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TEXTILE WASTEWATER REUSE IN NORTHERN ITALY (COMO)

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ABSTRACT

An extensive research programme has been carried out on advanced treatment of secondary effluents discharged by centralized activated sludge treatment plants fed on mixed textile/domestic effluents in order to produce a final effluent suitable for reuse in the textile factories. Activated carbon adsorption or membrane filtration (ranging from microfiltration to reverse osmosis) have been investigated at pilot plant scale in order to determine the most economical and performing advanced treatment. The increase in concentration of refractory pollutants and of salts discharged in the final effluents because of water recycling within the textile processes have been evaluated by relevant mass balances. A techno-economical analysis on the proposed treatment is also presented. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Granular activated carbon; microfiltration; nanofiltration; recycle; reuse; reverse osmosis; textile wastewater.

INTRODUCTION

Increasing water consumption for industrial and domestic purposes is leading to potential water shortages in many European countries and also to increasing water costs, either for primary water and for wastewater treatment. A rational water resources policy would allocate the purest water sources for direct human consumption and promote the development of effluent recycling processes to produce water for industrial use, for which quality requirements with regard to limitations on micro-pollutants are in most cases less stringent.

Many textile factories are widespread in the area of Como province and they use large amounts of fresh water, mainly for washing and rinsing operations and discharge appreciable pollution loads. It has been calculated that textile industry uses about 100 m^3 of water and emits some 100 kg COD per ton of produced fabric (Jekel, 1997).

The textile factories in the Como area are mainly small or medium sized (20 to 100 employes), and produce finished fabric process out of unbleached textiles. In the past, the main processed fibre was silk, which nowadays represent approximately 10 % of the total. Synthetic fibres (60%) and artificial cellulose-derived fibres (25%) cover the largest part of the production, while wool makes only a very small fraction of processed fibres (5%). Generally, the production of these factories is destined for a very high quality market and therefore the production is highly specialised, diversified and variable during the year. This situation results in a very large number of commercial dyes, detergents and auxiliaries that are used in the textile process and then partly discharged into the sewage.

Textile industries are supplied by underground water pumped from the water table and, since 1989, by an industrial aqueduct which draws water from the Lake Como and distributes 35,000 m^3/d. This industrial water is still rather inexpensive (of the order of 0.25 ECUs for the aqueduct) but its use should be reduced whenever possible because the level of the water table has appreciably decreased during the last decade. Similarly, the lake water, because of its high quality, should be saved or exploited for potable use.

The wastewater from the industrial processes is generally discharged into the public sewer where it is mixed with the domestic sewage and treated in centralised plants which influent total flow rate exceeds 100,000 m^3/d. Half of this capacity is located in the three treatment plants operated by Lariana Depur, the characteristics of which are reported in Table 1.

Table 1. Characteristics of the three plants managed by Lariana Depur

Plant	Unit	Alto Lura Plant	Livescia Plant	Alto Seveso Plant
Influent flow rate	m^3/d	25,000	3,000	22,000
Domestic wastewater	% dwf(*)	25	30	30
Industrial wastewater	% dwf	75	70	70
Origin of industrial wastewater:				
Printing mills	%(+)	32	4	38
Dyeing mills	%	50	0	28
Dyeing and printing mills	%	10	79	31
Other industries	%	8	17	3

(*)dwf = dry weather flow (+) % of the total influent flow

The final effluents of the treatment plants are discharged into rather small streams. Because of the low dilution capacity, more stringent discharge standards than the ones imposed by the national law will be required by local authorities in the near future (TSS < 20 mg/l, COD < 80 mg/l; BOD_5 < 10 mg/l, Total nitrogen < 10 mg/l; Total surfactants < 1 mg/l; Colour = undetectable when diluted 1:2).

As a consequence of the above situation, advanced treatment processes are needed to produce effluents to be recycled into the textile mills, possibly through the industrial aqueduct and to guarantee safe discharge into sensitive streams in spite of variability of the hydraulic and pollutant loads. Higher and more reliable treatment efficiency is needed especially to remove non ionic surfactants which are widely used in the textile industry; these generate foams at concentrations well below 1 mg/l. Improved removal of colour, COD and suspended solids are also required.

