).

LED street luminaries consist of the following functional units (Khan et al. (2014), Lasance et al. (2013)):

**Mechanical unit:** The mechanical unit, the housing, should have good thermal conduction and convection properties. This is especially important to bear in mind when designing a lamppost that should also produce snow, as the heat from the light may affect the snow production. The housing should reflect sun radiation as the thermal energy from these could have influence on energy flow. It is also important to shape the housing in such a way that accumulation of dirt is avoided.

**Electronic unit:** The electronic unit consists of a voltage supplying unit, a control unit (micro-controller), driving electronics and a circuit board with LEDs. It may also consist of sensors, such as temperature, movement detection and light sensors.

**Optical system:** An optical system is necessary to optimize the distribution of the light emission from the LED.

**Software:** Software that controls the lighting according to sensor values or custom values.

The different components are tightly coupled and the design of each will affect the others. One of the most important aspects of the design is to minimize the junction temperature of the LEDs for given LED power and ambient temperatures. This includes optimizing the components that are included in the thermal transfer chain. This will be even more relevant when

designing a combined lamppost and snowmaking unit, as the heat transfer from the light source may increase the water temperature or air temperature near the nozzle.

### 6.2.2 Requirements for Lighting

The lighting should provide sight for judges, coaches and audience as well as for the athletes. The lighting should be designed so that the surroundings experience as little as possible of stray light, as this is both disturbing for neighbours and a waste of resources. Design considerations affecting stray light are the angle  $\theta_f$  between the ground and the light surface, and the height, as seen in Figure 25. Aesthetically, the masts should be as low as possible to avoid disturbance in the nature. However, tall masts are good in order to prevent stray light, as the angle  $\theta_f$  can be reduced.

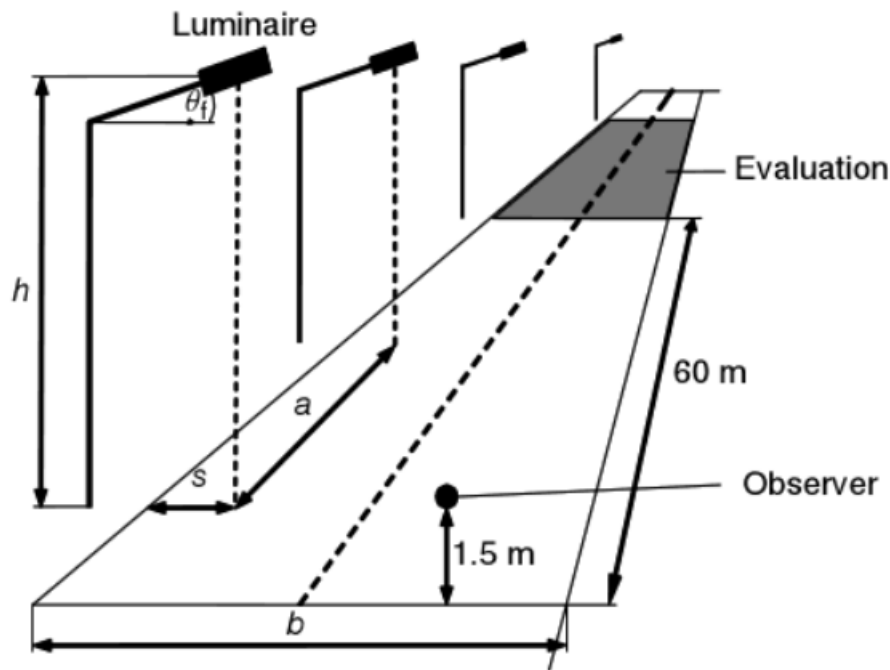


Figure 25: Street luminaire design, with parameters (Khan et al. (2014)).

Ideally, the light source should have all the following properties:

- Good color rendering properties,
- Color temperature that is adapted to the surroundings and conditions,

- Long life-time,
- Low luminance,
- Good luminous efficiency,
- Small dimensions,
- Low price.

