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Eco-Efficiency: A Prerequisite for Future Success

Manuel Glauser* and **Peter Müller**

Abstract. At *Roche*, eco-efficiency – the optimal use of material, energy, human resources, and capital to supply innovative products to the market – is considered as a prerequisite for business success in the future. Group-wide activities to rise eco-efficiency are focussed on manufacturing processes rather than on product design, since chemical composition and structure of the *Roche* pharmaceutical products are defined by the desired therapeutic effect, in contrast to commodities. Three examples of currently operating eco-efficient processes at *Roche* are described. They cover main areas for further improvement of both environmental performance and economical benefit: less material intensity and waste for disposal, energy recovery, minimization of water consumption. Furthermore, four different indicators currently used at *Roche* to track environmental performance and eco-efficiency are presented: the *Roche* Environmental Impact Figure (REIF), the *Roche* Energy Rate (RER), the *Roche* contribution to man-made global warming (CO_2 equivalents), and the Eco-Efficiency Rate (EER). These key indicators are used as a basis to recognize weaknesses and strengths, to take decisions for improvement, to set environmental targets, and as management information.

1. The Concept of Eco-Efficiency: Development and Definition

Until about thirty years ago, it was the accepted economic theory in the industrialized world that the growth of wealth was directly linked to the consumption of resources, especially energy. It took some time before it was realized that the concept of ever-growing consumption, coupled with the growing production of wastes, would inevitably lead to environmental collapse. As a consequence, legislators set limits for emissions into soil, water, and air, and the response from industry was the construction of so-called 'end-of-pipe' plants to control their emissions. Expensive wastewater treatment plants, waste incinerators, and waste-air scrubbers were built to remove pollutants from industrial waste streams before they were discharged into the environment. However, with the ongoing increase in the consumption of resources, ever stricter emission limits had to be set to meet environmental targets. As a consequence, end-of-pipe installations had to be modernized and became even more expensive. It became apparent that this strategy could not be the final solution. It was at this point in the middle of the 1980s that the first steps towards eco-efficiency were undertaken.

What is eco-efficiency? The World Environmental Center (WEC) defines eco-efficiency as 'obtaining economic and ecological efficiency through the optimal use of all inputs, *i.e.* raw materials, energy, water, human resources, and capital to supply products and services to the market. Hence, a totally eco-efficient process would not generate wastes or emissions'. Although waste-free chemical processes remain an unachievable goal, eco-efficiency is a useful concept for the optimization of economic and ecological goals. It is a strategy:

- to get more environmental protection per capital invested,
- to save money while improving environmental performance,
- to add value while reducing consumption of resources and the generation of pollution.

Obviously, this is a win-win concept, and the examples below show that it can work in practice.

In the chemical industry, efforts to improve the input side of a synthesis in order to save raw materials and costs have been undertaken for a long time. However, costs on the output side, *e.g.* for waste treatment and disposal, were usually not allocated at process level. Therefore, one key route to become more eco-efficient is by stepping up production-integrated environmental protection measures. This means to avoid, reduce, and, where ecologically and economically feasible, recycle waste by-products at source. Such improvements are normally less capital-intensive than end-of-pipe technology and often lead to higher yields, as well as less waste. Thus, such improvements also entail economic benefits. To cut a long story short, production-integrated environmental protection is one of the main prerequisites in raising eco-efficiency.

Correspondence: Dr. M. Glauser
Corporate Safety and Environmental Protection
F. Hoffmann-La Roche Ltd.
CH–4070 Basel

2. Examples of Eco-Efficiency at *Roche*

Roche develops and manufactures highly innovative products which serve to prevent, diagnose, and treat diseases and promote general well-being. Chemical composition and structure of the *Roche* products are defined by the desired therapeutic effect. The issue of environmental compatibility of *Roche* products is not critical – in contrast to commodities – since they are manufactured in rather moderate amounts and normally consumed by man and animals. However, the eco-compatibility and eco-efficiency of the manufacturing processes are of prime concern.

Of course, the principle of eco-efficiency was not developed overnight at *Roche*. According to its policy on safety and environmental protection, *Roche* is committed to a continuous improvement of its environmental performance. The change from a more reactive attitude of pollution control by end-of-pipe technology to the proactive attitude of eco-efficiency by process-integrated improvements developed gradually over the last ten years. The following three examples of eco-efficient processes currently operating at *Roche* underline this development.

