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# Destruction of Medical $N_2O$ in Sweden

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## 1. Introduction

The potent greenhouse gas nitrous oxide ($N_2O$) is widely used in Sweden and many other countries as a mild anaesthetic or pain relief for mothers in labour. The Stockholm County Council (SCC) realized that the nitrous oxide used was responsible for a significant part of the total emission of greenhouse gases from their activities, including public transport. In 2002 SCC started to look for economically and environmentally sound ways to stop or lower the emission. Since nitrous oxide is effective, cheap, easy to use and without risks for mother or baby the maternity wards wanted to continue to use it as one of several methods for pain relief.

Different ways to collect and destroy the used nitrous oxide were therefore investigated in co-operation with IVL Swedish Environmental Research Institute (IVL). Efforts were soon concentrated on an existing Japanese unit treating mixed anaesthetic gases from operation (Kai et al, 2002). This was rebuilt for the new purpose by Showa Denko K.K., and installed in one of Stockholm's main hospitals in 2004. The unit called Anaesclean-SW was effective and reliable from start, and destroyed more than 95 % of the collected gas. Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) showed that the method was both environmentally and economically sound (Ek & Tjus 2008). The results were so good that SCC as one of their environmental goals said that the emission of nitrous oxide from the hospitals in 2011 should have decreased by 75 % as compared to that in 2002.

This chapter will discuss the development in Stockholm and the rest of Sweden up till now. It includes

- Choice of destruction method
- Tests of systems to capture as much of the gas as possible from the delivery rooms
- Different ways to reduce the energy demand
- Competition with more suppliers
- Lower prices and adaptation to smaller hospitals
- Continuous information to other county councils in Sweden

There are now 12 units running in Sweden. LCA and LCC for the latest ones will be given, and the future development discussed.

## 2. Different ways to decrease the emission of $N_2O$ from hospitals

The use of $N_2O$ in Swedish hospitals has decreased during the last years, but it was still about 155 tons in 2009 (Borgendahl, 2011). Since 1 kg $N_2O$ has the same effect as greenhouse gas as 298 kg $CO_2$, this corresponds to about 46 000 tons of $CO_2$. It is a small part of the total emission of $N_2O$ from Sweden, that was reported to be about 23 000 tons $N_2O$ in 2009 (UNFCCC, 2011) but it is easier to influence than the emissions from agriculture which is the totally dominating source. About 90 % of the total amount of $N_2O$ used in the Swedish hospitals is estimated to be used for pain relief during labour, and the rest mainly for surgical operation and special dental care. $N_2O$ is stable in the patient lung and blood system, and all the used gas is finally emitted from the body.

In 2002 the environmental director of SCC, Åke Wennmalm, pointed out that $N_2O$ used in delivery in Stockholm was responsible for a significant part of the total globing warming potential from the SCC. Electricity was mainly from renewable sources, and the transport sector was rapidly going over to non-fossil fuel. A broad and long-term work was started to decrease the emissions of $N_2O$. Several steps in the chain of $N_2O$ use were studied.

### 2.1 Decreased use of $N_2O$

The most direct way to reduce the emission of $N_2O$ is to reduce the use. In surgical operation $N_2O$ is now used just in small quantities, combined with other anaesthetics. The use is minimized by circulation of the anaesthetics in the breathing air. This is possible since the patient is anaesthetised and the breathing mask is firmly attached to the patient. Recirculation of $N_2O$ is much more difficult in delivery or dental care with more open systems. It is important that the mother in labour pain can dose the pain relieve herself, without the aid of medical professionals. This means that she just uses the mask with gas when she is in pain, most of the time she doesn’t use the mask.