Apart from the centralized reuse of purified effluents through the aqueduct, end of pipe treatment flow-sheets within the factories are possible, such as separate collection of residual printing pastes from the frames (the amount of water saved could be as high as 0.17 m^3/kg printed textile) followed by a drying process or anaerobic digestion (Bonomo *et al.*, 1995; Malpei *et al.*, 1998)

QUALITY REQUIREMENTS FOR TEXTILE WASTEWATER REUSE

It is quite difficult to define a general quality standard for textile water reuse because of the different requirements of each fibre (silk, cotton, polyesther etc.), of the textile process (e.g., scouring, desizing, dyeing, washing, etc.) and because of the different quality required for the final fabric.

Low hardness water is usually needed for scouring, dyeing and for preparing printing pastes but softening is not necessary for all the washing cycles. A high salt content may interfere with the dyeing process and with the detergent action of the surfactants used in washing the dyed fabric. Chemical reduction of the chromophores in the dye molecules by ammonia, nitrite and sulphide may alter the colour and therefore spoil the dying process. Organic substances, and particularly surfactants and traces of dyes, may interfere with bleaching, dying and printing by causing differences in hues and tones.

Probably because of the different requirements of the textile processes, as indicated above, wide variations in water quality for textile reuse have been reported in the literature. Groves *et al.* (1979) used effluents from a treatment pilot plant which were still appreciably polluted (40 to 300 mgTOC/l, 50 to 427 ADMI values colour and 1,300 to 8,000 µS/cm) and nevertheless found quite acceptable results in dyeing tests for wool, polyester and viscose even with TOC values as high as 300 mg/l and ADMI values of the order of 400. Unacceptable results were found only when dyeing by very light colours was tested and when the effluent conductivity was higher then 3,000 µS/cm. A much better purified wastewater is obtained in a full-scale recycling plant near Florence (Comodo *et al.*, 1993), which supplies textile industries that mainly process low quality wool. (Average values of the constituents in the reused water are: hardness = 300 mg $CaCO_3$/l, conductivity = 2,000 µS/cm; COD = 40 mg/l; Absorbance 426 nm = 0.02; anionic surfactants = 0.21 mg/l, non ionic surfactants = 0.26 mg/l.)

In the Como district, the characteristics of the recycled effluent must be very good (Table 2), first because of the very high quality of the textile production and secondly because the reference standard to compare the polished effluent is the Lake Como water (TSS = 0.32 mg/l, COD = 4 mg/l, hardness = 90 mg $CaCO_3$/l, conductivity = 200 µS/cm; absorbance = 0). Hardness, however, is not a limiting parameter for the reuse (note the high value reported in Table 2), because the factories have their own softeners and because only one third of the water used by the local textile industry must be softened.

Table 2. Required characteristics for the water to be recycled

Parameters	Units	
pH		7-8
Hardness	mg $CaCO_3$/l	270
Conductivity	µS/cm	1,800
Colour	426 nm absorption	0,01
TSS	mg/l	10
COD_{tot}	mg O_2/l	30
Anionic surfactants	mg MBAS/l	0.025
Non-ionic surfactants	mg BiAS/l	0.5

Quality control tests have been carried out during the research programme by a specialised laboratory of the Como Textile Association to verify the suitability of some among the polished effluents, after partial softening, as process water in some textile operations. The characteristics of the effluents are reported in Table 3. They were used, after softening, for scouring and dying (acid, reactive and disperse dyes and light medium and dark hues) silk, viscose and polyester. The results were considered to be fully acceptable, except for silk scouring with effluent A, because only partial removal of serine from the fibre was obtained. However, these results might be ascribed to the residual hardness, which was higher than other samples, rather than to an organic content higher than acceptable (see Table 2).

Table 3. Characteristics of the effluents used for of silk, viscose and polyester scouring and dying

Parameter	Effluent A	Effluent B	Effluent C
PH	7.52	8.10	7.9
Hardness (mg $CaCO_3$/l)	29	3	1.4
Conductivity (µS/cm)	1,740	1,900	2,050
COD (mg/l)	38	31	42
Absorbance 426 nm	0.002	0.001	0.003

POLISHING SCHEMES TESTED

Several polishing schemes based on advanced wastewater treatment (AWT) have been tested at pilot scale on the Como area effluents. As described by Bonomo et al. (1995) and Rozzi *et al.* (1997) both granular activated carbon (GAC) and nanofiltration (NF), after a suitable pretreatment (coagulation, flocculation and settling, CFS), make it possible to reach the desired water quality. The addition of ozonation prior to GAC or nanofiltration further reduces colour and surfactants, but with a significant increase in capital and operation costs. Some data related to the experimental tests are reported here.