2.1. *New Process Design*

The pharmaceutical active substance DMP, a morphinan derivative, is used as a cough remedy in syrup, drop, and tablet form. In the final steps of the former production process, large amounts of both starting materials and energy were consumed and substantial quantities of wastes were produced. This unsatisfactory situation led to a systematical review of the process steps and the introduction of new process technology and chemistry in 1986.

In the old process, a ring-closure reaction was performed using an extremely aggressive mixture of hydrobromic and phosphoric acid. A reaction temperature

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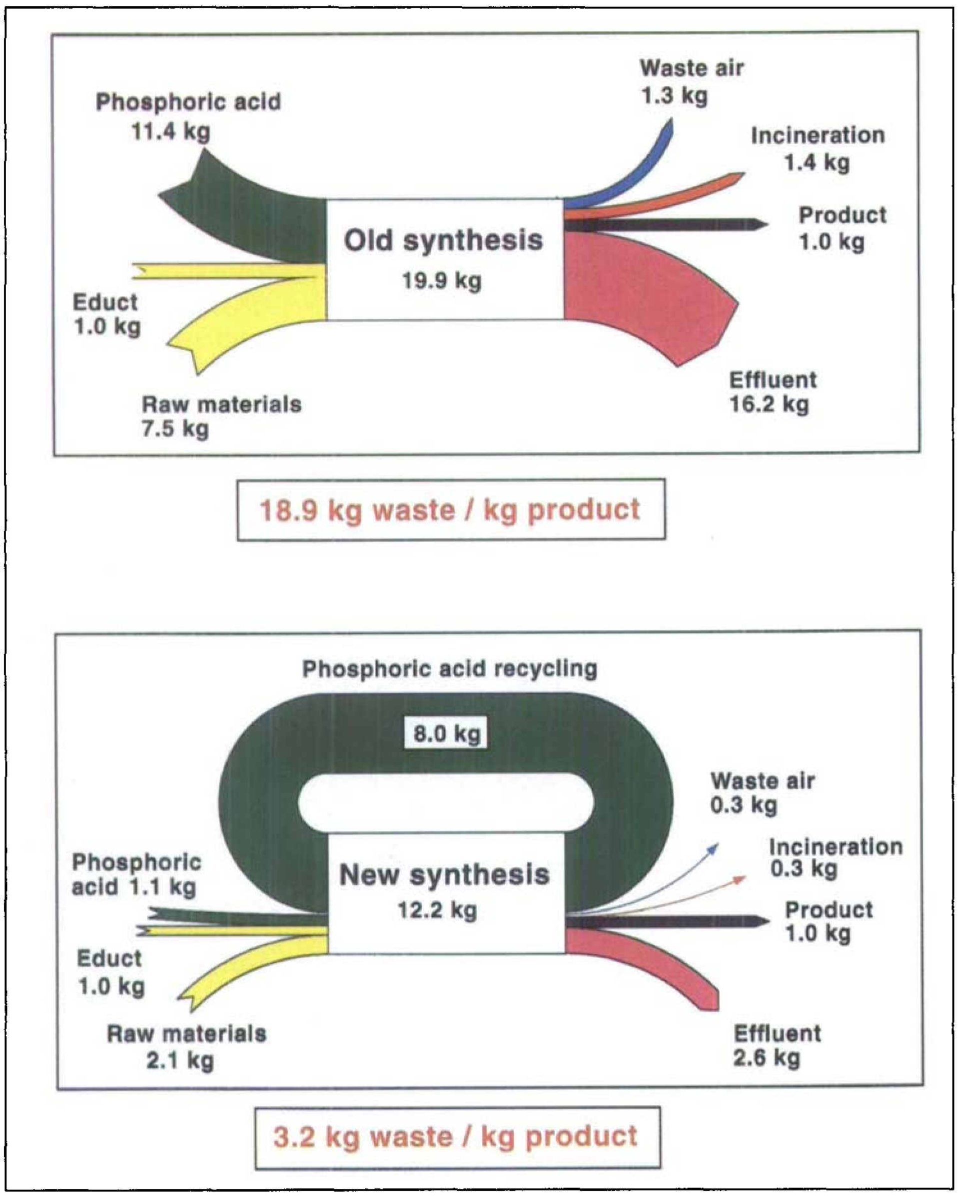

Fig. 1. *Step design in cough-syrup production.* Material balance comparison of old *vs.* new synthesis.

around 100° and a reaction time of several days were required for complete conversion. Several by-products were formed in this process, *e.g.* methyl bromide which was emitted to the atmosphere. After completion of the reaction, the mixture of acids and by-products had to be separated from the product, neutralized, and discharged as effluent; it could not be reused. The microorganisms in the wastewater treatment plant (WWTP) had to deal with a heavy load of ammonium phosphate. For every kilogram of active substance, the process produced *ca.* 19 kg of waste products for disposal (*Fig. 1*).