If it is difficult to reduce the use of $N_2O$ in delivery, why not use other methods? There are several, like epidural, uterine and pelvic anaesthesia. However, most anaesthetics in Sweden consider $N_2O$ to be the best method in normal birth, since it can be handled by the mother herself, it is cheap and it is without known negative side effects on children and mothers. $N_2O$ is now used in about 70 % of the births in Sweden (Borgendahl, 2011). Other countries with more than 50 % use of $N_2O$ are Finland, Norway, England, Australia and New Zealand. In Canada it is used in 20-30 % of all births, while it is very rare now in USA. There is a debate now in USA to again start to offer $N_2O$ as an alternative method, mainly due to the low cost and easy handling by the mothers themselves. But there are also two negative aspects when using $N_2O$. Besides the strong effect as a greenhouse gas, it can also affect the health of the delivery ward personnel negatively during long time exposure (Berge, 2001). The occupational health 8 h limit value in Sweden is 100 ppm $N_2O$.

Of course all $N_2O$ that is purchased should be used by the patients. However, a survey of the often old distribution systems in many hospitals revealed leakage points responsible for up to 20 % of the purchased amount, or even more in some hospitals. Another point of loss of $N_2O$ is the residual in pressurised bottles returned to the supplier. Since gases for medical use have to be filled in clean, empty bottles, the residue has to be let out. This can be 5-10 % of the total amount, depending on the practice of the hospital. There has to be a certain safety margin so that there is always gas available. The residual gas is sometimes used for other purposes by the supplier, but in many cases it is (was) just released to the atmosphere. Many County Councils now demand that their supplier destroy the residual $N_2O$ that is not used for other purposes.

### 2.2 Collection of used $N_2O$

Since the negative effect on occupational health has been known for a long time, the delivery wards already have systems to reduce the concentration of $N_2O$ in the delivery rooms. The distributing masks are also collecting most of the gas in the exhalation, and this is ventilated out of the room in different ways.

In Sweden different types of masks and suction systems are used. In the so called single masks there is just one compartment in the mask, and both inlet of $N_2O$ and suction of exhalation gas are connected to this. The suction is normally via an ejector pump in the main ventilation shaft, and the capacity is about 25 L/min. The collected $N_2O$ is considerably diluted in the shaft, to concentrations of about 50-100 ppm. As will be discussed later this is a serious drawback for destruction.

In many hospitals there is a more powerful and separate exhaust system. This uses double masks, with one central compartment where the gas is distributed, and a surrounding compartment where the exhaled air is collected, mixed with some of the surrounding air, and sucked out with a fan. This fan normally has a capacity of about 500 L/min, and it has its own outlet tube to the atmosphere. This system can collect more of the exhaled $N_2O$, and the concentration is higher in spite of the high air flow.

Fig. 1. A midwife demonstrates the use of a double mask. (Photo Mattias Ahlm)

Studies of systems with double masks have shown that 70-75 % of the used gas is collected by the mask (SLL, 2008). The figure varies a lot between deliveries, dependent on the handling of the mask. As much as 25-30 % of the used $N_2O$ is lost to the room atmosphere and evacuated by the main ventilation. One reason is imperfect handling of the mask; this is not the main concern of the mother at the time. Some gas leaks out beside the mask.

Another reason is that the gas dissolved in the mothers blood is ventilated out during several exhalations after she has stopped inhaling the gas. This means that the mask should be used for exhalation for half a minute or more, without inhalation through it, after the pain has decreased. With special instruction about this the collection ratio was shown to increase to 80-85 % (SLL, 2010).

A small step in this direction is the new practice with the mask in a string around the mother's neck. In this way the mask continues to suck out some of the exhalation air even if the mother is walking around in the room.

### 2.3 Ways to destruct $N_2O$

When most of the used $N_2O$ is collected in a relatively concentrated stream it is possible to destroy it in different ways. It is also possible to separate $N_2O$ from the air stream for purification and reuse. However, the relatively low capacity of e.g. zeolites, cost of purification of a medical gas and the low price of new $N_2O$ make this less interesting.

$N_2O$ is a quite stable gas, but like most chemical compounds, it can be oxidised or reduced, depending on conditions.