In reality, however, no existing light source exhibit all these properties. Therefore, some qualities have to be prioritized, and some minimum value requirements have to be satisfied. The following requirements are taken from Standard Norge (2007) and Lyskultur and Kulturdepartementets idrettsavdeling (2013):

- The CRI value should always be better than 65. A minimum value of at least 80 is preferable.
- The illuminance on the spectator area should be at least  $10lx$ .
- For television camera shooting, the vertical illuminance is particularly important, and also the uniformity of the illuminance.
- An adequate relationship between horizontal and vertical illuminance is obtained by:

$$0,5 \leq \frac{E_{have}}{E_{vave}} \leq 2 \quad (1)$$

- Glare has to be limited to avoid reduction in visual performance. Outside, glare rating shall be calculated for agreed observer positions and angle.
- For outdoor installations with a significant daylight contribution, the color temperature of the artificial lighting should be between  $4000K$  and  $6500K$ .

Specific requirements for cross country skiing is presented in Figure 27. Here, the requirements for illuminance and horizontal uniformity is given for each lighting class. For lighting class I, the illuminance requirement is  $20lx$  on average.

Outdoor			Reference Area		Number of grid points	
			Length m (See NOTE)	Width m	Length (see NOTE)	Width
Running Street /Cross Country				4	11	3
Skiing Cross Country				4	11	3
Class	Horizontal illuminance					
	$\bar{E}_m$ lx	$E_{min}/\bar{E}_m$				
I	20	0,3				20
II	10	0,3				20
III	3	0,1				–
NOTE Between luminaires.						

Figure 26: Specific lighting requirements for cross country skiing.

### Example from Tinnløypa in Telemark

Tinnløypa was the first outdoor track with LED-lighting according to international standards. Here, the distance between the masts is dictated by the lighting requirements. They have followed an international requirement of  $13lx$  on average. This is sufficient to satisfy Class II from the Norwegian Standard, according to Figure 27. The tracks have a width of  $5m$ , and it is  $29km$  long. To satisfy the requirements, the solution required  $9m$  tall masts with a luminous flux of  $11000lm$  placed with  $32m$  distance between each mast. They have used different armature designs depending on the local terrain to optimize the conditions (Ladelys AS (2016)).



Figure 27: LED lighting example from Tinnløypa. (Ladelys AS (2016))

### 6.2.3 Comparison of Throw Length vs. Light Range

This section gives a rough comparison of the typical throw length of commercial lances and typical light range. The "hit area" of the snow is estimated from the paper of Rogstam and Dahlberg (2011). As one can note from Figure 28 the range of a lance is 33,6m if it is possible to rotate it.

The light range in Figure 28 is taken from a commercial LED-streetlight developed by Ladelys AS (2016), to serve as an example. This LED gives 23,3lx in average with a lighting area of 21m · 8m when mounted 7 meters above ground level. With the requirements of Class I and the LED armature from Ladelys AS (2016), there need to be approximately 21 meters between each unit. As the snow projection is longer, and it is possible to dose the snow even longer, the light range will be the controlling factor.