GAC adsorption

Three GAC filters were tested at the Alto Lura WPT plant: a 20 m^3 volume column and two 300 dm^3 volume columns. The characteristics of the activated carbon were: origin = peat; backwashed density = 230 g/l, ash content = 7%, porosity = 1,2 cm^3/g, iodine number = 800 mg/l, molasse number = 500.

The columns were fed on wastewater coming from the ozonation unit of the Alto Seveso plant at empty bed contact time (EBCT) on the order of 30 minutes. The large filter (A) and a small one (C) were directly fed on the ozonated effluent, which was quite high in oxygen (up to 20 mg/l DO) and promoted biological growth on the carbon surface. The second small column (B) was fed at reduced oxygen concentration and was periodically sterilised to provide a control in which the removal process was adsorption in contrast to the combination of biodegradation and adsorption (referred to here as BIO GAC) in columns A and C.

In Table 4 the preliminary experimental results (Rozzi *et al.*, 1997) obtained on those pilot facilities are reported. From the table it may be observed that the removal efficiency of the BIO GAC filters was not appreciably higher than carbon adsorption alone, probably because of the limited operating period of the columns and the difficulty to keep adsorption control filter strictly anoxic. The fraction of the exhausted carbon in the 20 m^3 column after 55 days was of the order of 30% - 35%. The total amount of water filtered was 33,372 m^3, equal to 1,604 m^3 water/m^3 GAC. The total COD removed was approximately 2,000 kg, with a specific removal ratio of 0.419 kgCOD/kgGAC.

Table 4. Quality of feed and effluent of GAC filters and corresponding percentage removal

		pH	COD mg/l	TOC mg/l	TSS mg/l	Abs. 426 nm 0.01 optical path	Abs. 550 nm 0.01 optical path	Abs.660 nm 0.01 optical path
A	In	7.7	132	18.6	22	0.061	0.029	0.011
	Out	7.9	77	12.5	6	0.039	0.017	0.007
	Removal %		42	32	73	36	41	36
B	In	7.6	135	16.6	19	0.052	0.022	0.009
	Out	7.7	72	9.0	6	0.028	0.013	0.005
	Removal %		47	46	68	46	41	44
C	In	7.6	135	20.3	19	0.052	0.022	0.009
	Out	7.9	67	11.7	5	0.024	0.012	0.005
	Removal %		50	42	74	51	45	44

Membrane processes

Three types of membranes (spiral wound module) were used at pilot scale: ceramic microfiltration membrane (MF) with a nominal cut-off of 300,000 daltons in a cross-flow module; composite polyamide nanofiltration (NF) membrane (150 daltons nominal cut-off, 96% minimum rejection on $MgSO_4$) and modified polyamide reverse osmosis (RO) membrane (93% minimum rejection on NaCl).

The MF ceramic module was tested as pre-treatment to the NF or RO membrane in order to lower concentrations of colloids and suspended solids, to reduce fouling problems and maintain sufficiently long operating cycles. Axial flow velocity was fixed at 3 m/s. It was possible to filter the effluent for 5 days (8 hours operation each day) with a short washing (about 5 minutes) with tap water at the end of each run, keeping the MF permeate flux at the selected value, i.e. 102 l $m^{-2}h^{-1}$. Up to 50 mg Al as coagulant had to be added to obtain satisfactory performance. The recovery of the module permeability after the short washing and the 16 hours night time interruption in operation is remarkable. Using the value of the permeability from the beginning of the previous day run as the reference value, this recovery was of the order of 70%. The average performance of the MF module operating according to the above conditions is reported in Table 5. As could be expected from the characterisation of the wastewater by a series of ultrafiltration membranes of different molecular weight cut-off, the ceramic MF module was able to achieve a reduction of about 50% in total COD.