#### 2.3.1 Oxidation

Oxidation here means introduction of more oxygen in the molecule, giving compounds like $NO_2$, or in general $NO_X$ with $X > 0.5$. Just mixing $N_2O$ and oxygen (or air) is not enough, but in conventional combustion the temperature is enough. High concentrations of $N_2O$ can be incinerated without extra fuel, but for the concentrations in the delivery exhaust external fuel has to be added. This fuel and the incinerator are of course extra costs, and can only be justified if the heat energy is needed close to the hospital. Today most of the Swedish hospitals are connected to district heating systems, and don't have furnaces. However, experiments with combustion in a hospital furnace still in use have been performed. It showed that the $NO_X$ production was so high that the experiments were stopped (Engman, 2011).

$N_2O$ can also be oxidised at lower concentrations by using a heated catalyst. No extra fuel is needed, but the catalyst has to be heated in some way all the time, since the reaction is not exothermic enough. Also in this process $NO_X$ is formed, with its negative environmental impact.

#### 2.3.2 Catalytic reduction

Reduction here means removal of oxygen, and the result is $N_2$, nitrogen gas that constitutes most of our atmosphere. On the catalyst something else has to be oxidised, like any organic gas or hydrogen gas. The temperature of the catalyst doesn't have to be so high, but the problem is the high concentration of oxygen in the collected exhaust gas. This is about 20 %, compared to about 0.2 % of $N_2O$. This means that a lot of organic material or hydrogen gas has to be added to reduce the oxygen to water before most of the $N_2O$ is reduced. To be of interest the catalyst has to very selective for $N_2O$.

### 2.3.3 Catalytic splitting

A third method to break the $N_2O$ molecule is to split it into nitrogen gas, $N_2$, and oxygen, $O_2$. This can be done with a catalyst at temperatures about 400-500°C, without any addition. As with the other methods the catalyst has to be heated all the time, so energy recovery from the treated gas is important in order to improve the environmental performance and reduce cost. In 2002, when the method had to be decided, this seemed to be the most promising method. At that time there was a presentation of a Japanese system that treated exhaust gas from surgical operation (Kai et al., 2002). It removed other anaesthetic gases and split $N_2O$ catalytically. After discussions between SCC and Showa Denko K.K. the Japanese company started to investigate the possibilities to treat $N_2O$ in much lower concentration than in Japan, and without other anaesthetic gases. After it was shown that the process created no or very little $NO_X$ the process was a candidate for delivery wards in SCC.

## 3. Installed destruction units

### 3.1 Generation 1

Early in 2004 SCC made an international enquiry for tenders. The only final offer was given by Showa Denko. There were obviously no other systems close to commercialisation. The first unit, called Anesclean SW, was installed at Huddinge hospital in southern Stockholm in December 2004.

Anesclean SW consisted of
Inlet $N_2O$ concentration meter (IR based flow through system),
Textile particle filter to minimise clogging of the catalyst bed,
Fan with manual speed control,
Air flow meter,
Heat exchanger between inlet and outlet gas to the catalyst bed,
The catalyst bed with electric heating,
Outlet $N_2O$ concentration meter and
A fan to dilute the treated gas, to cool it further before discharge to atmosphere.

Heat recovery was from start considered to be important, due to the great amount of air that passed the catalyst and cooled it down. The temperature of the treated air stream before mixing with ambient air was about 80°C when the catalyst temperature was 400°C. The catalyst, being the heart of the system, had a secret composition and manufacturing process, but was mainly 5 % rhodium on aluminium oxide.

The 11 delivery rooms at Huddinge hospital already had double masks and efficient exhaust system (Anevac) so Anesclean SW could just be connected to the suction system outlet. The Anevac system is common to all 11 rooms, but the valve to each room is closed as long as no $N_2O$ is used there. When a mother wants pain relief the first time the personnel activates the system, and the mother can breathe in a mixture of oxygen and $N_2O$ whenever she wants. The suction system is automatically activated and about 500 L/min is from now on sucked out through the mask. This continues until the $N_2O$ system is turned off, normally after the birth. This means that the 500 L/min for long periods, between the worst labour pains, is mainly air. When the mother uses $N_2O$ the concentration can be up to 30 000 ppm in peaks.

