European F-Gas Legislation

Oko Recherche Briefing Paper Response

Executive Summary

The following is a summary response by ESB to the Briefing Paper presented by Oko Recherche. The major points from the briefing paper have been highlighted with italics and the ESB response below it without italics.

Briefing Paper Comment (shown in italics):
"Various types of SF_6 free switchgears have existed in parallel to SF_6 switchgear for a long time. Currently, SF_6 solutions are commonly used, certainly when there are special constraints such as space, as it is the case in secondary distribution. In primary distribution, SF_6 free solutions always have had a significant market share."

ESB Response (shown in standard format)

ESB has undergone significant restructuring and renewed its strategic objectives to align with the low carbon future it aspires to be a part of. This set of 2030 goals for ESB is known as the "Brighter Future Strategy". It consists of major investment in clean renewable projects (such as Project RedBox Wind Farm Development - 8 Wind Farms totalling 400MW) and a shift away from fossil fuel based generation (such as Project Gemini – using renewable biomass in place of peat for Midland Power Stations). Part of ESB's new focus and strategic intent is to develop "a safe, smart, reliable network that enables the transition to low carbon".

ESB recognises the harmful effects of SF_6 releases into the atmosphere and is committed to reducing SF_6 loss in so far as possible while ensuring a cost effective, reliable and efficient electricity supply. As an essential services provider we must manage risk efficiently on micro and macro levels, particularly with regard to adopting new technology, and by considering a phased approach in consultation with the environmental stakeholders such as Dept. of Communications, Climate Action, and Environment (DCCAE). While ESB is focused on the requirements to decarbonise, it must also under its own strategy, ensure that any new measures are safe and new technology is reliable, particularly in an increasingly interconnected and complex network (and in critical times of national and global crisis and the current climate of the Covid-19 pandemic). ESB is involved in international working groups, researching non-SF_6 switchgear to develop experience in this area.

Any initiative or basis of decision on future use of SF_6 in switchgear must also bear reliability in mind. According to the F-Gas Regulation, alternatives to SF_6 gas equipment were to be assessed against the following four criteria (F-Gas Regulation Article 21, section 4):

a) Cost Effectiveness

b) Technical Feasibility

c) Availability of Reliable Alternatives

d) Energy Efficiency

Cost Effectiveness was not demonstrated for the banning of MV secondary switchgear as abatement costs were significant, particularly in comparison to the emissions reduction, as demonstrated also in the original 2011 EU Fluorinated Gases study by Oko Recherche. The obligatory use of non-SF_6 equipment in this way would be better applied elsewhere, with lower abatement costs as the costs per tonne of CO_2 Equivalent could actually be larger, even if based only on the cost of the equipment itself.

Technical Feasibility was not demonstrated; non-SF_6 MV Switchgear was not shown to be proven or reliable, as most of the products listed were at a very early stage in development without much market experience. Major issues involving partial retrofitting and extension of brown field sites with non-SF_6 equipment if a ban was introduced were not addressed which is of particular importance considering some common European issues (cost over the lifespan, technical performance, location and space restrictions, humidity and temperature range, security concerns, environmental and health risks of new gases, market risks, track record & experience).

Important Notes:

- MV should be defined as up to 36kV , not up to 52kV, in order to maintain coherence between directives - EU EcoDesign Directive, IEC 60038 and internationally - ANSi/IEEE 1585-2002.
- The briefing paper is right to distinguish between different voltage levels and especially between primary and secondary medium voltage (MV) distribution. There are huge differences in the availability of alternatives to SF_6 between these application areas.
- The focus of the paper should be on the secondary MV level since the report required according to Regulation (EU) No 517/2014 and subsequent political evaluation is on secondary MV.
- There is a lack of Toxicological Studies for the non-SF_6 switchgear; only limited studies have been completed which is not sufficient, particularly for assets installed in urban areas, close to living areas (or built into them in the likes of hospitals).

Reliability was not demonstrated with a long enough timeframe of proven performance. A larger volume is also required to be installed for at least ten (10) years to establish the required level of performance, durability and reliability (in comparison to equipment which is required for a service life of 40 years minimum).

In particular, the EU Procurement Directive needs to be met to allow for tendering and procurement of non-SF_6 equipment based on established international standards and market experience; this involves specific measurable market experience and definitive, agreed international criteria to be able to compare equipment and ensure the product is proven and reliable for its lifetime and to avoid risks to security of supply. Reliabiity is particularly important for emergency planning in times of national and global crisis (and the current climate of the Covid-19 pandemic).