Table 5. MF feed and permeate quality

	Feed				Permeate			
	Total COD mg/l	Sol. COD mg/l	TSS mg/l	Absorbance 426 nm	Total COD Mg/l	Sol. COD mg/l	TSS mg/l	Absorbance 426 nm
Mean value	125.7	95.3	26.6	0.1137	65.13	55.79	4.21	0.0689
St.dev.	26.4	20.35	12.9	0.00228	13.08	11.26	1.66	0.0101

The permeate obtained from the ceramic MF module was stored in a tank and then fed to the NF pilot plant unit. The NF pilot plant was operated in batch mode, both with constant and increasing feed concentration. The test were carried at a feed pressure of 10 bar, with a feed flow rate of 250-350 l/h. A concentration factor of 5-6 was achieved with a retentate recirculation rate of 1,500-2,000 l/h. Permeate and retentate discharge were respectively 150-210 and 100-150 l/h.

As predicted, no major fouling problems occurred and membrane cleaning was required only after 120-150 hours of filtration. Permeate quality was always high enough to meet standards for reuse, as can be observed from Table 6. This research confirmed that reuse secondary effluent for textile industry purposes is possible after a 2 stage (MF+NF) membrane filtration without any other pre-treatment.

The RO membrane has been tested in continuous feeding on the effluent of ozone treatment using different feed pressures (5, 10 and 30 bar) with a permeation rate ranging from 42.7 to 5.0 l $m^{-2}h^{-1}$. Tests were stopped when the module permeate flux decreased to less than 70% of the initial value. The operation time was very short because the colloids in the feed water were still too high and the Silt Density Index was SDI>10 while it should be lower than 5. The permeate quality is very high as reported in Table 6. A washing cycle consisting of acid and alkaline solutions allowed full recovery of permeate flux.

Table 6. Quality of NF and RO feed and permeate

Parameter	Nanofiltration – Constant feed concentration			Reverse Osmosis		
	Feed Average	Perm. Average	*Reduction %*	Feed Range	Perm. Range	*Reduction %*
CODtot [mg/l]	76.5	24	*68.63*	134-172	7-10	*94-95*
CODsol. [mg/l]	72.0	24	*66.66*	-	-	-
TOC [mg/l]	16.0	2.1	*86.88*	14-27	2-3	*85-90*
TSS [mg/l]	5.5	0	*100.00*	12-32	0	*100*
Hardness [mg $CaCO_3$/l]	180	66	*63.33*	-	-	
Conductivity [μS/cm]	1,480	880	*40.54*	2,000-2,400	135-400	*83-93*
Absorbance 426 nm	0.081	0.003	*96.30*	0.019-0.037	0.002-0.008	*78-89*
Absorbance 558 nm	0.049	0.001	*97.96*	0.010-0.013	0.000-0.007	*46-100*
Absorbance 660 nm	0.017	0.000	*100.00*	0.005	0.000-0.002	*60-100*

EVALUATION OF WASTEWATER RECYCLING

In addition to the identification of the polishing schemes needed to reach the desired water quality, several other considerations play a role in determining the feasibility and the optimal solution for wastewater recycling in this area. In the following, the application of the three polishing schemes previously identified

(CFS + GAC, MF + NF, MF + RO) to the effluent of the Alto Lura plant will be discussed. The major requirements are for constant water quality and reliability of the water supplied to the factories. As already mentioned, the textile factories of the Como district produce very high quality goods and therefore they can not tolerate significant changes in the process water that could interfere with dyeing and printing and reduce the quality of the products. From this point of view, the schemes which include a membrane treatment are obviously preferable because they maintain constant characteristics of the effluent. Another aspect to be considered is the possible scaling or corrosion of the industrial aqueduct pipes due to the mixing of the water coming from Lake Como and the effluent of the polishing schemes, which has different pH and salt contents. Last but not least, recycling and reuse of the purified effluents within the textile factories increases the concentration of non-biodegradable organic compounds (i.e. refractory pollutants) and of inorganic species (mainly salts) in the industrial wastewater and therefore in the final effluents of the treatment plants. This will result regardless of the advanced treatment process. Altough membrane processes make it possible to obtain the best quality water, they also produce concentrates which contain most salts and residual organic pollutants originally in the feed of the membrane modules. These concentrates must be disposed of and, because of their high flow rate, there is no other sustainable alternative than the discharge back to the plant. The refractory COD might be reduced by appropriate chemical oxidation such as ozonation, to increase the biodegradable fraction before being recycled to the secondary biotreatment, but the salts may not be abated unless very expensive processes such as electrodialysis or evaporation are used. In other words, the treatment schemes which include the recycle and reuse within the textile factories of an appreciable fraction of the industrial effluents make it more difficult to reach the required standards for the final effluents even when a post-treatment is added to the concentrated wastes before final discharge.