500 L/min is not an exact figure; it is regulated by certain under pressure in the system. When there is no room activated there is still a base air flow, due to small intentional leaks in the system. This is illustrated in figure 2. There were hours with no $N_2O$ to destroy, but still there was an air flow of 1 $m^3$/min in this period. For short periods there were up to 5 or 6 rooms connected. This is a problem since the fan in Anesclean had to be changed manually. In practice you had to decide which air flow to set in order to collect most of the exhaust gas most of the time. In this case it was set to 2.3 $m^3$/min, based upon flow rates and concentrations measured over a long period.

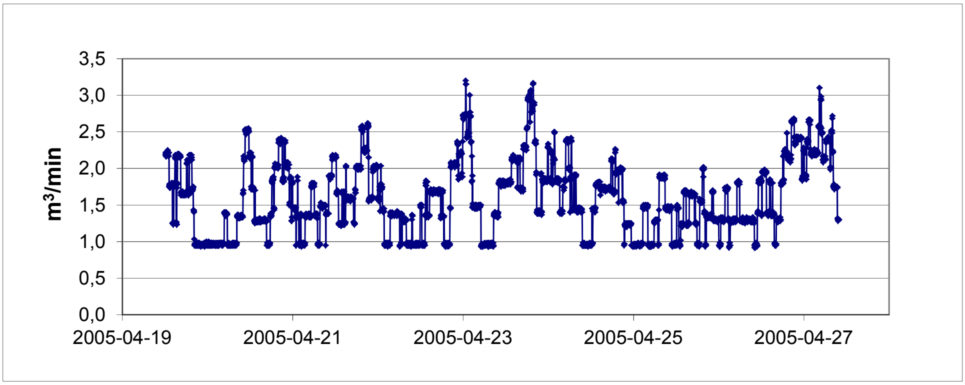


Fig. 2. Variation of gas flow rate in the Anevac system dependent on the number of mothers using $N_2O$.

Not just the flow rate varies quickly over time. The concentration of $N_2O$ varies even more, for this installation between 0 and about 10 000 ppm. This is illustrated in figure 3. The reason to have constant flow rate in Anesclean SW was fear about the temperature control of the catalyst not being able to follow fast variations in flow rate, and thus cooling. With this fixed air flow rate of 2.3 $m^3$/min in average about 5 % of the collected $N_2O$ from the Anevac system wasn't taken into the Anesclean SW, it was directly led to the atmosphere.

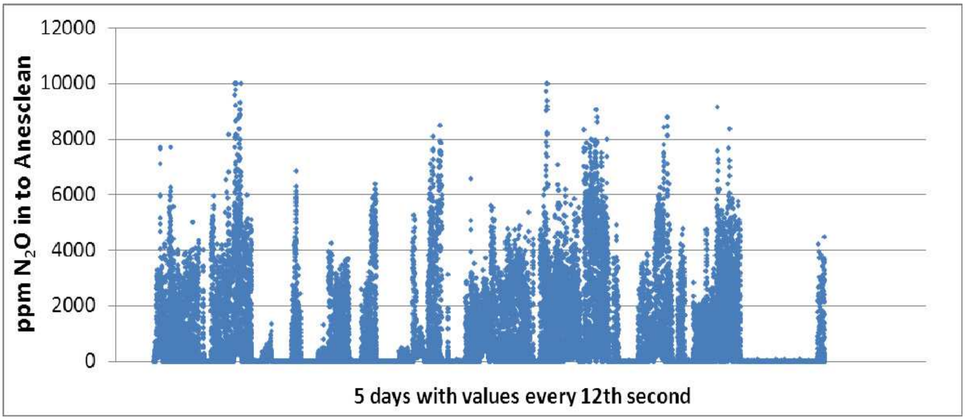


Fig. 3. Variation of concentration of $N_2O$ in the Anevac system, average concentration about 700 ppm.