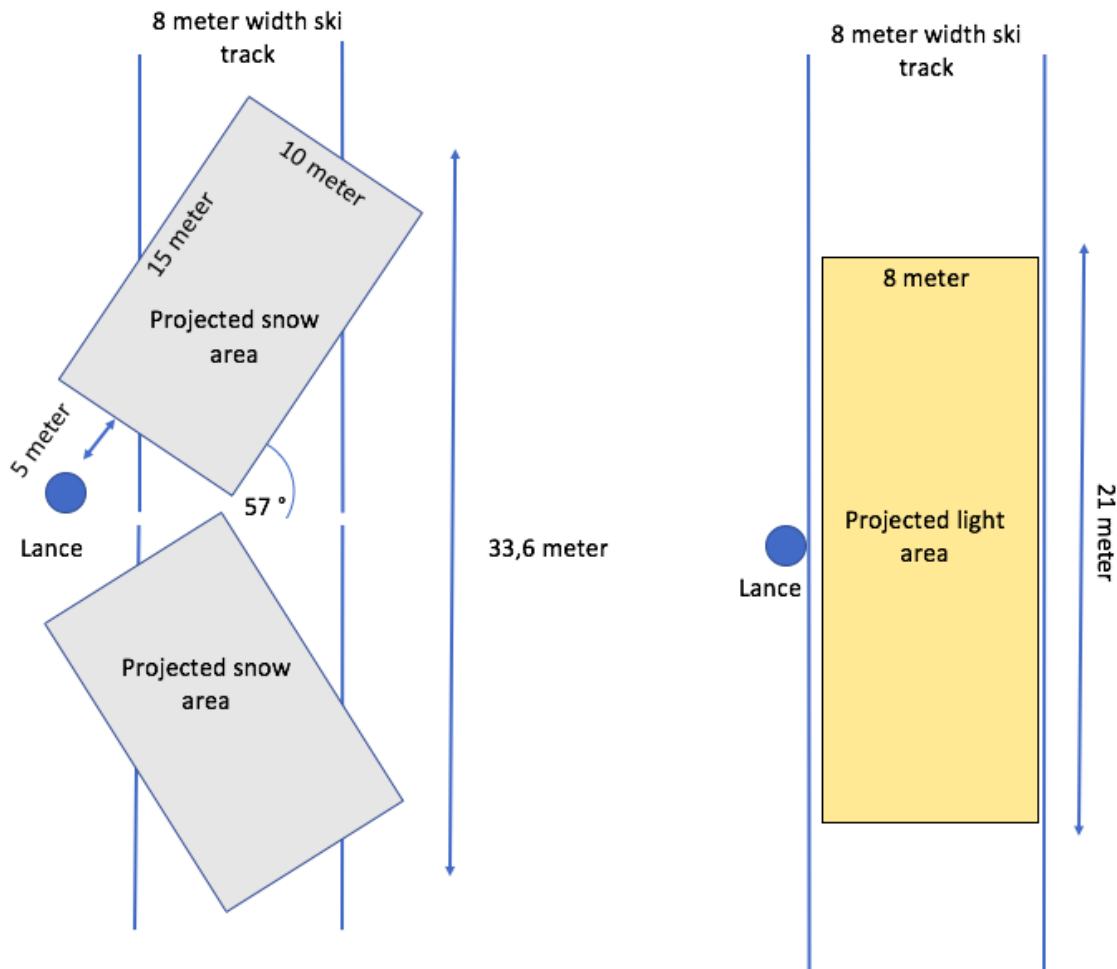


Figure 28: Comparison of snow projection vs light range.

### 6.2.4 Power from Solar Cells

Today a standard 250 Watt panel meters  $1m \cdot 1,6m$ . The idea is to let the panels charge a battery placed on the unit that powers the lighting. A conflict of interest is the size of the panels. It will be difficult to place a panel on the unit in a good looking way.

By using the performance grid calculator by the European Commission one can estimate the energy output potential at an exact location (European Commission (2017)). For this calculation, Granåsen was chosen with an installed power of 250W and an efficiency of 15%.

As an example one can estimate the need of energy during a year. The energy output is estimated for a 120W LED light.