Relevant mass balances in terms of salinity and COD have been derived to evaluate the effects of purified water recycling. On the basis of the ionic composition, a salinity to conductivity ratio of 0.55 $mg \cdot cm \cdot l^{-1} \cdot \mu S^{-1}$ may be assumed for both lake water and effluents. As depicted in Figure 1, the industries are partly supplied with recycled water and partly with Lake Como water. The total amount of water used by the textile industries and discharged into the sewer is assumed to remain constant at the present value. Part of the effluent is treated with the advanced processes previously identified and then recycled to the industries. In terms of salinity, the average increase in concentration of the industrial discharge (defined as ΔS) over that of the supply water is calculated to be about 1,160 mg/l. This amount is due to the chemicals used in the process and does not include the brine produced by the softener that is not discharged into the sewer. The partial softening of the water supply does not modify appreciably the salt content of the water (there is a slight increase due to the exchange of Ca and Mg with Na that is neglected in the following calculations). Case A refers to the use of the scheme CFS + GAC. The following equations report the mass balances in terms of salinity referred to the industry and the treatment plant (symbols and assumed values are reported in Figure 1) and allow the determination of the industrial wastewater and plant effluent concentrations (Si and Se) as a function of the recycled flow Qr, where Se and Sr are equal:

Industry:	Salinity: $Qi \cdot Si = Qr \cdot Sr + Q_L \cdot S_L + Qi \cdot \Delta S$ -	Flow: $Qi = Qr + Q_L = 18{,}750\ m^3/d$
Plant:	Salinity: $Qe \cdot Se = Qi \cdot Si + Qd \cdot Sd - Qr \cdot Sr$ -	Flow: $Qe = Qi + Qd - Qr$

Case B refers to the use of an advanced treatment scheme based on membrane separation i.e., MF + NF or MF + RO. In this case Sr will be equal to $(1-\eta) \cdot Se$, with η representing the salt removal efficiency of NF or RO respectively. The salinity mass balance equation for the industries is the same as that in case A, while the corresponding mass balance equation for the plant is: $Qi \cdot Si + Qd \cdot Sd + \eta \cdot Se \cdot (Qr + Qc) = (Qe + Qr + Qc) \cdot Se$.

Figure 2 reports the trends of Se and Sr for the three schemes examined as a function of the recycling flow, expressed as a percentage of the total effluent flow. In case of using NF or RO, Se would increase more sharply than in the case of using GAC, particularly in case of recycling more than 40% of the influent flow to the plant. The Italian standards for the discharge in surface water do not limit the salinity but limit chloride (1,200 mgCl/l) and sulfate (1,000 $mgSO_4/l$). These compounds represent approximately 35% and 11% of the salinity of the effluent of the plant and therefore the salinity of the effluent should not be higher than 3,400 mg/l in order to comply with the Italian standard.

Recycling of part of the discharged flow to the industrial aqueduct might also be a concern with regard to the increase in the salinity of the effluent and of the water streams due to the very small dilution of plant effluent at the discharge point. The related detrimental environmental impact has not yet been considered.

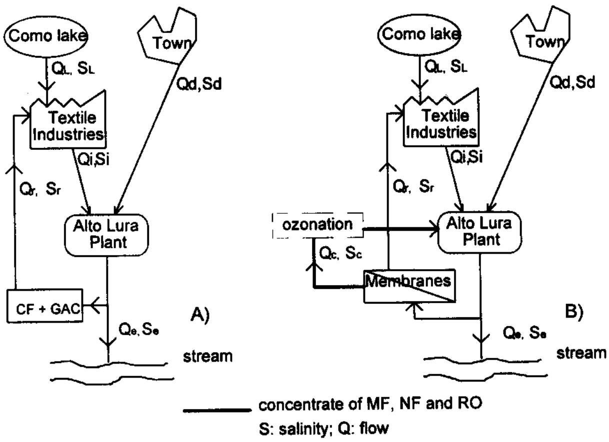

Figure 1. Salinity balances in case of recycling water treated with CFS + GAC (case A) or with membranes (case B) (Sd = 270 mg/l; SL = 110 mg/l; Qi = 18,750 m^3/d; Qd = 6,250 m^3/d; Qc/Qr = 0.2, η_{NF}: 0,4, η_{RO}: 0,88).