Of the $N_2O$ entering the Anesclean SW over 97 % was destroyed during the first year of operation. The availability of the system was high, over 99 %, without any maintenance. The short stop periods were due to testing of the back-up energy system at the hospital each month. Then the unit had to be restarted manually.

The only problem with this first generation was the high consumption of energy. Due to the constantly high air flow rate it used about 35 kWh/kg $N_2O$ destroyed. This is coupled to the relatively low average concentration of about 900 ppm $N_2O$ in the treated air.

### 3.2 Generation 2

After the successful installation of this first unit SCC decided to go on with installations in other hospitals. After some discussion about licence fees the Swedish company QMT in 2008 installed the second unit in Danderyd hospital in the northern part of Stockholm. The design was similar to the original one delivered by Showa Denko at Huddinge hospital, with the same catalyst.

There were some important differences however. The one big unit was divided in two, with a separate part for gas analyses and regulation of the unit. This was mainly to make it easier to install in crowded areas. Extra heat exchangers were added to recover as much as possible of the energy used. But the most important change was on line regulation of the amount of air that was actually treated. This was done by measuring the airflow from the exhaust system Anevac, and setting the fan capacity slightly higher. In this way all the collected air was treated and very little air from outside was added. This resulted in average $N_2O$ concentration about 2 400 ppm, compared to about 900 ppm in the first generation unit with the same number of delivery rooms connected.

Experience showed no problems to keep the temperature in the catalyst bed constant, and the overall destruction of collected $N_2O$ was more than 98 %. Mainly due to the regulation of air flow the specific energy demand was decreased to about 10 kWh/kg $N_2O$ destroyed.

### 3.3 Generation 3

One remaining drawback with the unit was the big size, which made it difficult to install in some hospitals. The price was also relatively high, especially for smaller hospitals with fewer deliveries. By now a new Swedish company Nordic Gas Cleaning, NGC, had developed their own system, with another catalyst without rhodium or other rare metals, built in modules and with simpler casing. The typical NGC unit is smaller and considerably lighter, about 1.0 x 3.3 m footprint, 2 m high and 1 400 kg (figure 4), compared to the first Anesclean SW with footprint 1.6 x 3.0 m, 2 m high and about 3 500 kg for the same number of delivery rooms.

The later NGC units also have another system for heat recovery. Instead of the conventional gas/gas heat exchangers it uses ceramic heat storage systems, one on each side of the catalyst. Heating is still just in the catalyst itself, to about 500°C in their case. Hot air leaving the catalyst heats up ceramic bed 2. When the temperature in ceramic bed 1 has dropped to about 60°C, the flow direction changes and ceramic bed 1 is heated by the treated air while bed 2 is preheating air going in to the catalyst bed. Flow direction is changed about every 2-3 minutes. When changing flow direction a small amount of air doesn't pass the catalyst, but this is led through a bed of activated carbon. This $N_2O$ is then immediately desorbed and passed through the catalyst before the next change of direction.

Fig. 4. The unit from NGC installed at Södertälje hospital. (Photo Anette Andersson)

In these units the fan and the air flow is regulated by a certain under pressure at the inlet, this means that just a little more air is treated than the amount given by the collection system from the masks. About 98 % of the collected gas is destroyed.

In spite of the higher temperature in the catalyst the specific energy demand is still lower than in the second generation Anesclean SW. With the same loading (i.e. the same number of delivery rooms connected) it is about 5 kWh/kg $N_2O$ destroyed. The smaller and more flexible units with both lower energy demand and lower price has resulted in just this third generation type being sold the last two years.

## 4. Energy savings

The most important factor for energy demand is the amount of air treated. However, a very good recovery of heat from the treated air also influences the energy used. The specific energy demand, kWh/kg destroyed $N_2O$, is highly dependent on the mean concentration of $N_2O$ in the treated air.