Energy Efficiency (energy consumption during operation/use) is not a differentiator between SF_6 and non-SF_6 Switchgear so is not a relevant criterion for assessing a ban on SF_6 in Switchgear.

ESB experience has shown that SF_6 filled technology is the principal switchgear solution for technical, economic and operational reasons regardless of the size constraints; it requires lower maintenance, achieves higher ratings and low emissions (majority of equipment installed is hermetically sealed), and is safer due to low pressures (particularly at primary and secondary MV level with hermetically sealed units). SF_6 equipment design has developed over decades and is more standardised. Technical knowledge on SF_6 equipment has been developed in ESB and by the OEM's; it is well understood with more detailed/documented asset lifecycle processes.

On a utility and wider European level SF_6 gas is very well controlled, leaks are repaired, emissions are monitored/recorded and reported and monitoring has developed around strict control of emissions (specifically with pressure densimeter monitoring for HV equipment, above 36 kV, and alarmed at MV primary switchgear, up to 36kV). RMUs are sealed for life with negligible lifetime emissions (less than 0.1% emissions with installed capacity of 0.7 – 2.5 kg). And because of this SF_6 gas is widely used in Europe and remains the practically ideal solution.

Briefing Paper Comment (shown in italics):

"In recent years, the technological development of SF_6 free switchgear in GIS design for medium voltage switchgear in secondary distribution has made very good progress, providing alternative technologies that are comparable in many ways to SF_6 GIS systems."

"The time period required for alternatives to be ready for large scale application depends, among others, on the level of voltage and application area. It may be quite short for standard applications in primary distribution (MV switchgear in substations) and the most common RMU configurations (secondary distribution). It is foreseen that SF_6 free switchgear can become technically feasible and associated with reasonable extra investments for nearly all segments of MV applications within 2 to 4 years."

"The time needed for large-scale application in HV is longer, in particular for applications >145 kV where the scheduled development periods can last up to 5 years and the commercialisation can start only after this period. At all voltage levels some exceptional applications exist, where adequate alternatives are not yet readily available. These applications have to be evaluated on a case by case basis."

ESB Response (shown in standard format)

Products using SF_6 for insulation and for circuit breaker switching have reached a high degree of maturity; products and components are highly standardised, leading to competition among manufacturers, and lower purchase and maintenance costs. The SF_6 high voltage switchgear used today is highly performant and reliable. The industry possesses long and intense experience (more than 50 years) with this technology, enabling a high level of understanding and technical knowledge on safe handling regarding maintenance processes.

MV and HV equipment will require a minimum of ten (10) years for manufacturers to gear up to produce alternative non-SF_6 switchgear in the quantities required for commercial production, provided production models are tested and available. This time is required, to expand production and retool factories and reduce existing stocks of SF_6 switchgear (as now rendered unsaleable) should any restrictions be put in place. Utilities in Europe purchasing alternatives would require time for development of new specifications, extended time for tender and procurement processes, to physically alter/replace switchgear itself and make changes to designs in which the switchgear is used. Additionally, any projects already underway either need to continue or be altered, although altering these projects has consequences for customers in terms of both cost and delay.

At present, alternatives proposed are not proven with sufficient volume and are limited in supply (particularly at higher voltages) and require increased testing and pilot schemes to be able to demonstrate a robust track record which is comparable with utility experience of equipment already available in the market place. A limited number of equipment types are available, for example vacuum switchgear (ring main units at 10 and 20kV) are readily available however SF_6 gas is still required for insulation in this equipment. Vacuum circuit breakers are available up to approx. 40kV as indoor metal clad switchgear but only in limited numbers (ESB have limited experience). At higher voltages vacuum switchgear has not been used by ESB.

Longer terms will be required to prove the same robust track record for equipment in development and not yet available. Ten (10) years is the most likely time needed to carry out additional studies, in particular toxicology studies and gas developments, in order to open up the market, to carry out the development of equipment adapted to the needs of distributors and carry out large-scale pilots over long periods (10 years) for a robust track record.

In particular, the EU Procurement Directive needs to be met to allow for tendering and procurement of non-SF_6 equipment based on established international standards and market experience; this involves specific measurable market experience and definitive agreed international criteria to be able to compare equipment and ensure the product is proven and reliable for its lifetime and to avoid risks to security of supply.