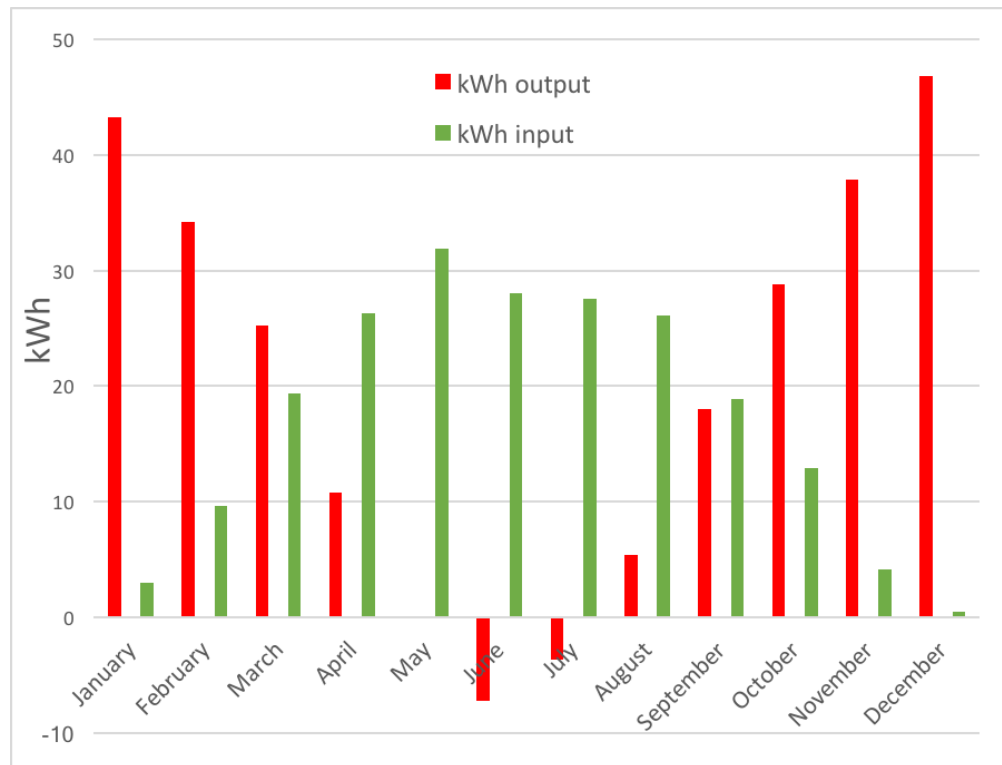


Figure 29: Green columns showing monthly energy input from a solar panel of 250W placed in Granåsen. Red columns showing the monthly energy output for LED lights of 120W (European Commission (2017))

An obvious problem is that the power consumption is highest during the winter when the energy output from the solar cells is at its lowest. One solution could be to store the energy during the summer. During one year the energy savings from a solar panel is 213kWh. With a kWh price of 0,93NOK the saving will only be 198NOK/year.

### 6.3 Product Requirements

The product requirements states valid targets for the development. It should be formulated in a way that does not constrain the technical solution space more than necessary. The amount of details in the product requirements should be adapted after how radical the new solution will be.

Table 10: Product Requirements

Requirement description	Required	Should	Value
<b>1 Snow Production Requirements</b>			
1.1 Minimum height	x		3-6 m
1.2 Adjustment for wind	x		
1.3 Throw length		x	5-20 m
1.4 Energy consumption	x		< 1 kWh/m <sup>3</sup>
1.5 Start up time		x	
1.6 Maximum production temperature	x		-2°C
1.7 Production rate	x		10-20 m <sup>3</sup> /h
<b>2 Environmental requirements</b>			
2.1 Temperature range			-30°C to 30°C
2.2 Corrosion resistance	x		Life-time of 25 years
2.3 Withstand Wind load	x		35 $\frac{m}{s}$
2.4 Withstand fatigue			Life-time of 25 years
2.5 Withstand impact	x		
<b>3 Luminaire and lighting requirements</b>			
3.1 Heat can not affect the snow production	x		
3.2 Lighting should be able to satisfy the requirements from Lighting Class I according to European Standards	x		Avg. of min. 20lx
3.3 Light levels should be automatically adjusted according to ambient light, clock, etc.	x		
3.4 Luminaire design prevents accumulation of dirt	x		
3.4 Minimize stray light		x	
3.5 Minimum height		x	>6m is recommended for lighting
3.6 Power consumption		x	< 200 W



## 7 Summary, Conclusions and Further Work

### 7.1 Summary

In this report the possibility of developing a combined snow production unit and light mast has been investigated. The objectives as stated in the introduction were:

1. To become familiar with the conditions and technology that influence snow production.
2. To become familiar with the challenges of today's arena in Granåsen and to know the local conditions and constraints that will affect the design and implementation of the new unit.
3. To evaluate some relevant product development methodologies for this project and further work.
4. To map the users and stakeholders.
5. To create an initial requirement specification.

The main objective has been to familiarize with the conditions and technology that influence snow production. The most influential parameters for snow production are: Wind; height; water temperature; wet bulb temperature; water and air pressure; and nozzle design.

