Norges Skiforbund – Arrangør- og anleggsseminar/Høstmøte

Lørdag 23. oktober 2021, Quality Hotel Hasle Linie

NTNU
Norwegian University of Science and Technology

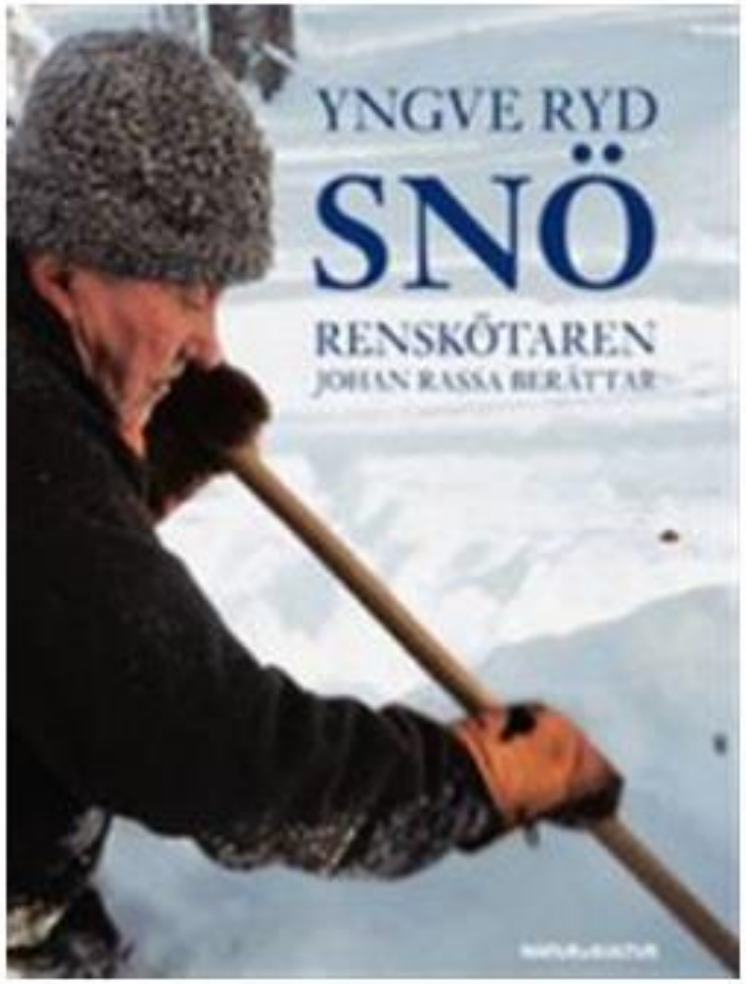
«Snow for the Future»

Temperatur-uavhengig snøproduksjon

Trygve M. Eikevik
Professor

Norwegian University of Science and Technology (NTNU)
Institute for energy and process technology
E-mail: trygve.m.eikevik@ntnu.no, http://folk.ntnu.no/tme

300 words of snow and ice

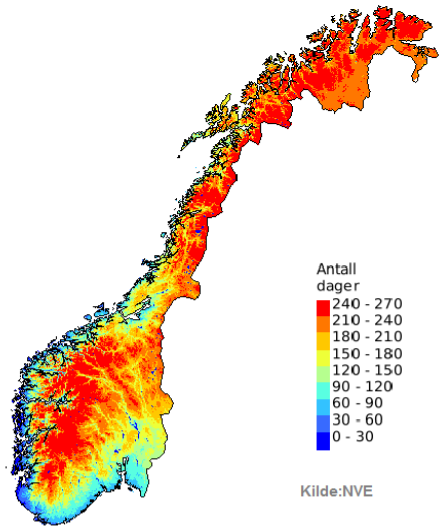


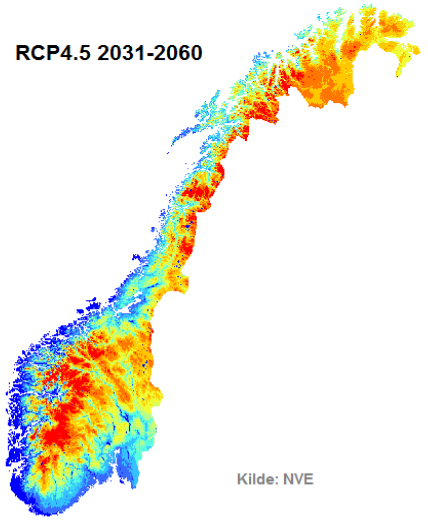
Snö : renskötaren Johan Rassa berättar

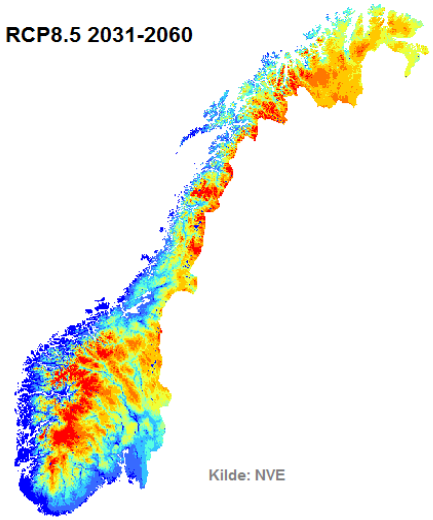
av Yngve Ryd

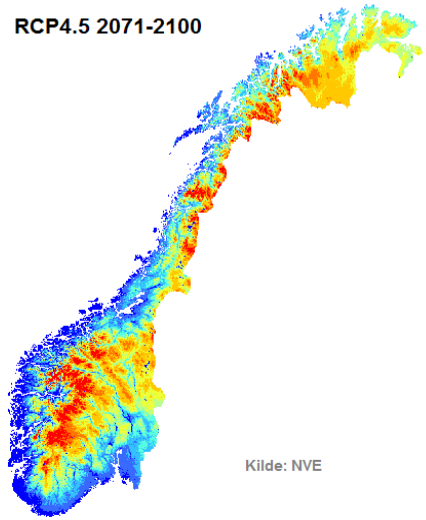
INNBUNDET, Svensk, 2007

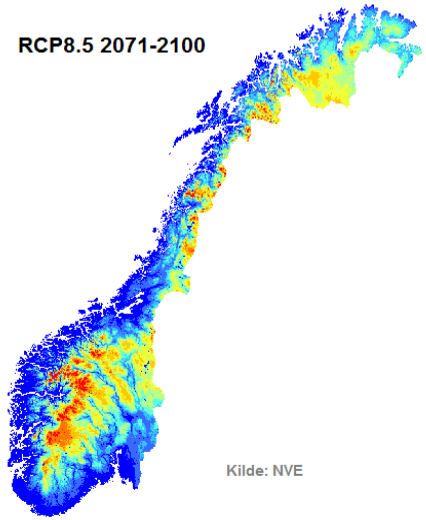
Why?











Blue marking indicates areas with less than 30 «snow covered» days per year – based on two emission scenarios

Competence


There we have one more who regrets that he did not educate within refrigeration engineering

Prolonging and stabilizing the skiing season in Norway and Europe to:

* Maintain the skiing traditions
* Reduce risk for the organizers of ski competitions
* Develop the mass and elite sports relying on stable snow conditions
* Secure the business of skiing resorts
* Develop new business opportunities for Norwegian and European vendors

To achieve this, we think snow near where people live will be crucial.

Aims of temperature independent snow production

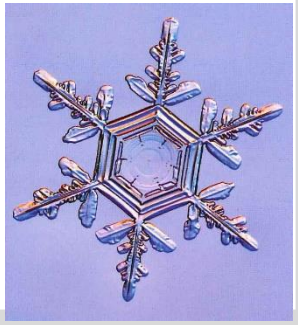
* The snow making system at ambient temperatures above zero will be environmental and energy efficient, using natural working fluid that do not harm the atmosphere and in the close environment.
* Utilization of the surplus heat from the system will reduce drastically the operational costs.
* Different case studies will be investigated to minimize the operational costs.