The air flow per connected breathing mask is a compromise between working environment and energy saving. Low air flow means less $N_2O$ captured, but less energy needed to destroy this. High air flow collects more $N_2O$, gives better working environment, but takes a lot of energy for destruction. In all three systems in table 1 the collection system had the same design with double masks and roughly the same air flow per mask (400-500 $m^3$/min).

| Type of unit | Delivery rooms | Average air flow, $m^3$/min | Average concentration, ppm $N_2O$ | Specific energy demand, kWh/kg $N_2O$ |
|---|---|---|---|---|
| Generation 1 (2004) | 11 | 2.3 | 900 | 35 |
| Generation 2 (2008) | 12 | 1.9 | 2 400 | 10 |
| Generation 3 (2010) | 12 | 1.5 | 1 500 | 5 |

Table 1. Energy demand in $N_2O$ destruction systems at three hospitals of similar size.

The development over time is obvious, and this has also been the main reason for designing new systems. The destruction ratios for $N_2O$ have been 98-99 % in all three systems.

These are relatively big hospitals and delivery wards. With the same system the specific energy demand increases rapidly for smaller units, with longer periods without $N_2O$ used and lower concentrations. To change this a new generation with smart regulation of air flow to the unit has to be developed. Much could be saved by not treating the air completely without $N_2O$. This is both in periods without any birth with $N_2O$ (the system not activated) and in periods where the exhaust system is activated but no mother at the moment is breathing $N_2O$. However, as will be seen later, the energy demand in the new units has very little influence on the total cost.

## 5. LCA

LCA, or Life Cycle Assessment, has been used to evaluate the total environmental impact of the destruction units. Methods and results for the first installation have been reported (SLL, 2005a). All steps are included, from production of equipment material and electricity needed, period of use and finally discharge of the equipment. In all stages use of resources and emissions of different kinds are calculated and sorted into different impact categories. The most important impact categories here are

- Global warming
- Acidification
- Photochemical ozone formation
- Nutrient enrichment/eutrophication and
- Stratospheric ozone depletion

The functional unit in these calculations was 1 kg of $N_2O$ collected by the exhaust gas system. In the case of no destruction the only impact is the potential global warming effect, and this is for 1 kg $N_2O$ 298 kg $CO_2$-equivalents.

With a destruction unit the direct emission of $N_2O$ is decreased by about 98 %, leaving 0.02 kg $N_2O$ or 5.96 kg $CO_2$-equiv. But production of material needed, transports and electricity also contributes to global warming. This is added to get the total impact of this kind. The same is done for all relevant impact categories.

This is a hard work, but still quite scientifically based. The problem comes when you want to compare the possible impacts from one process with another, or in this case no destruction compared to destruction with a well-defined process. The impacts have different units, and some of them are local or regional, while others are global. Which one is most important? Now it is not strictly scientific any more, you can choose different suggested methods to compare the total impact. In this case we show the method with the average annual impact of one person in the world for global impacts and in the EU for regional impacts, table 2. The absolute impacts from the delivery room and the destruction unit are divided by these reference quantities. This is called normalisation. The unit of the normalised values is (European) annual person equivalent. (Hauschild & Wenzel, 2001)

| | Global warming (global impact) | Acidification (regional impact) | Photochemical ozone formation (regional impact) | Eutrophication (regional impact) | Stratospheric ozone depletion (global impact) |
|---|---|---|---|---|---|
| Unit | kg $CO_2$ equiv. | kg $SO_2$ equiv. | kg $C_2H_4$ equiv. | kg $PO_4^{3-}$ equiv. | kg CFC11 equiv. |
| No treatment | 298 | 0 | 0 | 0.27 | 0 |
| Destruction | 6.45 | 0.00117 | 0.000128 | 0.00581 | $2.9 \cdot 10^{-8}$ |
| Normalisation references[1] | 6 310 | 34 | 5.3 | 37 | 0.029 |
| No treatment, annual milliperson equiv. | 47 | 0 | 0 | 7.3 | 0 |
| Destruction, annual milliperson equiv. | 1.0 | 0.034 | 0.024 | 0.16 | 0.001 |

[1] kg of the respective impact / year/ person (in the world or in the EU). References per year from the Centre of Environmental Science – Leiden University (CML), version CML2001 – Dec. 07, divided by data from population statistics.