Ten (10) years minimum is currently required at MV level (up to 36 kV) to gain market experience with products in sufficient volume on the market and to allow for competitors and products to enter the market (even though it has been noted that it is not cost effective to use non-SF_6 switchgear at MV level, given increased costs and low emission rates).

At least ten (10) years is required for HV and EHV (above 36 kV) for equipment currently available to be considered mature and ready for use (an additional 10 years is required from the date of commercial release for a robust track record).

If new technologies are installed in pilot projects over the different voltage levels in the early 2020s, manufacturers and ESB will be able to gain experience by the end of the decade. Once alternatives are available on the market in a sufficient number, from different manufactures (competitive market) and for reasonable prices, and ESB have trained their staff on handling the new technologies and established the necessary life-cycle processes, they will be able to buy and use these new technologies. New technologies must provide the same performance and reliability levels as switchgear using SF_6. Therefore, more pilot projects must be carried out, allowing manufacturers and users to get more experience and to continuously improve products, handling and recycling, and develop best practice standards and specifications around this equipment.

Utilities should be encouraged to use non-SF_6 switchgear where it is economic and technically feasible for a particular application on an individual basis. Such pilots are only likely for ‘greenfield’ situations where the new station can be designed to accommodate differently sized switchgear. This could be enacted using incentives to promote the use of non-SF_6 technologies in electrical equipment. ESB is involved in international working groups, researching and funding installation of non-SF_6 switchgear to develop experience in this area.

In any case, a transition phase for existing SF_6 switchgear must be granted until their end of life cycle is technically reached. It is more economic to avoid early removal from service as doing so before the end of an assets lifecycle would result in higher costs of ownership, and production processes required for new assets will increase the energy used and CO_2 emissions produced. SF_6 equipment has been used for decades and the processes involved during its life cycle are well documented. At end of life SF_6 equipment is decommissioned, SF_6 gas is recovered and materials disposed of in a controlled and phased manner. Early adoption of new equipment would involve disposal of good condition assets and management of bulk quantities of newly categorised waste equipment and SF_6 gas at significant cost. Installation of new assets would be costly, not to mention the ancillary design and planning required by the utility in addition to the disruption to customers.

<u>*Briefing Paper Comment (shown in italics):*</u>
"However, in general such a shift may result in an initial cost increase of up to 20%, raising to 30% in exceptional cases, compared to systems using SF_6. On the other hand, the costs related to the treatment of the equipment at the end of life, is likely to be lower compared to SF_6 equipment."

<u>ESB Response (shown in standard format)</u>

Costs from manufacturers are speculative at the moment and only consider the equipment cost itself while there are potentially much greater costs associated with installation and operation of new technologies. It is difficult for technology adopters to be able to perform any complete lifecycle or economic analysis, particularly as other key factors are not known and have not been considered to compare against SF_6 switchgear; for example life expectancy, costs of maintenance, technical training and additional handling/quality analysis equipment as well as other internal costs and times for homologation (time to adopt and develop processes for best practice management, specific company standards, policies and procedures).

Aside from the initial cost of the non-SF_6 switchgear, the operational costs (handling expertise and equipment, fault response/end of life considerations) could escalate with adoption of multiple non-SF_6 technologies. This could lead to a lack of operational expertise at critical points of the grid, overutilization of company resources and incomplete maintenance of switchgear. In addition, solutions using specific new manufactured gases might pose the problem of dependence (or even monopoly) on the supplier, which is not acceptable on an industrial level for a distribution system operator.

Older MV Switchgear at 10 and 20 kV (e.g. air, oil, resin etc) was used before SF_6 switchgear but was comparatively large and bulky. In contrast SF_6 allows for considerably smaller switchgear and hence a considerably smaller packaged substation. Secondary substations have been built around switchgear in densely populated areas where space is limited – to the point there is no physical room to replace SF_6 switchgear with others of larger footprint/dimensions. Such types of MV Substation are the norm in continental Europe and Ireland.

Should restrictions be put in place for SF_6 MV Secondary Switchgear without an alternative of the same dimensions or smaller, it would result in significant additional costs including replacement of the whole of the existing substation with a larger modular one to accommodate new larger equipment (existing cable connections dictate the site location and cannot be moved) and the purchase of the additional land beyond the curtilage of the ESB site (from the adjacent household/landowner) to accommodate this new substation. This would cost multiples of the entire cost of the modular substation. Other ancillary costs need to considered including labour, civils, and delays involving planning permissions (loss of space to developers in new projects is an additional premium to be considered outside of utility costs). ESB has over 20,000 such substations which rapidly increases costs which will ultimately be borne by electricity consumer. These additional considerations require a detailed study, taking into account the economic, technical and environmental issues which has not currently been carried out for the non-SF_6 MV Secondary Switchgear.