Produce snow /ice when:

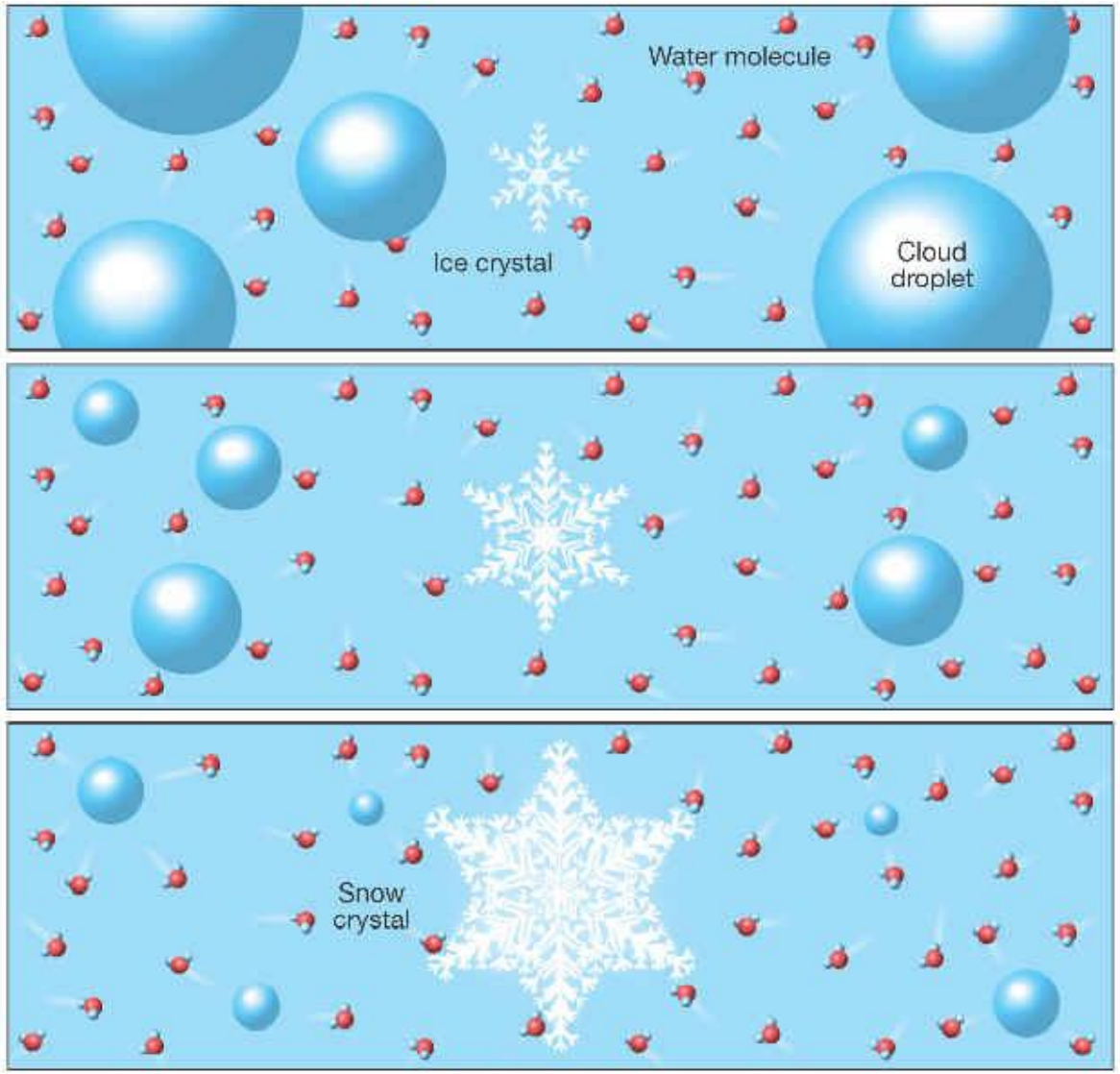
* it is a need for snow – capacity limitations
* there is a need for heat – require snow storage
* there is variation in need of heat – require thermal storage and snow storage
* electricity price is low – require snow storage
* Indoor snow production (snow guns) at temperatures similar to outdoor snow production but need to cool down a larger volume (space). Make smaller ice particles that ice factory.

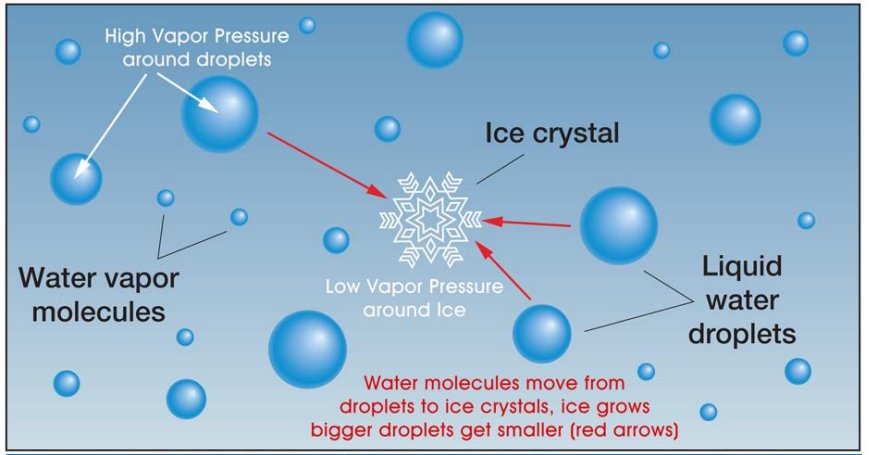
Snow – what is it?

* Snow is ice formed as small crystals or particles
* Like the rain droplets, the ice crystals will start to grow in a cloud, and it starts when the cloud is saturated or oversaturated with moisture (saturated air that will be cooled down will start to condense moisture)
* When the temperature comes below 0^{o}C it will be possible to grow ice crystals
* The crystal growth starts from a nuclide in the air (could be dust) or at very large subcooling
* Temperature level and temperature gradient and availability of water molecules will influence the growth of the crystal on its journey down through the atmosphere
* Different types of ice crystals in the atmosphere is depending on the temperature level is start to grow and the period it is growing