In the new process, the reaction is carried out in 100% phosphoric acid slightly above room temperature. After the addition of water, the product is extracted with toluene. The aqueous phosphoric acid is then concentrated and *ca.* 88% reintroduced into the process; in addition, the toluene is also recycled. With this process, only 3.2 kg of waste are generated for every kilogram of active substance, representing a reduction of waste of over 80% (*Fig. 1*). The air emissions have been significantly reduced and methyl bromide is no longer formed. Since 1994, also no volatile organic compounds (VOCs) are emitted any more into the air from this process, as the remaining 0.3 kg of non-halogenated VOCs are disposed of in the central waste-air incinerator at the Basel site. The residual 12% of waste phosphoric acid is fed as a nutrient to the microorganisms of the WWTP. A separate pipe conducts this phosphoric acid from the plant in the desired quantities directly to the biological step of the WWTP.

It goes without saying that the drastic reduction of raw materials and generated waste of these redesigned process steps led to significant savings of manufacturing cost. Additionally, the lifetime and maintenance of the reaction vessels have also been improved significantly due to the less corrosive reaction conditions. Furthermore, the production capacity was significantly increased due to the shorter reaction times.

2.2. *Recovery of Waste Heat*

Roche is also trying to apply the principle of eco-efficiency in the area of energy supply and consumption. A lower fossil-fuel and electricity consumption reduces purchasing costs and leads to less air pollution as a result of combustion in the boiler house.

At *Roche* Basel, water from the Rhine river is used for cooling purposes in production processes and air conditioning/refrigeration units. The heat-loaded cooling water at *ca.* 17° (in winter time) is collected in a separate pipe system (*Fig. 2*). As the cooling water does not come into contact with chemicals of the reaction and purification processes, it is not contaminated, and before 1993, it was discharged together with the unused thermal energy into the Rhine.

On the other hand, fresh air is needed to ventilate and heat four laboratory buildings, close to the waste cooling-water outlet into the Rhine. During winter time, the air was heated entirely by means of steam, generated with oil and natural gas in the boiler house.

In 1993, a new heat-recovery unit has been commissioned which enables *Roche* to use the waste heat from the cooling-water system to preheat the fresh air for the four laboratory buildings (48, 68, 69, and 70), containing in total *ca.* 800 rooms. The unit runs for *ca.* 6400 h per year, when ever the outside air temperature is below 15°.

The whole heat-recovery system consists of two circuits (*Fig. 2*). In the primary circuit, waste cooling water of 17° is pumped out of a collecting basin (building 33). The energy is transferred to the secondary circuit (water/glycol mixture 30%) by two plate heat exchangers. In the secondary circuit two speed-controlled centrifugal pumps deliver the water/glycol mixture of 15° to the four buildings through a closed pipe system. The energy is transferred to the fresh air of the buildings by air/water heat exchangers. The unit is designed to run without continuous local supervision. The air/water heat exchangers in the buildings can be disconnected from the secondary circuit according to the availability of and the demand for energy.

The environmental and economic benefits of this heat-recovery unit are remarkable:

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– Heat savings:	13 Mio. kWh/a
– Electricity savings:	0.4 Mio. kWh/a
– Reduction of emissions:	4200 t/a CO_2, corresponding to the amount emitted by *ca.* 450 single-family houses per year, 3–5 t/a NO_x
– Cost savings per year:	CHF 650 000
– Capital investments:	CHF 3 000 000

After an analysis of this successful pilot study, this system may be adopted in all other production buildings at *Roche* Basel, leading to a significant reduction of water consumption and to an overall efficiency increase for the cooling-water heat-recovery unit.

2.3. *Saving Water in Production*

As already mentioned above, *Roche* Basel requires large quantities of water for the cooling of chemical processes and the condensation of solvents in recycling columns. For this purpose, *ca.* 13 Mio. m^3 of water from the River Rhine and from *Roche*'s own groundwater wells are needed every year. In a first step, these have to pass a sand filter prior to being pumped into the different plants. The costs of water consumption and pretreatment are significant for the site.