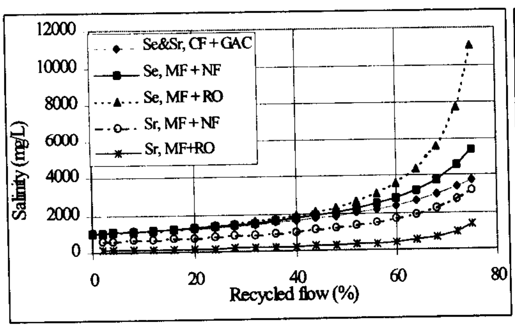

Figure 2. Salinity of the effluent (Se) and recycled water (Sr).

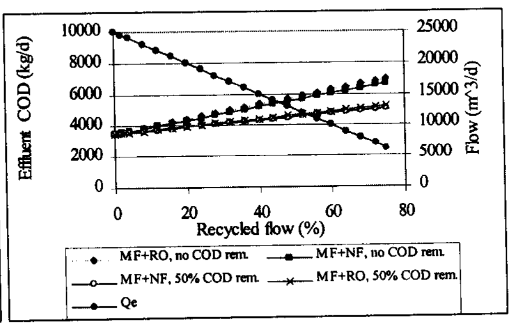

Figure 3. COD load and flow discharged as a function of recycling flow, in case of MF + NF and MF + RO schemes.

Figure 3 reports the discharge flow and the COD concentration of the effluent of the plant as a function of the recycled flow for the MF + NF and MF + RO treatment schemes. 50%, 68% and 85% COD removal efficiency were assumed for MF, NF and RO respectively. Two hypothesis are considered: a) the COD of the retentates is not biodegraded in the plant due to the fact that it is composed of the non biodegradable fraction of the influent COD that was not previously removed; b) a 50% removal of the COD of the retentates is achieved with ozonation of the retentates, which remove part of the COD but above all increase their biodegradability.

The cost of the industrial aqueduct water supply is around 0.25-0.4 ECUs/m^3, depending on the location of each factory. Energy to pump the water from the lake to the factories located on the Brianza hills over the lake basin divide is the major cost factor.

A rough estimation of the capital and operation costs for the three AWT schemes showed that the specific cost of the sequence CFS + GAC is around 0.35 ECUs/m^3 and is therefore comparable with the cost of the current source water. The schemes based on the membranes, is at present much higher (of the order of 1.3-1.5 ECUs/m^3) due to the high cost of the MF and NF membranes.

CONCLUSIONS

Several advanced treatment processes allow recycle into the factories of purified textile wastewater produced from centralized treatment plants fed on mixed industrial and domestic wastewaters.

The scheme based on a conventional pretreatment (clarification and/or filtration) followed by granular carbon adsorption produces an effluent with a lesser but nevertheless acceptable quality. The residual organic pollution in terms of COD, colour and surfactants does not interfere with the textile processes, as evidenced by specific tests performed by a laboratory of the local Textile Association.

Implementation of water recycling AWT based on membrane separation would be a preferable option in the textile district of Como because these schemes provide a very constant quality effluent, that is partly or almost completely softened and free of colour and surfactants.

The main drawbacks of membrane AWT are: a) the cost, which is still quite high and b) the increased impact of the retentate flow on the conventional treatment plants and on the recipient water bodies. In fact, the increase of conductivity and COD due to the need to dispose of concentrate in the final effluent discharge heavily affects the fraction of the total effluent flow that may be recycled to the factories.

At present, the best solution for the textile recycling as far as sustainability is concerned seems to be a process including GAC, possibly preceded by an ozonation step, which is needed in any case because of the very strict limits on colour and surfactants imposed at the discharge. However, this situation may change in the future because membrane costs are rapidly decreasing and high performance modules are being designed and commercialized.

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