Lances use high pressure air to atomize water into fine droplets through the nozzle. The height of the lance is important to let the water be able to freeze before it reaches the ground. This again makes snow production more fragile in windy areas, as the the snow can be blown away from the tracks. A wet bulb temperature of about  $-3^{\circ}\text{C}$  is sufficient to produce snow. However, good snow quality requires a wet bulb of about  $-7^{\circ}\text{C}$  or lower.

The lights will produce some heat. An important design consideration is therefore that heat must be distributed in such a way that it does not affect the snow production. Moreover, there are different recommendations for the height of light masts than for snow lances.

The second objective was to become familiar with the local conditions and constraints in Granåsen arena. The temperature is expected to increase. Snow production will therefore be crucial in order to guarantee snow during the winter seasons to come. The production system

that exists in Granåsen today demands very high efforts from the workers at Trondheim Bydrift. There is no doubt that an automated system is desired to make the production more efficient.

The third objective was to map the users and stakeholders. An initial mapping of these has been done. The focus so far has been on the employees in Trondheim Bydrift, because they will be operating the system. They have been the voice of the other users and stakeholders during this project, because their work is directed by their needs. Based on the mapping of users and stakeholders, an initial requirements specification has been created. The user requirements are based on the user needs, while the product requirements are based on the user requirements and technology analysis.

## 7.2 Conclusion

Snow production is crucial in order to guarantee snow during the winter season. The skiing resorts will require more artificial snow during the winter seasons in order to stay open. This increase of production will increase the work load on the employers, and will most likely not be possible in Granåsen with the system that exists there today. Automating as much as possible of the new snow production system would be ideal. A system of evenly distributed stationary lances that can automatically change the settings according to local conditions like wet bulb temperature, wind, etc. would be desirable. This would save time, energy and cost in operation. The new production system will most likely have a large investment cost, but also most likely lower operating costs than a solution with e.g. mobile fan guns. There has been addressed some challenges that has to be considered when designing the new unit:

- The requirements for lighting and snow production have to be balanced when it comes to height above the ground and the heat from the LED light:
  - There is a risk in having the nozzles too high in windy conditions. However, in windless conditions height is good in order to give the droplets time to freeze. Most lances today have the ability to adjust the height manually. This possibility should be considered automated.
  - When it comes to lighting, height is good in order to cover a large area with light, and at the same time reducing stray light.

- One possible solution can be to place the nozzles and lights on different heights on the mast.
- Snow production requires a different distance between the masts than the lighting. Therefore, a solution where not all of the units along the tracks produce snow could be considered.
- The lance head should be placed and adjusted to be able to cover the skiing tracks with minimal snow drift where this is suitable. Sometimes it might be expedient to produce snow in piles on the side of the track. The lance design should allow this as well.
- Semiconductor technology is evolving. This is relevant for LED lighting and solar cell technology in the future. Today, solar cells are not efficient enough to cover the power consumption of the LEDs. However, it is possible that they will be so in the future. The possibility of mounting a solar cell panel on the unit should therefore be kept in mind.

If these challenges are solved, a solution with stationary lances would be good in order to reduce operational costs and GHG emissions. The snow would be produced at its final destination, reducing the need for transportation.

### 7.3 Limitations

This paper does not consider any actual testing or precise calculations. Therefore there are still uncertainties on how the heat from the lighting armature will influence the snow production, and vice versa. There are also uncertainties regarding the design of nozzle setup for maximum snow coverage.

There is little literature on existing snow production technology. Some of the existing literature is commercial or owned by companies. Attempts to contact manufacturers of existing snow production units for technical information have given limited results.

Because of the late snow production start this year, there were not many opportunities to investigate the employees in Granåsen and the snow production equipment in operation. Therefore, the user interaction so far has been mainly verbal. This has given limited information about the user needs, as there can be difficult to extract truly meaningful information from

words alone in a product development setting. Some of the user requirements must therefore be evaluated. Both the product requirements and user requirements should be updated as the development process continues.

## **7.4 Further Work**

The work done in this paper should be revised and fulfilled in the master thesis. Before the concept development begins, it would be beneficial to visit a skiing resort where they have an automated production system.