MV Secondary Switchgear (10/20kV) contains small amounts of SF_6 (typically 0.7-2.5kg as per EcoFys Report) and comes pre-filled from the factory in hermetic 'sealed for life' units, which have leakages rates of <0.1% per IEC 62271-1. At end of life ESB has very well-defined processes and systems for decommissioning, recovering SF_6 gas and retiring assets in compliance with waste legislation and best practice. It is unreasonable to impose restrictions/change-outs on SF_6 sealed units as it is not cost effective; the amount of SF_6 emissions prevented is miniscule, the complexity of a change out of SF_6 equipment for non-SF_6 equipment is impractical and costs are orders of magnitude above the equipment costs alone.

For MV Primary Switchgear, size is also a significant factor as urban development will prevent expansion of the substation buildings and the existing substation is limited in dimensions for switchgear as busbars and infrastructure is designed in a predetermined configuration. If any SF_6 equipment had to be replaced with non-SF_6 switchgear that wasn't absolutely identical it would involve replacing the whole busbar (and overhauling the associated civil infrastructure) which would be inordinately expensive. This expense would arise not only for the purchase of multiple CB's but because it is not generally possible to simply rewire a switchboard in an existing station as the station loads are substantial and must continue to be fed.

Accordingly, it is more practical (but still costly) in such situations to replace the switchgear with a modular switch room completely equipped with new switchgear and associated protection relays, develop a new concrete plinth, dig new cable trenches and then joint and divert each MV cables from the old board to the new board. Typically, there is at least 10 such circuit breakers per station and the resultant costs involved are around €200,000+ for 10/20 kV switchgear (or higher if above 20kV).

More specialised applications such as wind farms and generation stations have considerable constraints:

- Wind turbine sizes are fixed in Wind Farms, widespread in locations across Ireland, geographically isolated and remote. The dimensions of the turbines cannot be altered and new equipment must meet the dimension restrictions, while replacing these units (even if the same size) would involve significant cost for transport and logistical planning and manoeuvring on site (redevelopment of access roads may be required). It may also incur additional intangible costs such as access rights or permission to pass through sites owned by external landowners which may have lapsed. All of these considerations would need to be reviewed and are likely to cause significant delay for development of new greenfield sites and retrofit of brownfield sites.

- Generator circuit breakers require significantly high ratings (currents specifically) which is currently not available and not likely to be available using non-SF_6 switchgear as it involves considerable investigation into alternatives, technology development and redesign of equipment (which is likely to be orders of magnitude beyond the return on investment for OEMs). This particular point was also noted in the briefing paper by Oko Recherche.

Any ban or introduction of restrictions for SF_6 filled switchgear has an excessive number of "knock-on" effects. All of these considerations mentioned above require a detailed study, taking into account the economic, technical and environmental issues which has not currently been carried out for the non-SF_6 MV Primary and Secondary Switchgear (for planning and development of greenfield sites already in progress and for use of new non-SF_6 switchgear in brownfield sites).

In general, technological and industrial market considerations of non-SF_6 equipment must match or exceed SF_6 equipment based on the items below:

1. Technological progress of non-SF_6 equipment:

    - Usability in different environments/use (temperature, pollution, humidity, etc.) and exposed to climatic hazards regularly affecting the network;

    - Level of safety and toxicity of materials for people (operation personnel and public) and impacts on the environment;

    - Proven reliability for new concepts using gas and / or high pressure mixtures and / or more complex articulated mechanisms;

    - Technical performance in terms of insulation characteristic and establishment / breaking.