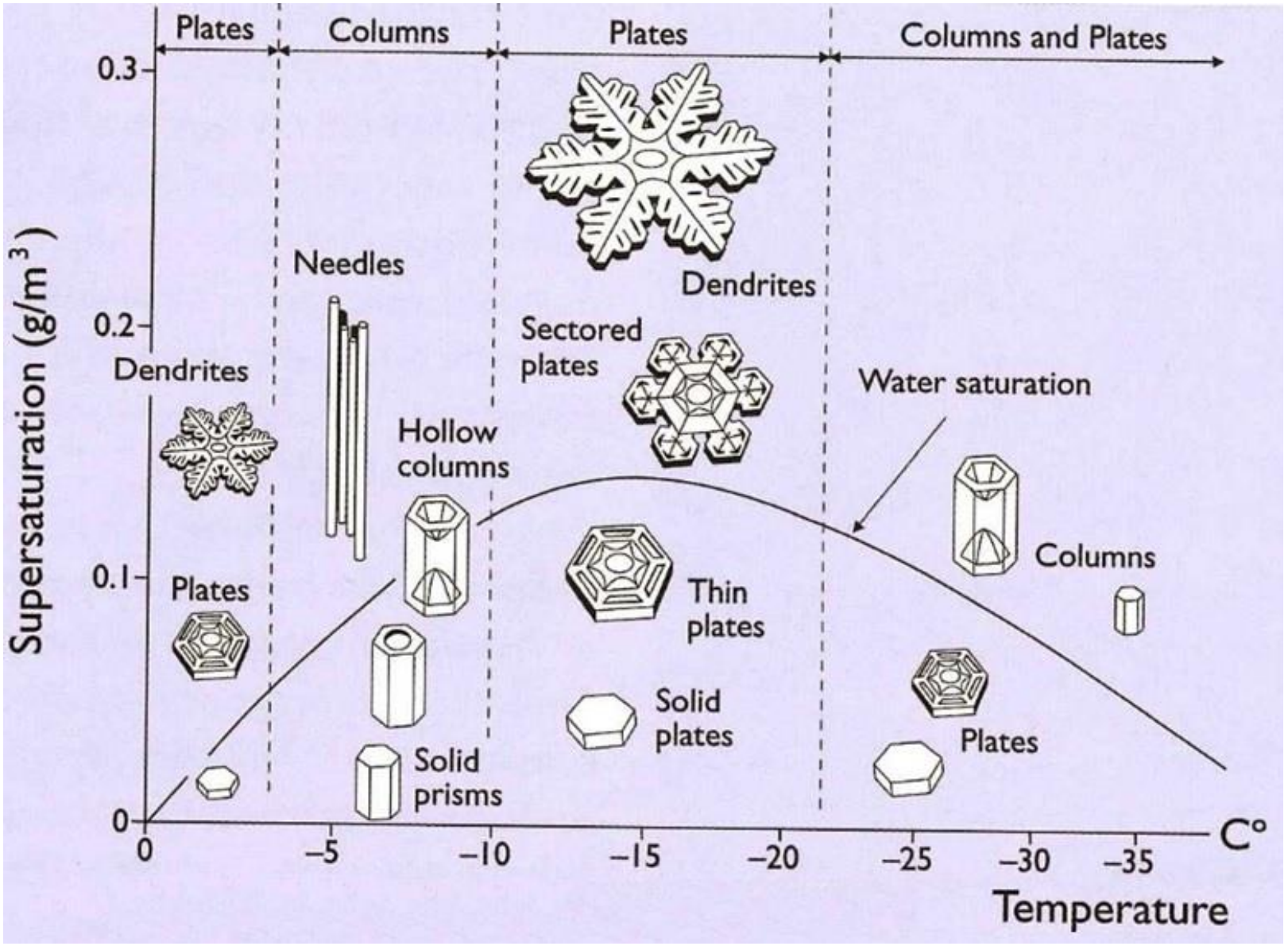


Growth of snow crystals in atmosphere





Different shape of ice crystals grown in the atmosphere



Melting point

All ice crystals melts at 0°C

Ice crystals

* Natural snow is grown by excess moisture in the atmosphere freezes (start to grow) from a pollution and where new water molecules connects and build the crystal in a hexagonal pattern
  * Has **very long time** in the air before it hits the ground
* Artificial snow is based on a water droplet (from a nozzle) that freezes from the outside and inwards. It gain a bulk density that are higher than the natural snow
  * Has **very short time** to freeze before it hits the ground. Limited height of the start point
  * Has a small temperature difference for freezing and needs a nucleate in the water to be sure the freezing starts without to large subcooling (for ex. «Snowmax»)

Conditions to make ice crystals

Temperature (°C) \ Relative humidity (%)	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
4	-2,4	-2,0	-1,6	-1,3	-0,9	-0,6	-0,2	0,2	0,5	0,9	1,2	1,6	2,0	2,3	2,6	3,0	3,3	3,7	4,0
3	-3,1	-2,7	-2,3	-2,0	-1,7	-1,3	-1,0	-0,6	-0,3	0,0	0,4	0,7	1,0	1,4	1,7	2,0	2,4	2,7	3,0
2	-3,7	-3,4	-3,1	-2,7	-2,4	-2,1	-1,7	-1,4	-1,1	-0,8	-0,5	-0,2	0,1	0,4	0,8	1,1	1,4	1,7	2,0
1	-4,4	-4,1	-3,8	-3,5	-3,1	-2,8	-2,5	-2,2	-1,9	-1,6	-1,3	-1,0	-0,7	-0,5	-0,2	0,1	0,4	0,7	1,0
0	-5,1	-4,8	-4,5	-4,2	-3,9	-3,6	-3,3	-3,0	-2,7	-2,5	-2,2	-1,9	-1,6	-1,3	-1,1	-0,8	-0,5	-0,3	0,0
-1	-5,8	-5,5	-5,3	-5,0	-4,7	-4,4	-4,1	-3,9	-3,6	-3,3	-3,1	-2,8	-2,5	-2,3	-2,0	-1,8	-1,5	-1,3	-1,0
-2	-6,5	-6,3	-6,0	-5,7	-5,5	-5,2	-5,0	-4,7	-4,5	-4,2	-4,0	-3,7	-3,5	-3,2	-3,0	-2,7	-2,5	-2,2	-2,0
-3	-7,3	-7,0	-6,8	-6,5	-6,3	-6,0	-5,8	-5,6	-5,3	-5,1	-4,8	-4,6	-4,4	-4,1	-3,9	-3,7	-3,5	-3,2	-3,0
-4	-8,0	-7,8	-7,6	-7,3	-7,1	-6,9	-6,6	-6,4	-6,2	-6,0	-5,7	-5,5	-5,3	-5,1	-4,9	-4,6	-4,4	-4,2	-4,0
-5	-8,8	-8,6	-8,3	-8,1	-7,9	-7,7	-7,5	-7,3	-7,1	-6,8	-6,6	-6,4	-6,2	-6,0	-5,8	-5,6	-5,4	-5,2	-5,0
-6	-9,5	-9,3	-9,1	-8,9	-8,7	-8,5	-8,3	-8,1	-7,9	-7,7	-7,5	-7,3	-7,1	-7,0	-6,8	-6,6	-6,4	-6,2	-6,0
-7	-10,3	-10,1	-9,9	-9,7	-9,6	-9,4	-9,2	-9,0	-8,8	-8,6	-8,4	-8,3	-8,1	-7,9	-7,7	-7,5	-7,4	-7,2	-7,0
-8	-11,1	-10,9	-10,7	-10,6	-10,4	-10,2	-10,0	-9,9	-9,7	-9,5	-9,3	-9,2	-9,0	-8,8	-8,7	-8,5	-8,3	-8,2	-8,0
-9	-11,9	-11,7	-11,6	-11,4	-11,2	-11,1	-10,9	-10,7	-10,6	-10,4	-10,3	-10,1	-9,9	-9,8	-9,6	-9,5	-9,3	-9,2	-9,0

Good snow quality Poor snow quality No snowmaking

* Water will freeze faster in dry air due to evaporation from particle surface (in the initial phase)
* Water temperature above 3°C should be cooled in an air-cooled heat exchanger
* When it is calm air, the air will be saturated with water vapor, and it will be foggy/misty – air temperature will raise, and the snow production will stop

NTNU
Norwegian University of Science and Technology

Temperature dependent production

* Water (high pressure) is sprayed from a nozzle by help of compresses air
* Normally 6-9 meters above the ground
* Normally connected to a common air compressor
* Heating element in the nozzle to avoid freezing

* Water sprayed from a large number of nozzles under high water pressure
* There is a fan that blows the water droplets in a long path way
* Control
  * number of nozzles active
  * air velocity at marginal temperatures
* Heating element in the nozzle to avoid freezing

NTNU
Norwegian University of Science and Technology

Temperature independent snow production

* The snow making system at ambient temperatures above zero will be environmental and energy friendly, using natural working fluid not harming the atmosphere.
* Utilization of the surplus heat from the system will reduce drastically the operational costs.
* Different case studies will be investigated to minimize the operational costs.

Temperature independent snow production

Different ways to produce ice. The ice will be crushed to small crystals.