Since October 1996, a pilot project has been running in a production building which consumes high amounts of cooling water. The new technical installations allow to save 75% of the water previously consumed during winter time and, in addition, save energy.

Until recently, cooling water was pumped from a central water tower throughout the building. After use, the cooling water, now 4° warmer, joined the main waste cooling-water stream of the site, passing the heat-recovery unit in winter time as described above, prior to be discharged into the Rhine (*Fig. 3*).

The interdepartmental energy-saving team of *Roche* Basel had the idea of mixing the cold fresh cooling water from the Rhine (6–18°, depending on the season) with the already warm waste cooling water in order to reduce water consumption during the winter months. As the production equipment is designed for a cooling-water temperature of 20°, a regulated average water temperature of 18° for cooling is also suitable during the colder periods of the year.

With the implementation of the new pilot study, cooling water is now circulating in a closed pipe system throughout the building (*Fig. 3*). A frequency-driven pump is adding the appropriate amount of cold fresh water to achieve a constant temperature of 18° in the cooling-water circuit. After the cooling process, the surplus waste cooling water at *ca.* 22° flows into the main waste cooling-water stream of the site and raises the temperature by 1°. This in turn allows for an increase in efficiency of the site cooling-water heat-recovery unit. The expected benefits of the pilot project in one building are:

- Cooling-water savings of 45% per year,
- 10% higher efficiency of the site cooling-water heat-recovery unit (savings of fossil fuels equivalent to the consumption of 45 single-familiy houses),
- electricity savings from water pumping due to a difference of 11 m in height between the admixing water pump and Rhine water-pump unit,
- overall cost savings of 180 000 CHF/a,
- capital investment: 750 000 CHF.

3. Indicators of Eco-Efficiency at *Roche*

Roche's goal is to develop and manufacture high-quality products with the best possible conversion of energy and raw materials and with a minimum of environmental impacts. In order to monitor continuous improvement in this area, data on 35 selected safety and environmental parameters from all the production sites in the *Roche* Group have systematically been