2. Industrial/market maturity of non-SF_6 equipment minimum requirements based on below:

    - Objective selection criteria to be able to compare the different experimental solutions from a technical and safety perspective, and to assess their environmental impact;
    - Elements (factory tests and experience by multiple European utilities and in multiple climates and operating conditions) making it possible to estimate the durability of this equipment on the network for at least 40 years. Reliability must be established for this equipment, deemed as strategic by the volume and function and as part of the critical infrastructure of the electric network which must be protected to ensure the safety of power supply, particularly within emergency planning in times of national and global crisis (and the current climate of the Covid-19 pandemic);
    - Mature industrial offers, comparable and sufficient for effective competition guaranteeing industrial independence and acceptable prices preserving the economic performance of networks and the economic balance of network operators;
    - Additional pilot projects have to be carried out, allowing manufacturers and users to get more experience and to continuously improve products, handling and recycling while providing for market experience and information to build effective best practice policy and processes, and develop best practice standards and specifications around this equipment.

Briefing Paper Comment (shown in italics):
"As for MV, instrument transformers rely on epoxy as insulating medium, but SF_6 is used during manufacturing. The final products contain only very low residues of SF_6. Further emission reduction in the manufacturing process is possible. Complete replacement of SF_6 may be possible for a limited number of applications (lower insulation levels) in the next 5 years."

ESB Response (shown in standard format)

Restrictions on use must be based on a detailed study of emissions and the effects of any regulatory instruction; i.e. if the instruction is cost effective for the amount of emissions recovered and it is technically practicable and feasible using the same consideration as above for MV and HV equipment. The considerations include:

- cost over the lifespan,
- technical performance of alternative for voltages, currents, humidity and temperature
- operation restrictions,
- environmental and health risks of new gases,
- market risks, track record & experience

As a final comment, the current environmental regulations are thought to rightly impose measures and penalties aimed at better control of gas filling operations in an industrial environment (assembly and end-of-life treatment plant), and on-site use (operation). It is recommended to continue with these controls and national reporting of SF_6 leakages for SF_6 use.

The recognition in the Briefing Paper that niche applications exist which cannot be served with standard products is positive (high currents in generator circuit breakers for example as outlined above). This derogation should be expressed in generic terms to provide for the impossible size/footprint constraints outlined above where non-SF_6 equipment cannot technically or economically be used, e.g. *where it is uneconomic or technically infeasible or impractical to use non-SF_6 Switchgear, then SF_6 switchgear may continue to be used'.* Allowing like for like replacement with modern SF_6 equipment with extremely low leakage rates will reduce emissions from gas handling, increase gas tightness and move toward a zero residual leakage rate while maintaining the performance of SF_6 filled equipment and homogenous company processes for maintenance, SF_6 management and end of life disposal.

1 MV Switchgear

Switchgear for voltages between 1 and 36 kV

MV is defined from 1 kV to 52 kV in this paper however this is inappropriate for technical issue as no switchgear solutions were proposed for non-SF_6 Switchgear above 36kV. This voltage level covers a wide variety of primary and secondary switchgear which all operate under a specific set of circumstances and which must be fit for purpose for the particular application (considering cost over the lifespan, technical performance such as voltages and currents, the location and space restrictions, humidity and temperature range, security concerns, environmental and health risks of new gases, market risks, track record & experience). Consideration of all applications must be made for any further restrictions, as opposed to "blanket" application of restrictions for all MV switchgear.

The EU EcoDesign Directive used 36kV to distinguish between transformer types on voltage, and IEC 60038 defines Voltages in Table 3 as from 1kV to 35kV, and in Table 4 from above 35kV to 245kV. This is also compatible with 'ANSi/IEEE 1585-2002 which refers to: Medium Voltage (1-35kV)' and 'IEEE Std 1623-2004 refers to: Devices rated to medium voltage (1kV – 35kV)'. It is imperative that there is coherence between directives and any proposals are strictly related to a voltage range such as '1- 35kV nominal' rather than using generic 'Medium Voltage'.

Briefing Paper Comment (shown in italics):
"In summary, non-SF_6 alternatives have always been used in primary distribution; AIS with vacuum breaker are state of the art and represent about 50% of the existing asset base"

"Different designs of switchgears for various applications in medium voltage distribution totally or partially replacing SF_6 have been traditionally used. There are however a number of limiting factors, in particular in secondary distribution, that restricted the choice of switchgear type, including initial investment needs, space constraints, required maintenance effort and environmental conditions (e.g. humidity, dust, salt, temperature). The solutions are designed to have similar properties to SF_6 switchgear with regards to use of space or reliability."