Table 2. Summarized LCA for destruction of $N_2O$ in a big hospital with a generation 3 unit, compared to direct emission of 1 kg $N_2O$.

The different units make it impossible to compare the impact of treatment in a strict scientific way. By transforming all impacts to units of annual person equivalents one can at least see the different impacts compared to the impact of an average person in the world or in the EU, as appropriate. The impacts on global warming and eutrophication have the highest figures. For global warming potential it is obvious that treatment of $N_2O$ is to prefer, while it is slightly negative for acidification, for photochemical ozone formation near the ground and for the stratospheric ozone destruction potential. If the effect of the destruction unit on eutrophication is positive or negative depends on the fate of the nitrogen of the $N_2O$ which is emitted to the environment. If this nitrogen actually contributes to eutrophication, then the destruction unit obviously has a positive impact on eutrophication.

Since the aim of the treatment is to reduce global warming, this category is obviously important, and it is possible to say that this method can decrease the global warming potential from the use of $N_2O$ without any strong negative impacts on some of the other common environmental impacts. The same was shown also for the first generation unit from Showa Denko (SLL, 2005a). A complete assessment should, however, also consider the possible discharge of toxic compounds from the manufacture and use of the destruction equipment, as well as the necessary use of resources.

The figures used in the LCA are as far as possible based upon actual material production and transports in this case. For electricity Nordic average electricity is used, that is mainly hydropower and nuclear power. This specific hospital uses "green electricity", mainly hydropower, with even less environmental impact. If electricity was based more upon coal, the impact would be higher, but destruction of $N_2O$ still appears to perform better than no destruction.

## 6. LCC

Even if the treatment of $N_2O$ is environmentally sound, it also has to be economically realistic. If it is too expensive per kg avoided $CO_2$-equivalent, the money should be used for other methods to decrease global warming. To evaluate this LCC, Life Cycle Cost, with the annuity method has been used. This was done for the first Anesclean unit before further investments were decided (SLL, 2005b).

LCC has also been calculated for generation 3 units. Investment cost is here the price of the unit and all costs for installation. Maintenance costs are electricity, service contract and a few hours for local check. The service contract includes changes of catalyst (every 4$^{th}$ year) and fans, and calibration of meters. The residual value is based upon scrap prices and costs for disposal of some components.

Table 3 shows the result for a big hospital (12 delivery rooms) and equipment from NGC, generation 3. The electricity price for SCC is now about 0.115 €/kWh, and also the double price was used in calculations. The technical and economic lifetime was set to 10 or 15 years, and the interest to 4 or 6 %. Electricity costs, service contract and other personnel costs were supposed to increase by 3 % each year.

| Life time years | Interest rate | Electricity price €/kWh (2011) | **Specific cost €/kg $CO_2$-eq.** | Capital cost | Electricity cost |
|---|---|---|---|---|---|
| 10 | 4 % | 0.115 | **0.073** | 84 % | 2.6 % |
| 10 | 4 % | 0.23 | **0.074** | 81 % | 5.1 % |
| 10 | 6 % | 0.115 | **0.079** | 85 % | 2.4 % |
| 10 | 6 % | 0.23 | **0.081** | 83 % | 4.7 % |
| 15 | 4 % | 0.115 | **0.057** | 78 % | 3.6 % |
| 15 | 4 % | 0.23 | **0.059** | 75 % | 6.9 % |
| 15 | 6 % | 0.115 | **0.063** | 80 % | 3.2 % |
| 15 | 6 % | 0.23 | **0.065** | 78 % | 6.2 % |

Table 3. Life Cycle Cost for destruction of $N_2O$ with generation 3 equipment in a big hospital, with different life time, interest rate and electricity cost.