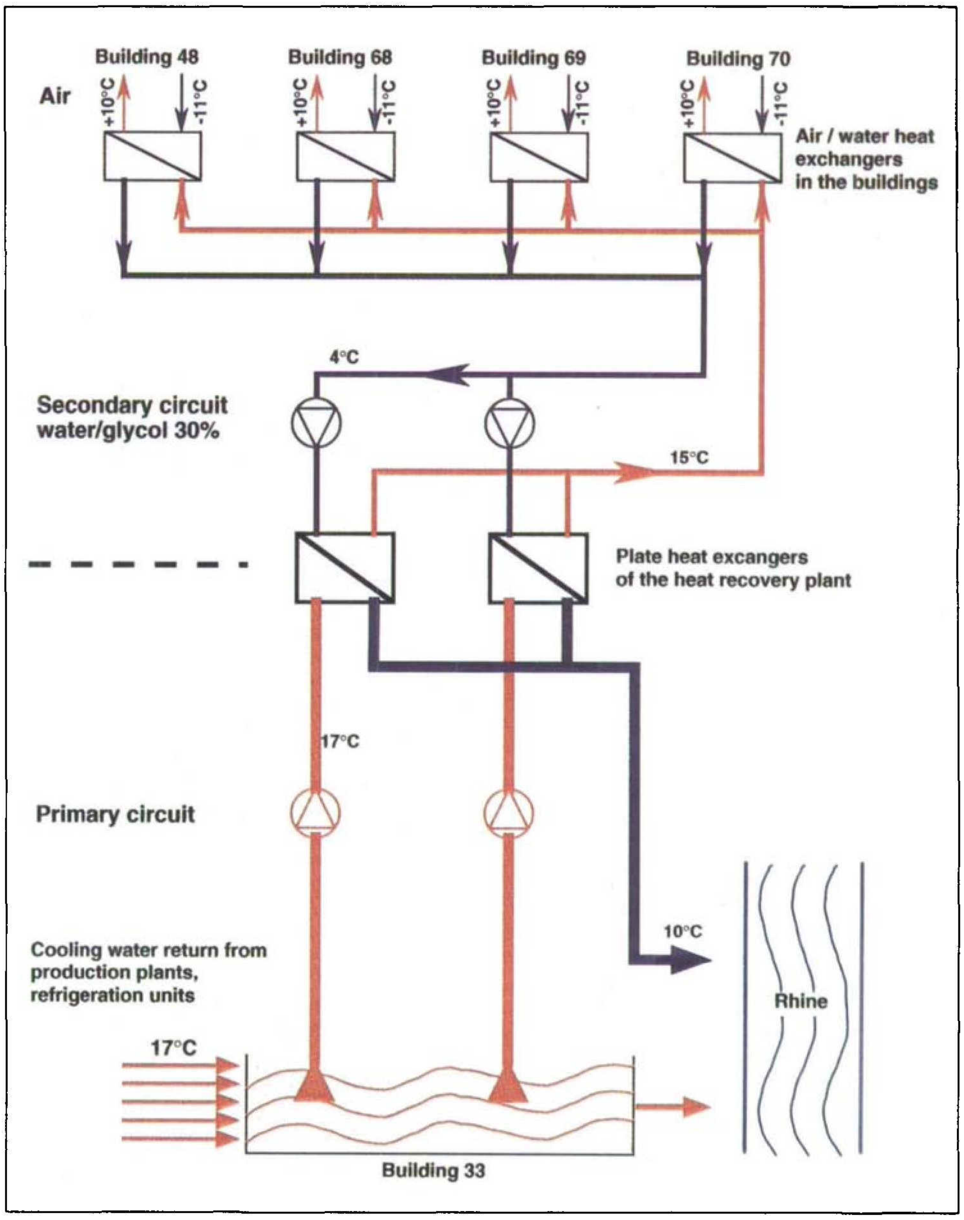

Fig. 2. *Cooling-water system – heat-recovery unit.* Schematic drawing of the heat-recovery unit at *Roche* Basel using the heat content of waste cooling water from production processes and refrigeration units to warm up the inlet air of four laboratory buildings in winter time.

gathered since 1992. These provide the basis for the calculation of indicators describing environmental performance and eco-efficiency. Four different indicators have been developed so far, which are used as a basis for recognizing weaknesses and strengths, to take decisions for improvement or to set environmental targets. The environmental performance indicators currently used at *Roche* are:

- the *Roche* Environmental Impact Figures (REIFs),
- the *Roche* Energy Rate (RER),
- the contribution to man-made global warming (CO_2 equivalents)
- the Eco-Efficiency Rate (EER)

The purpose and mode of application of these performance indicators are summarized in *Table 1*. REIFs and RER are used mainly internally, for production plants and sites. The global warming indicator and the EER are suitable at Group level as management information.)