ESB Response (shown in standard format)

In contrast to the published table demonstrating the use of vacuum technology in 50% assets, SF_6 gas is widely used in ESB as the switchgear solution for technical, economic and operational reasons (lower maintenance, higher ratings, safer and more easily managed). Vacuum technology for both switching and insulation plays a minor role in the total breakdown of asset types and use of SF_6 in switchgear. For MV switchgear (up to 36 kV) approximately 60% of equipment is SF_6 filled and significantly higher at HV level (above 36 kV).

	HV (above 36 kV) "Closed equipment"	MV (up to 36 kV "Sealed equipment"
SF_6 Quantity in Equipment	60%	40%

As the EcoFys study was based on experience in Germany it may not correctly reflect the more varied use of switchgear in other EU countries.

Briefing Paper Comment (shown in italics):

"In the case of RMUs, the average current running through the switchgears' components is far below rated values and hence operational losses on average are about one order of magnitude lower than rated losses."

"Except where explicitly mentioned, physical dimensions and electrical ratings of these alternatives are identical to products using SF_6."

ESB Response (shown in standard format)

It is ESB experience that in most cases alternative technologies require more space due to increased switchgear footprint, and have other adverse features including greater weight and incompatibility which makes their application difficult or even impossible on existing sites, especially in urban areas.

If ESB were required to replace existing switchgear by non-SF_6 technologies on a large scale, an adequate transition phase would be needed to be granted which allows time for new installation sites to be found and the grid restructured accordingly.

The key issue is technical performance; in particular where product footprint is concerned. For example, a new green field substation would be possible but replacing a faulted switch in an existing substation/urban area with a new non-SF_6 switch may be difficult if not impossible as a result of constraints regarding the substation size, particularly for the many underground substations/connections in urban areas.

In the secondary MV level, load-breaking switchgear prevails while at primary MV level switching dominates. The space limitation for densely populated urban areas is critical and SF_6 filled switchgear is the only option available for replacement in the same space with the same performance. Although vacuum switchgear is state of the art, they are normally insulated with SF_6.

SF_6 technologies are still state of the art: MV secondary equipment have a very compact design, are highly reliable and inexpensive. Maintenance costs are low particularly where the load-breaking switchgear is "sealed for life" – which also reduces SF_6 emissions significantly. Non-SF_6 alternatives do not yet reach this performance level: air-insulated devices still need more space and solid-insulated devices have a shorter life expectancy than SF_6 insulated load-breaking switchgear.

The older technologies are listed in the table below and should no longer be considered safe, reliable or cost effective. The cubicle information is specific to secondary MV switchgear however the risks and disadvantages of the technology are common to all voltage levels including primary MV and HV switchgear.

Technology	**Cubicle Info**	**Equipment Details – (Dis)/Advantages**
Air	Open, 3.5 m^2 space for a standard CCF configuration Very large footprint	High maintenance required, Danger from the point of view of contact with live equipment both for Network staff and members of the public who might gain access (vandalism) Severe consequences in terms of arc flash if there was to be a short while some one was in the station. Very time consuming to install, effectively the "RMU" had to be built on site. Very high skill level to install and maintain. More often than not contained oil-based switches or circuit breakers.
Oil	Enclosed in metal housing 11kV footprint approx. $1m^2$	High maintenance required, regular oil tests and inspection required. Danger from the point of view of contact with live equipment both for Network staff and members of the public who might gain access. Severe consequences in terms of arc flash if there was to be a short circuit while some one was in the station. Obvious fire risk, especially in substations in basements etc. Additional environmental risk of oil leakage. 11kV versions only available.
Solid Insulation (cast resin)	Cast resin block 0.75 m^2	Small footprint (big positive). Operator very exposed should there be a fault. Very high maintenance required if the equipment is to stay in good condition. One manufacturer only that we know of. Single phase operation only. Only up to 12kV rating.
Metal clad Solid insulation	Metal clad 0.75 m^2	Small footprint (big positive). Operator very exposed should there be a fault. Very high maintenance required if the equipment is to stay in good condition. One manufacturer only that we know of. Single phase operation only. Only up to 12kV rating.
SF_6 Used for both insulation and arc interruption	Closed, $0.8m^2$ space for	Safe, reliable, very low maintenance, easy to install and operate, secure against live contact even for copper thieves and vandals

The present ESB fleet of SF_6 primary and secondary switchgear is very reliable and the safest of all the technologies. Secondary switchgear is made of stainless-steel tanks and are very rarely operated so mechanical wear is not a factor that may shorten their life. Both primary and secondary switchgear could last for 50 years plus in the correct environment and when well maintained. At end of life, the SF_6 can be reclaimed and recycled. Therefore, there is no reason why there should be a drive to replace all existing primary and secondary MV SF_6 filled switchgear.