A total cost below 0.1 or even 0.2 €/kg $CO_2$-equivalent is considered as a good investment in SCC for reduction of climate change potential. It is obvious that the totally dominating cost is the capital cost while other factors have little influence. Personnel costs (mainly service contract) and spare parts are 10-15 % of the total cost. For the first unit from Showa Denko the total cost was about 0.099 €/kg $CO_2$-equivalent, and higher proportions on capital cost and electricity (SLL, 2005b). Cheaper units and better energy efficiency has paid off.

For smaller hospitals the cost will rise rapidly. So far the smaller units from NGC are almost as expensive as their bigger ones, they have higher specific energy demands, and destroy much less $N_2O$/year. The unit installed at Södertälje hospital with 6 delivery rooms have a life cycle cost of 0.20 €/kg $CO_2$-equivalent destroyed (15 years, 4 % interest and the lower electricity price). 72 % of this is capital costs, and the service cost has now reached 24 % of the total cost. With the design and technique used today installation in hospitals with less than 5 delivery rooms will have a high cost for each kg $CO_2$-equivalent.

## 7. Overall emission of $N_2O$ in 2010 in SCC

The total emission of $N_2O$ from medical use in SCC has decreased from 33 386 kg in 2002 to 15 959 kg in 2010 (SLL, 2011). This is about 52 % decrease, or about 5 200 tons of $CO_2$-equivalents less than in 2002. This is still far from the environmental goal 75 % decrease to 2011 in SCC. However, with the three new units installed late in 2010 it is quite possible to reach the goal. With the expected destruction in these the calculated decrease from 2002 will be about 72 %. If the emission is related to the number of births in SCC the decrease will be over 75 % since more children are born 2010 and 2011 than in 2002.

Most of the decrease is due to the 5 installed destruction units, but also better control of usage and leaks have contributed. As long as the collected $N_2O$ is not more than about 75 % of the used amount it is difficult to reach much further. Now just a few small users like special dentist care are without treatment, and for these new techniques are necessary.

## 8. Spreading of experience

After the successful installation and evaluation of the first unit in Stockholm the SCC decided to spread its knowledge and experience to other County Councils. Now all County Councils in Sweden are represented in a $N_2O$ consortium that meets via electronic conferences 4-6 times every year and physically at least once a year.

Now in 2011 there are 12 units installed, spread over 4 counties. Discussions are held in others, and there is also interest from other countries.

## 9. Conclusion

The focus upon emitted $N_2O$ as a significant part of the total greenhouse gas emission from SCC has led to development and installation of several units to destroy $N_2O$ used in child delivery. The units have become less expensive, and especially less energy demanding. In big hospitals with many births the installation of destruction units is positive to the environment and the cost per avoided $CO_2$-equivalent is competitive with other ways to decrease emission of greenhouse gases.

The results from the latest generation of units from NGC show that for small hospitals, with 4 or less delivery rooms, much cheaper units with even less need of service and maintenance have to be developed to give acceptable costs for $N_2O$ degradation.

The interest in collection of $N_2O$ for destruction has also led to increased efforts to minimize the negative effect on occupational health. The exhaust gas collection has improved, and several measurements of residual concentrations in delivery rooms have been done.

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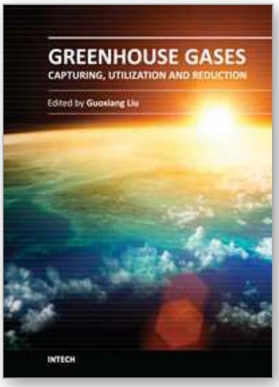


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Understanding greenhouse gas capture, utilization, reduction, and storage is essential for solving issues such as global warming and climate change that result from greenhouse gas. Taking advantage of the authors' experience in greenhouse gases, this book discusses an overview of recently developed techniques, methods, and strategies: - Novel techniques and methods on greenhouse gas capture by physical adsorption and separation, chemical structural reconstruction, and biological utilization. - Systemic discussions on greenhouse gas reduction by policy conduction, mitigation strategies, and alternative energy sources. - A comprehensive review of geological storage monitoring technologies.