A concept development should be done to try to fulfill the customer needs. Testing should be performed to verify and validate the design of the different components. The chosen concept should be modeled in a Computer Aided Design (CAD) program and the geometry of each part should be displayed. Finite Element Analysis (FEA) should be performed to verify the construction. If time and resources permit it, a comprehensive prototype should be made and tested during the master thesis.

## A Appendix

### A.1 Data for Calculations on Solar Cell Energy Output

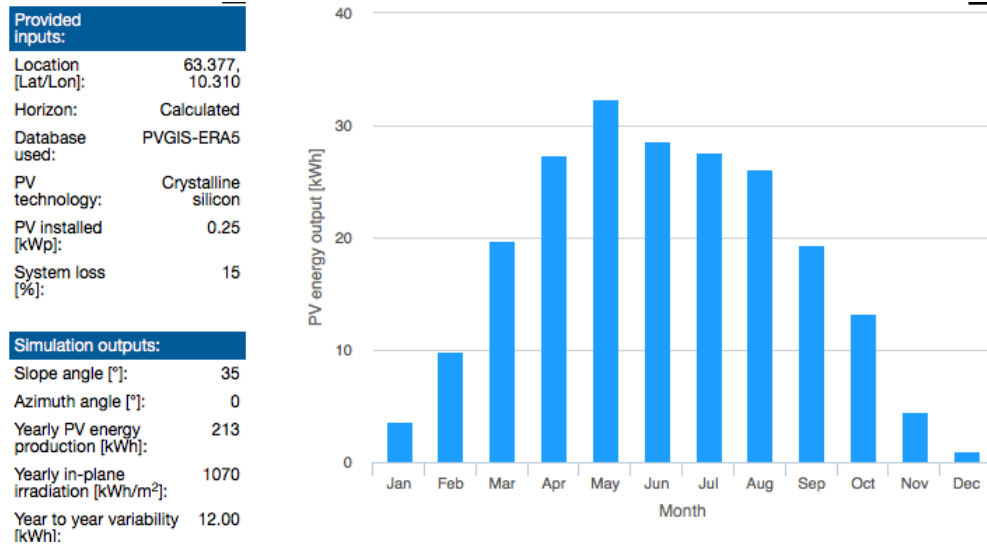


Figure 30: Figure showing monthly energy output from a solar panel of 250W at Granåsen. (European Commission (2017))

Daylight (h)	Power time (h)	Month	kWh output	kWh input	Sum kWh per month
6	12	January	43,2	3,2	-40
8,5	9,5	February	34,2	10	-24,2
11	7	March	25,2	19,6	-5,6
15	3	April	10,8	26,9	16,1
18	0	May	0	32,3	32,3
20	-2	June	-7,2	28,8	36
19	-1	July	-3,6	28,1	31,7
16,5	1,5	August	5,4	26,4	21
13	5	September	18	19,3	1,3
10	8	October	28,8	13	-15,8
7,5	10,5	November	37,8	4,3	-33,5
5	13	December	46,8	0,9	-45,9
		<b>Year</b>	<b>239,4</b>	<b>212,8</b>	<b>-26,6</b>

Figure 31: Energy calculation showing the kWh output for 120W LED and kWh input from a 205 solar cell panel (Time and Date AS (2017)).

## A.2 Project Plan

The plan serves as a guide and should be updated continuously through the project.

Table 11: Project plan

<b>Milestone</b>	<b>M1 - Vision</b>	<b>M2 - Needs- and technology analysis</b>
Delivery date	1.9.2017	1.12.2017
Deliveries	<ul style="list-style-type: none"> <li>•Project specification</li> </ul> Vision Mission Project plan	<ul style="list-style-type: none"> <li>•Analysis of snow production at Granåsen</li> <li>•User requirements</li> <li>•Analysis of existing technology (snow production, light armature)</li> <li>•Product requirements specification</li> </ul>
When delivered	Reflect on result and process	Reflect on result and process
Decision	Approved/Iterate	Approved/Iterate
Decided within	3 days	3 days

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