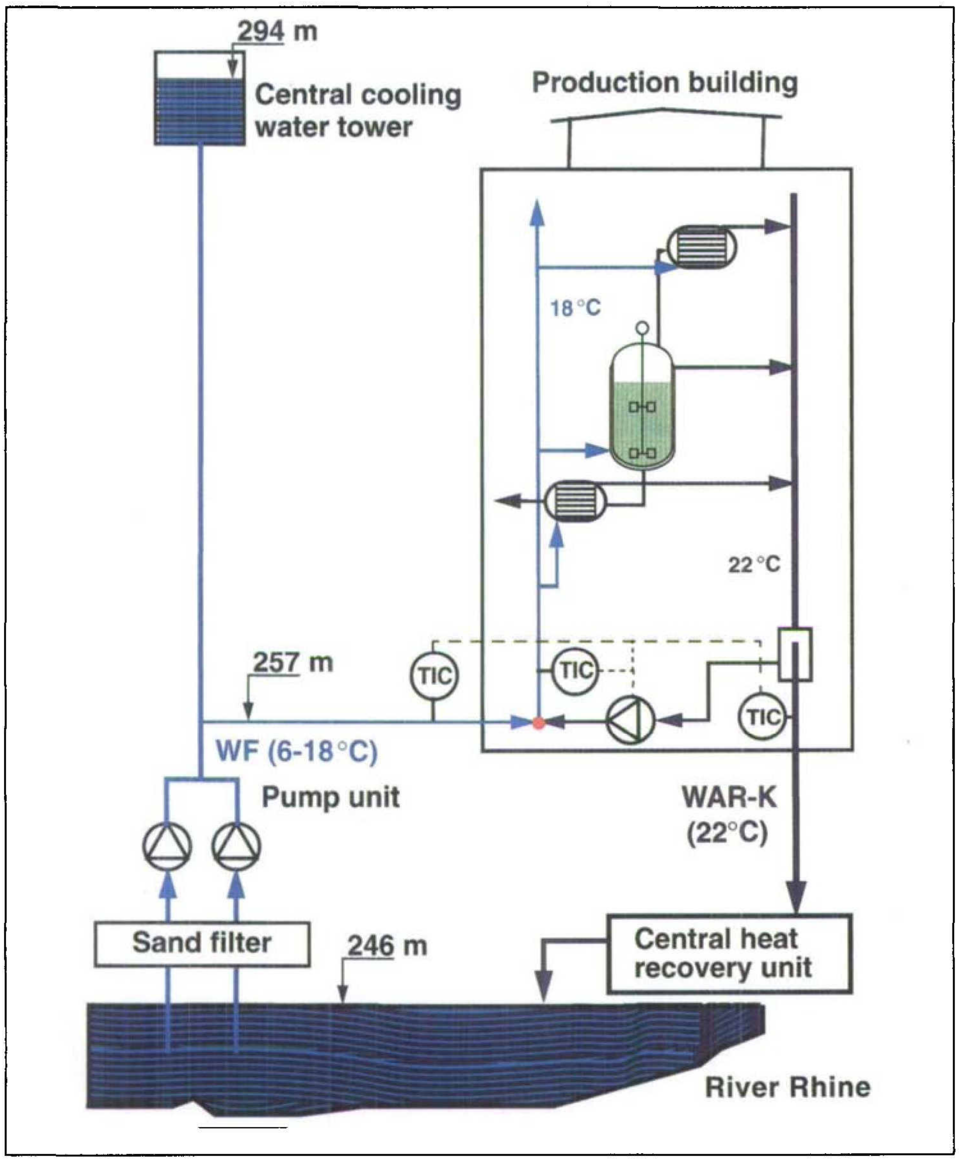

Fig. 3. *Admixing process for cooling water.* Schematic drawing of a pilot project in a production building at *Roche* Basel, which reduces cooling-water consumption by 45% per year. WF: fresh cooling water, WAR-K: waste cooling water, TIC: temperature control.

3.1. Roche *Environmental Impact Figures*

The REIFs represent the amounts of non-reusable wastes and emissions, before any end-of-pipe treatment, per kilogram of manufactured end product originating from production processes. The total REIF (Ws), *i.e.* the total amount of waste generated per kilogram of end product, is the sum of four compartmental REIFs (*Fig. 4*): per kilogram of end product the process waste air (Es), the waste disposed of by incineration (Is), the waste in the effluent prior to wastewater treatment (Fs), and the waste destined for landfilling (Ls).

The higher the total REIF of a production process, the lower the product yield and the higher the final environmental impact.

REIFs are suitable for internal monitoring of trends at process, plant, and site level. Another valuable application can be, together with material flow diagrams (*Fig. 1*), the comparison of similar processes designed to yield the same end product. As an example: the total REIF of the old cough-syrup synthesis was 18.9, compared to 3.2 for the optimized process.

3.2. Roche *Energy Rate*

Energy generation and consumption affect the costs of manufactured goods, as well as having an impact on the environment. Therefore, *Roche* pays great attention to an efficient use of energy.

The RER is a standardized yardstick for energy efficiency used at all sites of the *Roche* Group. The RER for a whole site divides total site energy consumption by the total number of employees and the tonnage of manufactured end products (*Fig. 5*). The lower the RER, the more efficiently energy is used. In order to address the different ranges of energy consumption by an employee, for the production of one ton of end product by chemical synthesis or pharmaceutical production (formulations) or by mixing operations, average weighting factors (k) have been determined as a reference. These different k factors reflect the existing *Roche* conditions, since they were defined after careful analysis of the energy consumption and production data of different sites.

We are aware that this approach leaves out energy-consumption factors, such as differences in product range, number of buildings to be heated, or climatic conditions, *etc.* However, the RER is easy to calculate even for smaller sites (*Table 2*), yields nondimensional figures of a manageable range, and helps to track energy efficiency increases from one year to the other within a site. RER determination for single production plants allows site management to recognize possibilities for further energy savings and also to monitor the success of already realized projects, independent of growth or decrease in production volume.

3.3. Roche's *Specific Contribution to Man-made Global Warming*

Roche accepts, within the limits of current scientific uncertainty, that global warming may become a serious environmental problem and that man-made emissions of greenhouse gases contribute to it.