Different types of machines / technics for ice freezing:

* Blocks of ice
* Ice cubes
* Flake ice
* Plate ice
* Ice slurry
* Vacuum ice

NTNU
Norwegian University of Science and Technology

Production snow /ice when

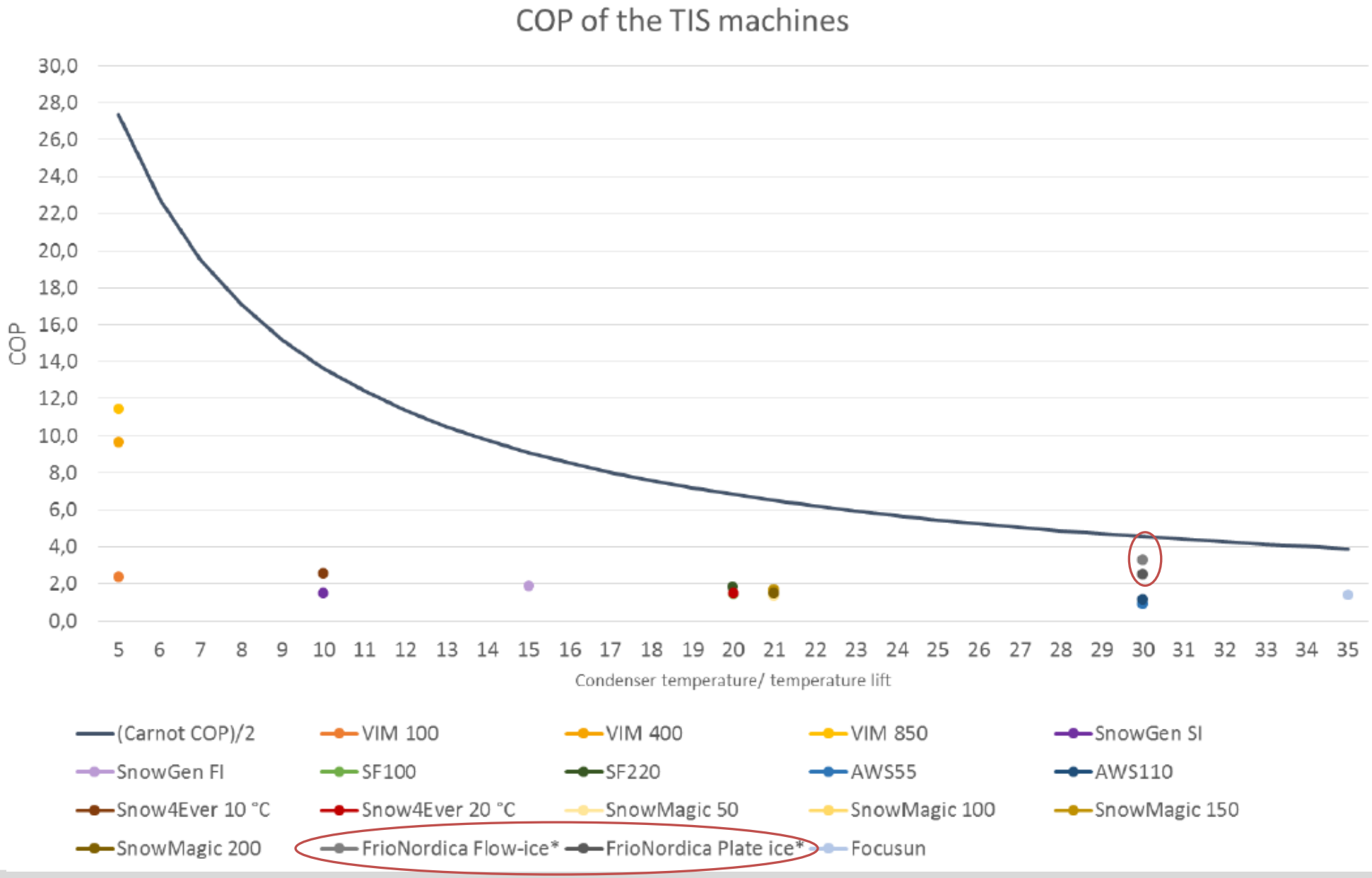
* it is a need for snow – capacity limitations
* there is a need for heat – require snow storage
* there is variation in need of heat – require thermal storage and snow storage
* electricity price is low – require snow storage
* Indoor snow production (snow gun) at temperatures similar to outdoor snow production but need to cool down a larger volume (space). Make finer ice particles that ice factory.

Some examples of systems

Company	SnowGen	TechnoAlpin SF220	IDE VIM100	SnowMagic 100	PTG
Prinsiples	Slurry ice	Flake ice	Vakuum ice	Flake ice	Plate ice
Type	Mobil	Stasjonær	Mobil	Mobil	Mobile
Capacity	220 m^3/day	220 m^3/day	200 m^3/day	200 m^3/day	50 m^3/day/unit
Power consumption	280 kW	227 kW	250 kW	248 kW	
Water consumption	1.4 l/s	1.5 l/s	1.3 l/s	1.6 l/s	
Workin fluid	Ammonia	Ammonia	Water	?	Ammonia
Energy per m^3	30.5 kWh/m^3	24.8 kWh/m^3	20.4 kWh/m^3	29.8 kWh/m^3	
References	Sochi 2014	Winterberg Sjusjøen	-	Ski arena in Japan og USA	

NTNU
Norwegian University of Science and Technology

PTG Group (FrioNordica +++)