Any non-SF_6 alternative will need to achieve industry required characteristics especially concerning required electrical, physical, environmental, health and safety criteria. The new non-SF_6 alternatives must meet the conditions laid out in the F-gas Regulation, i.e. be cost-effective, technically feasible, reliable (energy efficiency included but not a differentiator between SF_6 and non-SF_6 switchgear so not relevant).

The total environmental footprint of any non-SF_6 alternatives needs to be evaluated considering the entire lifecycle. New technologies have to provide the same performance and reliability levels as switchgear using SF_6. Therefore, more pilot projects have to be carried out, allowing manufacturers and users to get more experience and to continuously improve products, handling and recycling, and develop best practice standards and specifications around this equipment.

An adequate transition period is required to replace MV equipment with non-SF_6 alternatives as assets reach natural end of life. This transition will allow time for the market to grow, leading to price decreases, and allowing ESB to find non-SF_6 alternative sites bearing enough space where necessary. Instead of setting a firm timeframe for a transitional phase it is recommended to continue the national following and reporting of the SF_6 leakages and other related SF_6 data, while developing and testing the capabilities of alternative solutions.

Briefing Paper Comment (shown in italics):
Table 2 outlines the number of SF_6 alternatives on the market for MV use up to 36 kV (vacuum and other alternative gases).

ESB Response (shown in standard format)

The vacuum solution has been in the market for more than 5 years but the majority as outlined above are only used for switching, while the other methods of insulation have yet to be proven, considering current vacuum switchgear still uses SF_6 gas for insulation.

Other non-SF_6 alternatives have been outlined, however these are in pilot and type testing phase and none have been in use in the market. For reasons of reliability, good practice is to consider the use of equipment from an OEM with relevant European market experience, for which the product has been produced and sold for more than 5 years and has adequate use/purchases in Europe (owned and operated by multiple European utilities). It is not reasonable to consider these non-SF_6 alternatives at the moment without large scale market experience on a number of installations throughout Europe and for a reasonable period of time. For a new technology a reasonable period of at least ten (10) years is recommended before adequate maturity is reached.

The non-SF_6 alternative solutions for medium-voltage switchgear (MV) for 24 kV and 36 kV secondary substations will require further development in light of these requirements and to allow further technology development, competition and market maturation. Indeed, it is not conceivable to expect purchase of alternatives without ensuring the robustness, reliability and technical and economic relevance of the solution. Sufficient tests will have to be carried out to ensure a robust track record based on qualification tests and demonstrating the reliability of the alternative solutions with regard to the expected functions, i.e. how the technical characteristics of the alternatives and long term technical performance changes over time.

No solutions for replacement of 52kV Switchgear were covered in the report, only switchgear up to 36kV and beyond 52kV where no ban was proposed.

Additional studies are required, in particular toxicology studies. SF_6 is a stable gas without any recycling or re-use problem and the toxicity of decomposition products related to switching function is known. This briefing paper proposes fluorinated substances as alternatives to SF_6 (fluoronitriles or fluoroketones). These solutions, even if they have a lower emission-rate than SF_6, should not be compared to natural and non-toxic substances as if they are harmless as it has not been established yet. Toxicological studies have been limited to 1t volume but more in-depth decomposition analysis is required to ascertain the risks for urban areas (and close proximity to residential areas and hospitals). The use of fluorinated gases such as fluoronitriles and fluoroketones will also have to be assessed under the F-Gas regulation and may also be subject to restrictions in due course which will have to be considered as part of any regulatory measure for non-SF_6 gases.

Wide spread adoption of these new technologies will only take place when alternatives are available on the market in a sufficient number, from different manufactures (competitive market) and for reasonable prices, where the reliability is proven ((with a critical mass of utilities to have established best practices) and ESB have trained their staff on handling the new technologies and established the necessary life-cycle processes, with full details of toxicological studies taking into account the risks to staff and the public after a high energy event. Therefore, more pilot projects have to be carried out, allowing manufacturers and users to get more experience and to continuously improve products, handling and recycling, and develop best practice standards and specifications around this equipment.

Pilot projects should run a minimum of ten (10) years in order to receive at least “medium term experience”. If new technologies are installed in pilot projects over the different voltage levels in the early 2020s, manufacturers and grid operators will be able to gain experience by the end of the decade.