Hence, one attempt to assess eco-efficiency at Group level is to compare group-wide greenhouse-gas emissions with the company's total sales. Sales reflect best the operations related economic performance. The emitted greenhouse gases of *Roche* into the atmosphere consist prima-

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Table 1. Roche *Environmental Performance Indicators: Purpose and Application*

Purpose	Application levels			
	REIFs	RER	CO_2 equiv.	EER
Recognition of trends → problem identification	process, plant, site	plant and site	–	–
Base for management decisions → improvements	Management information: plant, site, division	Management information: plant, site division	Management information: Group	Management information: Group
Control → monitoring results of projects	Material efficiency: process, plant, site	Energy savings in plants; site energy efficiency	–	–
Target setting	Plant, site, division	Plant, site, division	–	–
Benchmarking	Plant, site	Plant, site	Group *vs.* competitors; investment, banking, insurance	Group *vs.* competitors; investment, banking, insurance
Communication	S+E workshops; local S+E site reports	S+E-Group Report since 1994; S+E workshops; site energy-manager meetings	S+E-Group Report since 1994	S+E-Group Report since 1995

rily of carbon dioxide (CO_2) originating from the combustion of fossil fuels and of chlorofluorocarbon (CFC) and halon losses from refrigeration units and fire-fighting equipment. These emissions are converted into CO_2-equivalent units by multiplying each ton of emitted CFC and halon by 14000, a reference value for the greenhouse potential of the common CFC R11 compared to CO_2 [1]. The *Roche*-specific contribution to man-made global warming is expressed as emitted tons of CO_2 equivalents per 1 Mio. of CHF sales (*Fig. 6*).

The trend was downward in the early 1990s, but reversed in 1995 due to the integration of environmental data from new sites recently acquired by *Roche* and the influence of currency exchange effects.

3.4. *Eco-Efficiency Rate*

In order to measure the overall eco-efficiency at a corporate level, another indicator combining ecological and economic parameters was created: the Eco-Efficiency Rate (EER). The EER develops proportionally to sales and in inverse proportion to environmental impact and to expenditure for environmental protection (*Fig. 7*). The EER can be improved either by doing more, *i.e.* increasing sales from a constant level of environmental expenditure and damage, or by using or impacting less, *i.e.* consuming less raw materials and thus reducing environmental impact while keeping sales and environmental expenditure constant.

The 'environmental damage', as a measure for the environmental impact of *Roche*'s activities, is calculated by multiplication of the amount of each of the eight selected pollutants by the appropriate

- RM = P + W + BP
- W = E + I + F + L

RM = Raw materials
P = End products
W = Total waste before end-of-pipe treatment
BP = Valorized by-products
E = Waste air
I = Waste to incineration
F = Effluent to WWTP
L = Waste to landfill

$$\frac{W}{P} = \frac{E}{P} + \frac{I}{P} + \frac{F}{P} + \frac{L}{P} \longleftrightarrow W_s = E_s + I_s + F_s + L_s = \mathrm{REIF}$$

(specific waste figures)

R_s = Raw material consumption / kg end product

Fig. 4. Roche *Environmental Impact Figures (REIFs) – Definition.* The REIFs represent the amounts of non-reusable wastes per kilogram end product of a production process prior to any treatment. The output waste streams E, I, F, L indicate the route of disposal. WWTP: wastewater treatment plant.

- [illegible]

  The RER is a nondimensional figure which expresses the relation between the total energy consumption of a site and the total amount of end products manufactured and the number of employees.

- Formula

$$\mathrm{RER} = \frac{\text{Total energy consumption (GJ/yr)}}{\text{Employees} \cdot k_M + \text{Chemical products (t)} \cdot k_C + \text{Pharma/mixing products (t)} \cdot k_P}$$

k_M = 100 GJ per employee and year
k_C = 100 GJ per metric ton of end product from chemical production
k_P = 6 GJ per metric ton of end product from pharmaceutical production or mixing operations

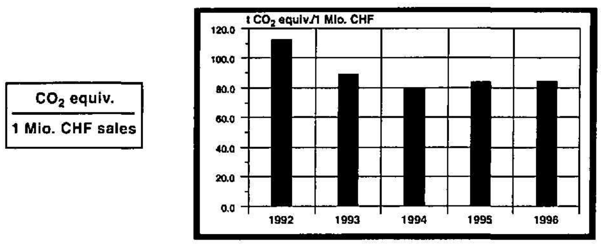
Fig. 5. Roche *Energy Rate (RER)*

Table 2. *RER – Calculation – Example:* Roche *Site X, Year Y*

Total energy consumption	=	150000 GJ/a
Number of employees	=	150
Manufactured end products from chemical synthesis	=	823 t/a
Manufactured end products from pharmaceutical production	=	268 t/a
RER (site X, year Y) = 150000/[(150·100) + (823·100) + (268·6)]	=	1.517