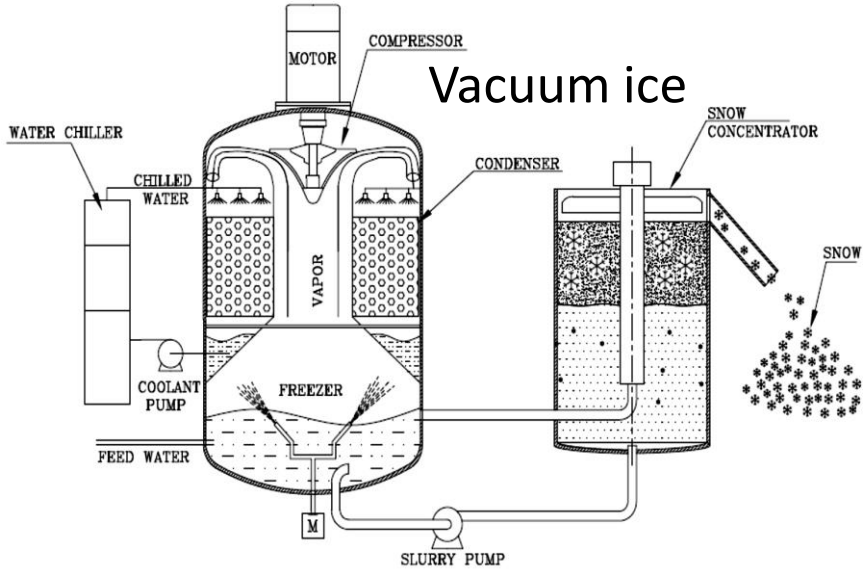


NTNU
Norwegian University of Science and Technology

Technologies - examples

Flace ice

Vacuum ice



Slurry ice

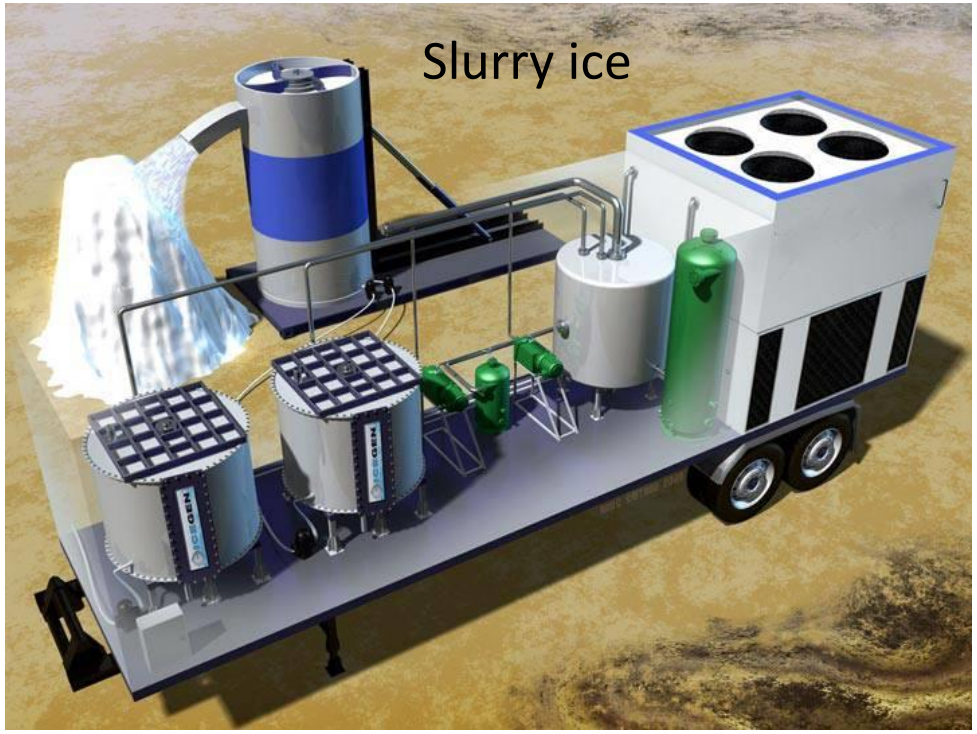
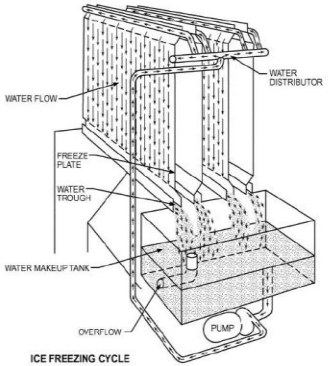
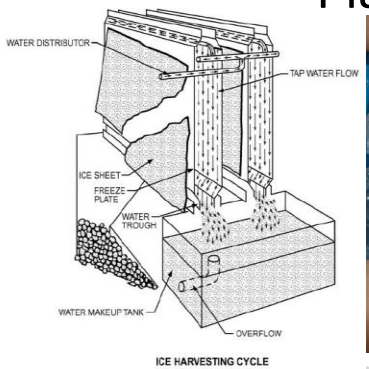


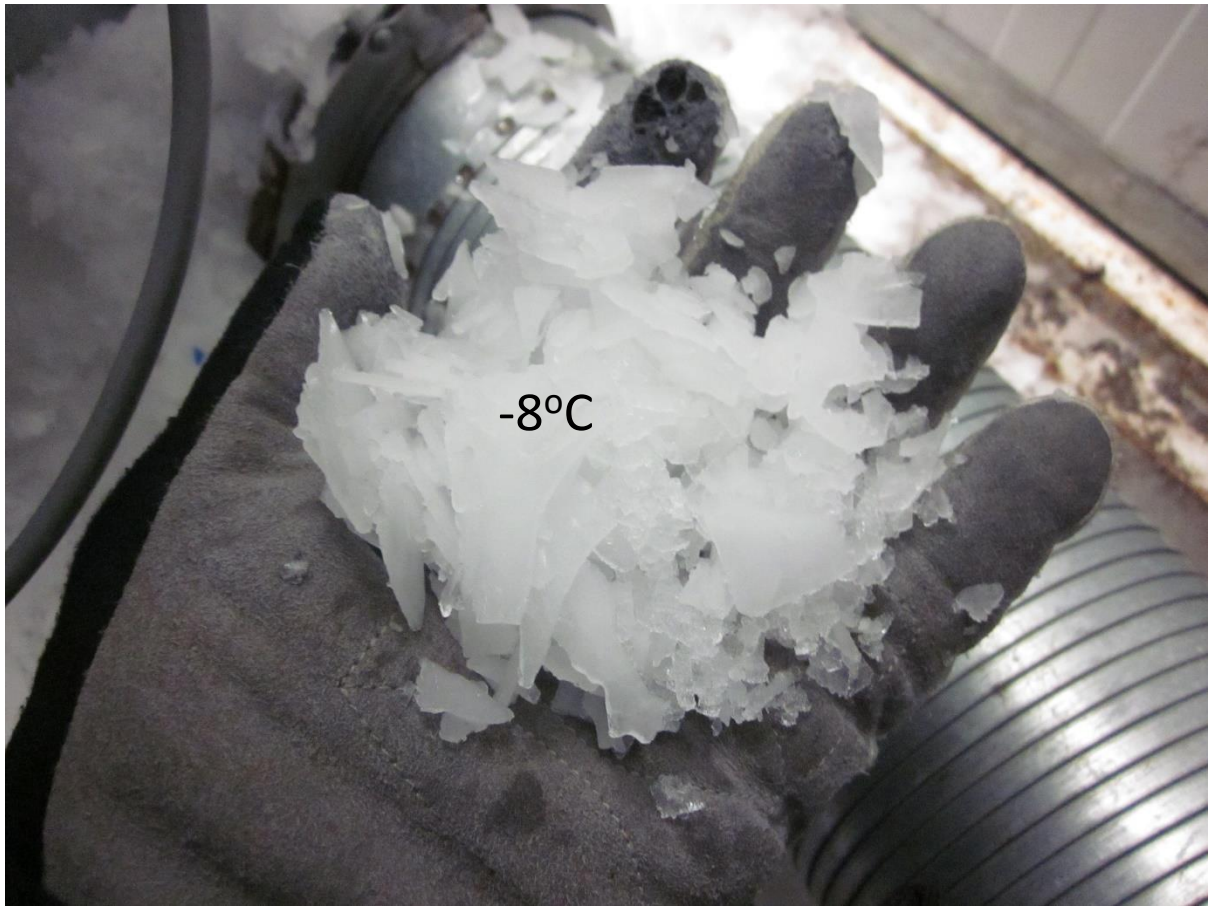
Plate ice





Production of flake ice

Ice before the crusher



Ice after the crusher

PTG group (Perfect Temperature Group)

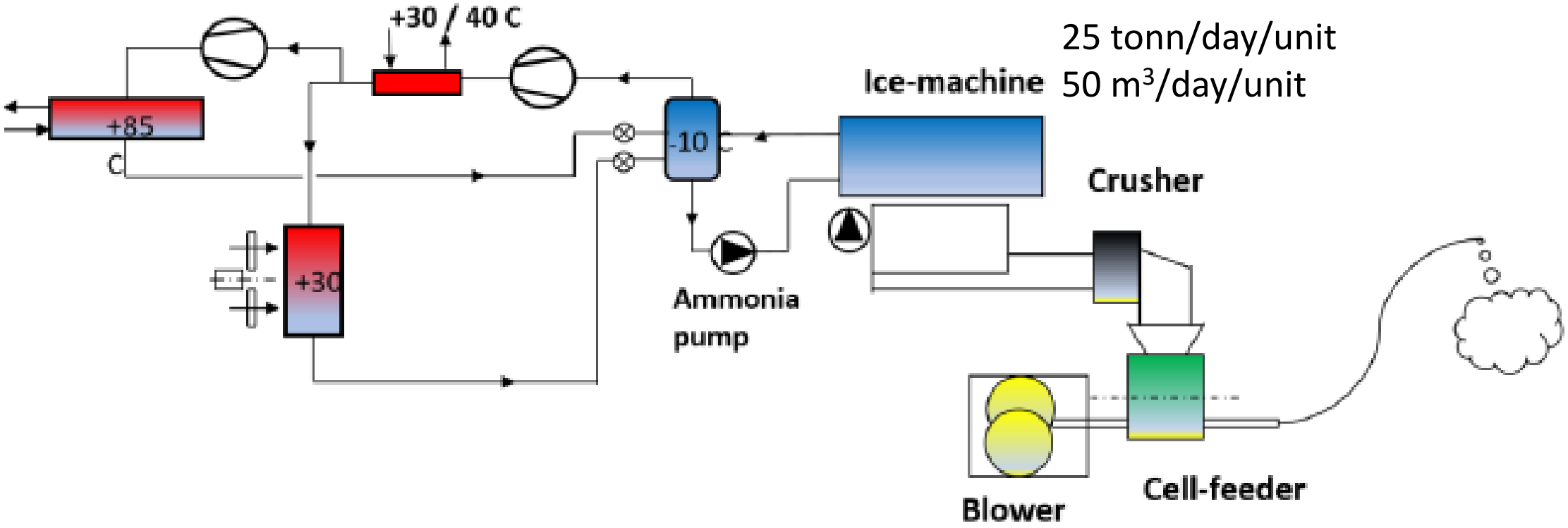
PTG group (Perfect Temperature Group)

Is-systemer

Is er det perfekte kjølemediet for fisk og annen sjømat. Vi leverer container-baserte is-anlegg, ismaskiner, og is-slurry-produksjon.