weighting factor (*Table 3*). The sum of all individually weighted damages gives the overall environmental damage used in the formula. These weighting factors are derived from emission and immission limit values of Swiss and international legislation and are standardized against CO_2 [2]. Their units are tons of CO_2 equivalents per ton of emitted pollutant. Therefore, the overall environmental damage is given in tons of CO_2 equivalents, *i.e.* environmental damage units. CFC and halon emissions are weighted by 14000 compared to CO_2 [1], as described above, and hazardous wastes with the factor of 1. Of course these weighting factors, derived from political decisions rather than from scientific facts, are open to debate. Nevertheless, we believe that the concept of linking sales to environmental expenditure and to environmental damage created gives a good idea of the efficiency of money spent for environmental protection.

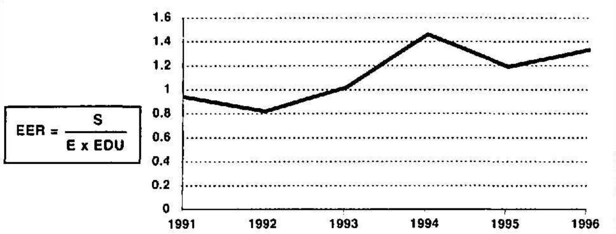
The EER is important less for its absolute level than for monitoring trends over time. It shows clearly that *Roche* became much more eco-efficient between 1990 and 1994, when the EER rose by 85% from 0.79 to 1.46. However, it declined by almost 20% in 1995, mainly because of outlays for site remediation and higher environmental impact due to the integration of environmental data from recently acquired new sites. In 1996, the trend was reversed again as a result of a sizeable reduction in groupwide VOC emissions.



	1992	1993	1994	1995	1996
Sales (Mio. CHF)	13000	14300	14700	14400	16000
CO_2 equivalents* (Mio. t)	1.459	1.273	1.180	1.211	1.347
CO_2 emissions (Mio. t)	1.025	0.971	0.984	1.002	1.125
CFC/halon emissions (t)	31.0	21.6	14.0	14.9	15.8

* CO_2 equivalents = CO_2 emissions + (CFC/halon emissions x 14000)

Fig. 6. *Specific contribution of* Roche *to man-made global warming*



	1991	1992	1993	1994	1995	1996
S (Mio. CHF)	11500	13000	14300	14700	14400	16000
E (Mio. CHF)	230	300	300	270	290	321
EDU (Mio.)	53	52	46	37	42	37

S = Sales
E = Expenditure on environmental protection
EDU = Environmental damage units (millions) = tons of CO_2 equivalents (millions)

Fig. 7. *Eco-Efficiency Rate (EER)*

Table 3. *EER – Weighting Factors and Calculation – Example:* Roche *Group 1995*

Emissions and wastes [t]			Weighting factors (t of CO_2 equivalents/t pollutant)	Weighted environmental damage (Mio. t of CO_2 equivalents = Mio. environmental damage units)
CO_2 [2]	=	1002012	1	1.00
CFCs/halons [1]	=	14.9	14000	0.21
NO_x [2]	=	2937	4154	12.20
SO_2 [2]	=	2294	4154	9.53
VOC [2]	=	4596	4154	19.09
TOC [2]	=	3912	82	0.32
Heavy metals [2]	=	2.6	16341	0.04
Hazardous waste[a])	=	90861	1	0.09
Total				42.48

Sales (Mio. CHF) = 14426
Environmental expenditure (investments + operating costs, Mio. CHF) = 291
EER = 14426/(291·42.48) = 1.17

[a]) Weighted as 1 for lack of reference.

4. Summary and Conclusions

Eco-efficiency is a prerequisite for business success in the future. *Roche* wants to supply its products to the market not only at the lowest possible cost – with the efficient use of raw materials and energy – but also with less impact to the environment. Some progress has been achieved so far, but further significant improvements can still be found.

At *Roche*, four indicators are currently used to track environmental performance and eco-efficiency: the *Roche* Environmental Impact Figures (REIFs) and the *Roche* Energy Rate (RER), mainly at process, plant, and site level, the contribution to man-made global warming and the Eco-Efficiency Rate (EER) at a corporate level. The last two indicators have recently found some interest among financial investors and bankers who are starting to incorporate environmental performance and risks as further aspects for the assessment of a company. A stronger international consensus on a few key environmental performance indicators would be helpful in the future.

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