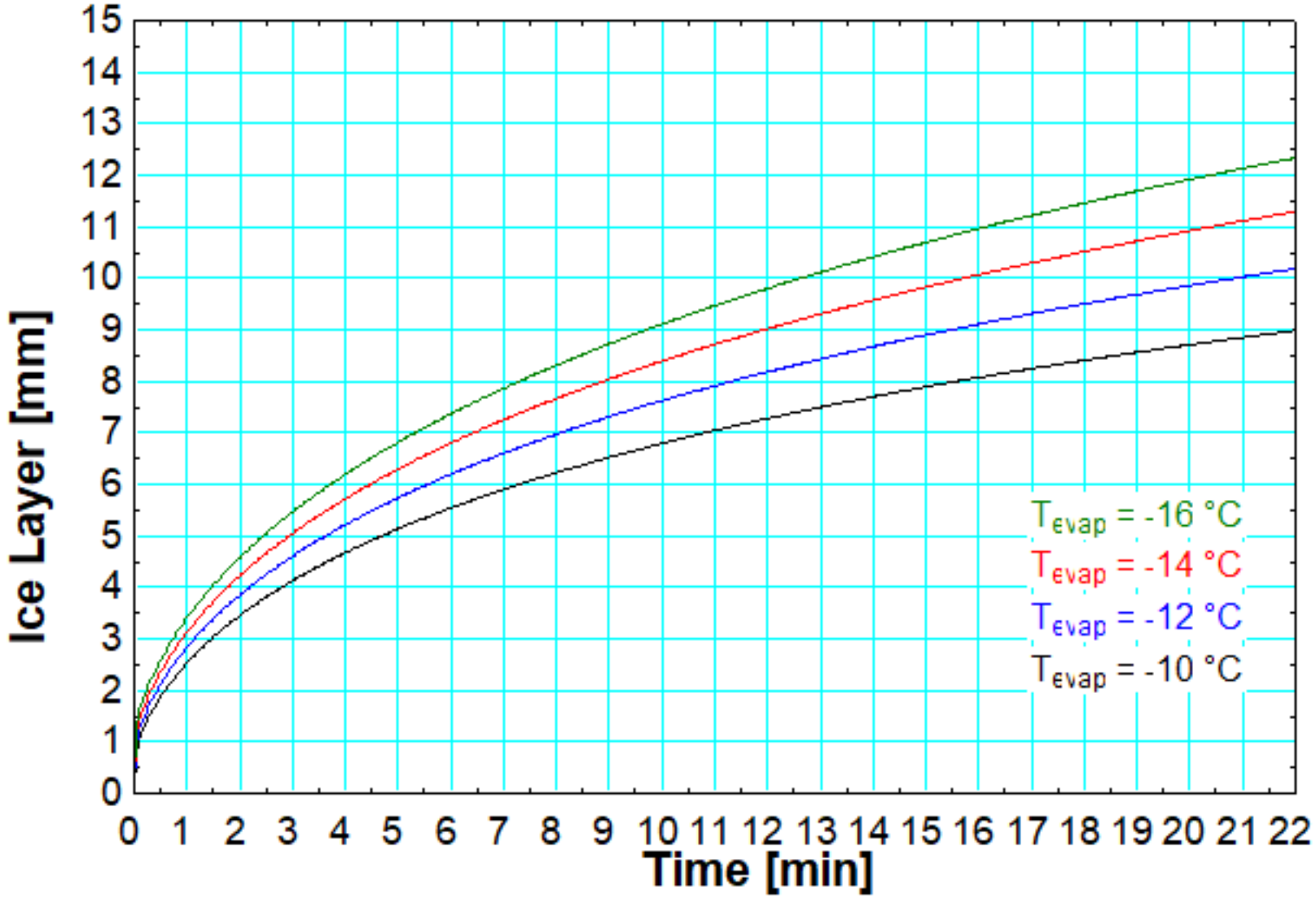
- ↓ Finsam isanlegg
- ↓ Finsam plate-is
- ↓ Finsam flow-ice
- ↓ Finsam slurry-is
- ↓ Finsam auto-is-system

Plate ice machine with heat recovery

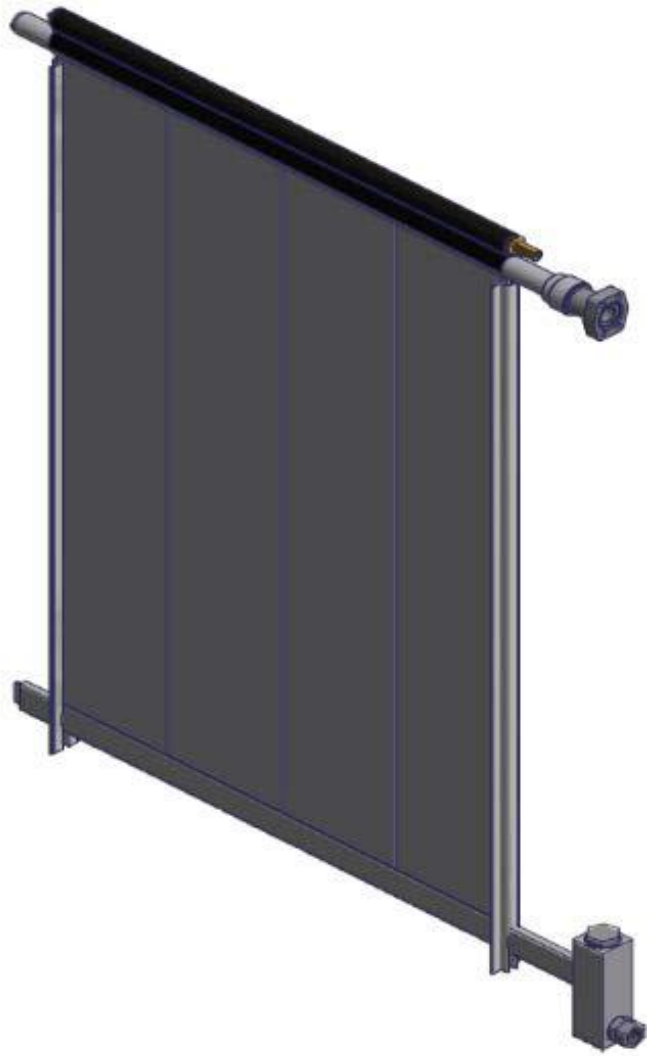


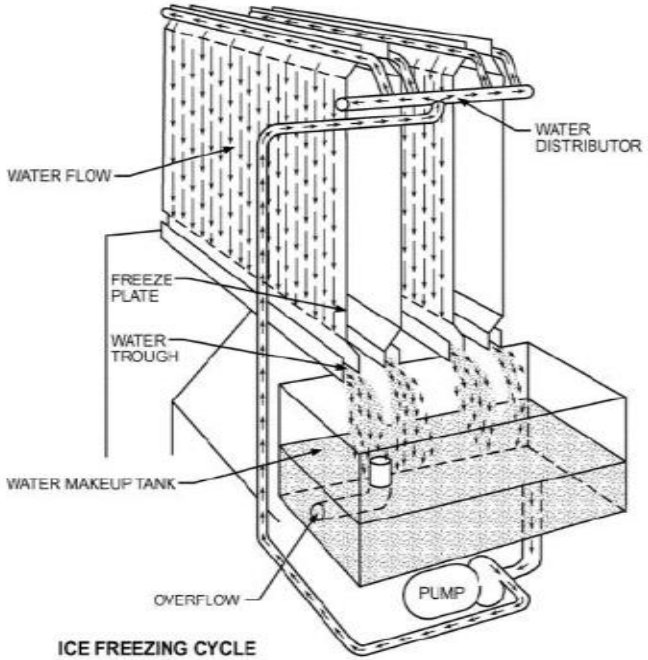
25 tonn/day/unit
50 m^3/day/unit

Ice build up, with different freezer temperature

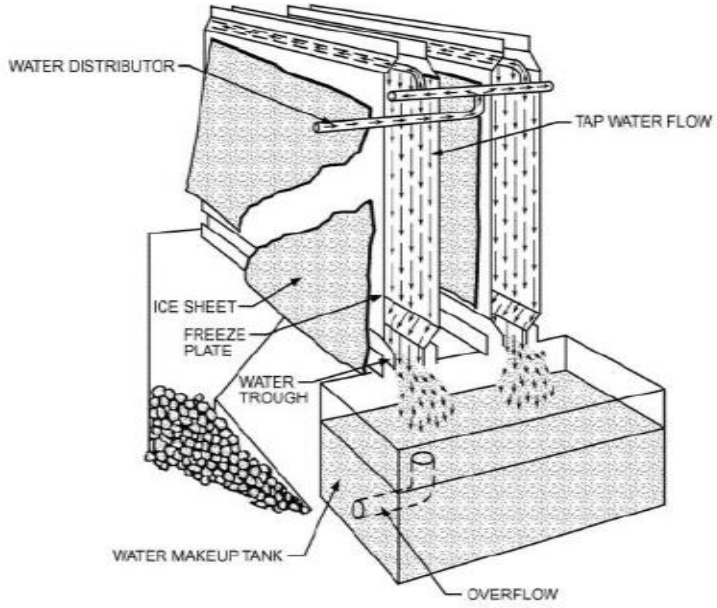


Freezing plates





ICE FREEZING CYCLE



ICE HARVESTING CYCLE

Aim for the work is to reduce the cycle time for each harvesting of ice

OL2022 – Beijing - CO_2 Snow making with heat recovery

NTNU Norwegian University of Science and Technology

在冬奥滑雪场 建设中**试示范样机已经完成**，通过库体优化，降低风速，能**快速、高效成雪、储**

Google translate

The construction of the pilot demonstration prototype of the Winter Olympic Ski Resort has been completed. Through the optimization of the library body, the wind speed can be reduced, and the snow can be quickly and efficiently formed and stored.

Planned 3 mill m3 snow produced in 200 hours.

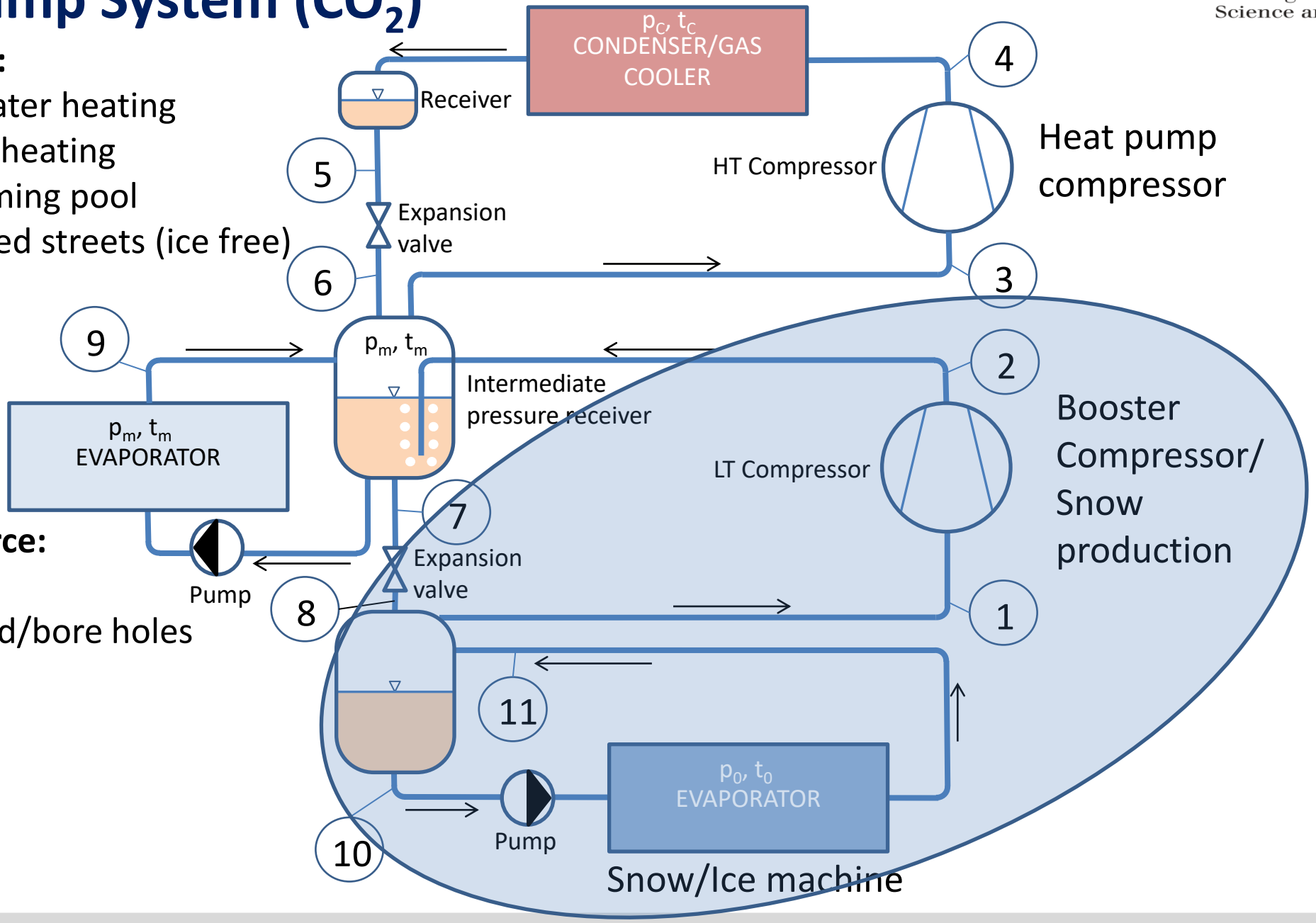
Heat Pump System (CO_2)

Heat sink:

- Tap water heating
- Space heating
- Swimming pool
- Selected streets (ice free)

Heat source:

- Air
- Ground/bore holes
- Water

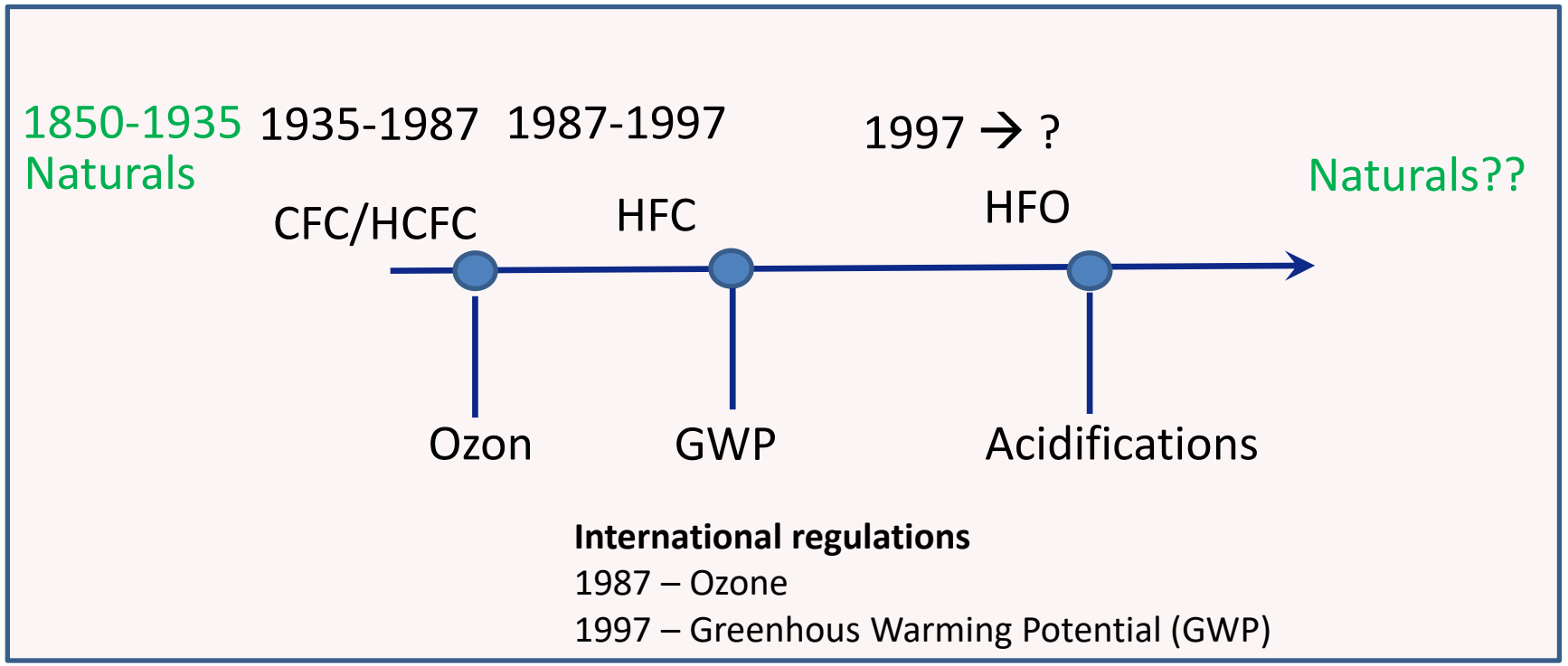


NTNU
Norwegian University of Science and Technology

Natural Working Fluids strategy in refrigeration and heat pump systems

Natural five

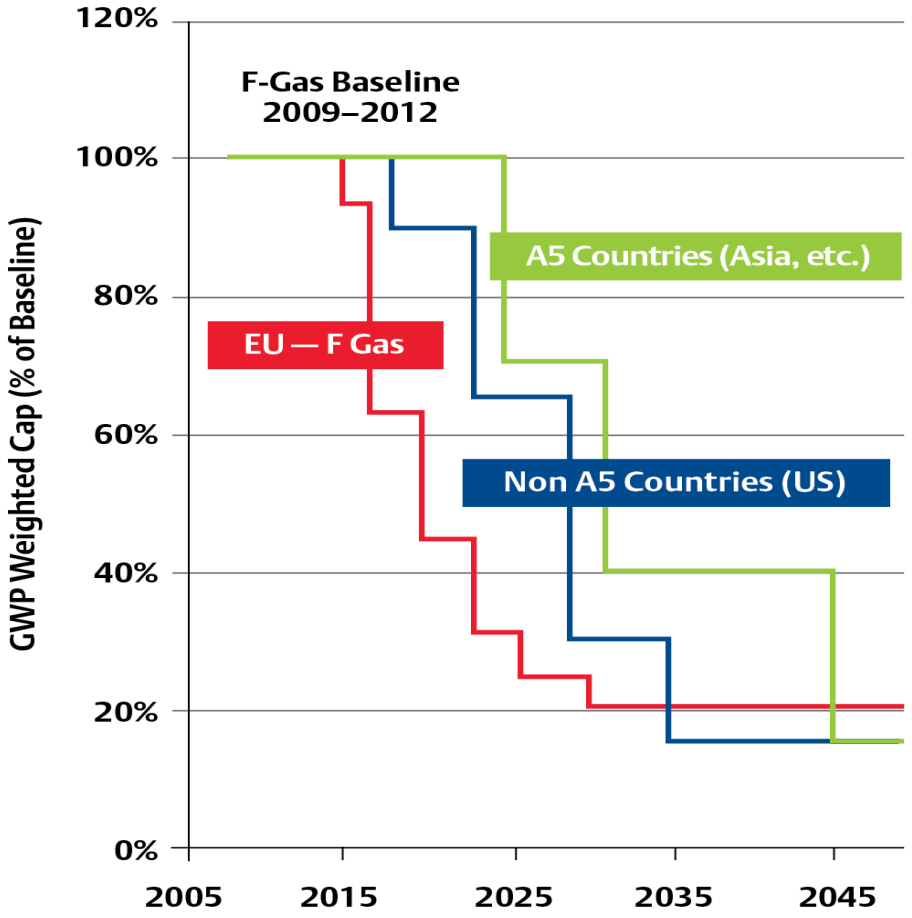
* CO_2 – Carbon dioxide
* NH_3 - Ammonia
* HC – Hydrocarbons
* Water
* (Air)



NTNU
Norwegian University of Science and Technology

EU – F-gas Regulation

Limitation of the amount of fluorinated greenhouse gases emitted to atmosphere



Service and maintenance bans	GWP	Timing
HFC's	2,500	Jan. 2020
'Placing on the market' (new equipment) bans		
Domestic refrigerators and freezers	150	Jan. 2015
Refrigerators and freezers for commercial use (hermetically sealed systems)	2,500	Jan. 2020
Refrigerators and freezers for commercial use (hermetically sealed systems)	150	Jan. 2022
Stationary refrigeration equipment (except equipment for temperatures below -50 °C)	2,500	Jan. 2020
Multipack centralized refrigeration systems for commercial use with a capacity of ≥ 40 kW (140 kBTU/hr) (except in the primary refrigerant circuit of cascade systems, where fluorinated greenhouse gases with a GWP of less than 1,500 may be used)	150	Jan. 2022
Movable room air-conditioning appliances (hermetically sealed equipment which is movable between rooms by the end user)	150	Jan. 2020
Single split air-conditioning systems containing < 3 kg	770	Jan. 2025

NTNU
Norwegian University of Science and Technology

NTNU – Project woks and Master thesis

Project work – fall semester 15 credits

Bernhard Haver Vagle (F2015):	Utilization of surplus heat from snow producing machines
Jon-Brede Rykkje Dieseth (F2015):	Snow production equipment at ambient temperatures above 0°C
Kaja Wright Bergwitz-Larsen (F2016):	Energy Efficient and Environmentally Friendly Snow Production Equipment at Ambient Temperatures above 0°C
Marianne Heimdal (F2017):	Energy Efficient and Environmentally Friendly Snow Production at Ambient Temperatures Above 0°C
Jostein Birkeland (F2017):	Snow for the future, dynamic modelling and simulation of an energy system for a sports facility with snow production
Harald Undheim (F2019):	A review of snow storage in Norway with emphasis on Granåsen
Baptiste Flohic: (F2021/S2022)	Optimization of defrosting systems for plate ice freezing machine
Susanne Lang: (F2021)	Indoor refrigeration system for snow production – design and optimization

Master thesis – Spring semester 30 credits

Bernhard Haver Vagle (S2016):	Utilization of surplus heat from snow producing machines
Jon-Brede Rykkje Dieseth (S2016):	Snow production equipment at ambient temperatures above 0°C
Kaja Wright Bergwitz-Larsen (S2017):	Energy Efficient and Environmentally Friendly Snow Production Equipment by Refrigeration Systems
Marianne Heimdal (S2018):	Climate Independent Snow Production and Solutions for Snow Storage
Harald Undheim (F2020):	How particle size affects the melting of snow

NTNU
Norwegian University of Science and Technology

Summing up

* The climate and control strategies is of importance for production of snow
* Strategies for production of snow depends on electric price, need for heat and distance of transport
* Snow storage will be necessary due to capacity and costs/investment. In the season and/or between seasons
* Snow production at temperatures above zero degree Celsius is energy demanding
* Heat recovery from refrigeration system with for example CO_2 as working fluids can make it profitable
* Development of intelligent monitoring of snow quality and quantity in the slops will be of importance

Thank you for your attention!