Restrictions on SF_6 in primary and secondary Medium Voltage (MV) switchgear, up to 36 kV, if they are to be introduced, must only apply to new equipment. Early adoption of new equipment before the end of an assets lifecycle would result in higher costs of ownership, increased energy use for additional production processes and CO_2 emissions.

<u>*Briefing Paper Comment (shown in italics):*</u>

“Like SF_6 products, all new SF_6 free as well as some of the commercially existing alternatives are sealed for life, thus from a maintenance perspective, such alternatives are comparable to the GIS solutions using SF_6.”

“The weight of solutions using enhanced gas pressure may be slightly higher. Alternatives listed indicate that, in principle, there is no general technical barrier for using SF_6 free switchgear in new installations in the MV segment.”

<u>ESB Response (shown in standard format)</u>

The nature of a Distribution Network is that it consists of very large numbers of assets with long life- times and whose installation costs and value in service are far greater than their equipment costs. In a Transmission Network similar considerations apply, and although the number of the assets is far less their criticality is far greater, and the consequences of failure on large numbers of customers are more severe.

Accordingly, in choosing equipment which is very expensive and disruptive to install, it is essential that the equipment is *proven* (not *expected*) to work reliably when installed for its full 40-50 year lifetime. Considerations of equipment costs are a distant second – the equipment must meet the 'proven reliability 'criteria, and only then does cost come into play. At the moment, the non-SF_6 equipment proposed in the briefing paper are not proven reliable equipment.

Reliability in operation, as evidenced by significant volumes working for long enough for failures to be able to develop and become evident, is what is required by utilities. Each utility literally has about one Ring Main Unit for every 250 customers, so that as Units are replaced or new ones installed there is likely to be large amount of equipment which will either provide reliable or faulty.

If faulty they can either fail, give rise to an outage and then be replaced, or they can fail functionally, where because of an inherent fault they are not considered safe to operate and all switching operations with them is disallowed en masse. This means that any planned work or fault repairs on the system can then only be carried out by switching the remaining un-faulted units, with customers on faulty units having to be left without supply until switching on these units can be carried out de-energised.

Either way, the costs associated with installing switchgear which is not fully reliable is very high and lasts for many years, and utilities have experience with failures of such units. As experience with non-SF_6 switchgear is limited in comparison with that of SF_6 Switchgear, further time is required to prove the operation of such units in the field.

Low pressure sealed for life SF_6 gas equipment is preferred as it is the least maintenance and lowest emissions option, both over the lifetime and in the event of a rupture. On a utility and wider European level SF_6 gas is very well controlled, leaks are monitored and recorded, specifically with pressure densimeter monitoring for HV equipment (above 36 kV) and alarmed at MV primary switchgear (up to 36kV). RMUs are sealed for life (introduction of densimeters on 'sealed for life' would risk an increase in emissions) with negligible lifetime emissions (less than 0.1% emissions with installed capacity of 0.7 – 2.5 kg). And because of this SF_6 gas is widely used in Europe and remains the practically ideal solution.

In order to allow replacement of existing (very compact) MV SF_6 switchgear in areas with limited space, non-SF_6 equipment with reduced sizes/footprint is required.

Air-insulated switchgear would be preferable to replace secondary SF_6 devices, otherwise atmospheric/alternative gas mixtures with vacuum switches. However it must be noted, that the use of dehumidified air under high pressure as insulation would greatly complicate the management of the equipment and would impose a series of additional lifecycle maintenance requirements, as is typical of pressurised air systems, and not required today from SF_6 equipment. A recent enquiry with one OEM has also shown that, in comparison to its SF_6 gas equivalent for the same size unit, only half of the insulation value can be reached using a dry air system alternative; only 12kV in comparison to 24kV using SF_6 equipment of the same footprint.

Vacuum switchgear would be preferable to replace primary SF_6 devices, otherwise air/atmospheric/natural gas mixtures with vacuum switches. It must be considered that like for like replacement be allowed in order to replace older SF_6 filled equipment with its modern equivalent with increased gas tightness in areas with limited space. This would allow for an improved (lower) leak rate while retaining the operational capabilities SF_6 switchgear provides.

<u>Briefing Paper Comment (shown in italics):</u>
"Some users express concerns regarding technical performance, cost and health and safety issues related to SF_6 free alternatives. However, whereas the initial investment costs are indeed likely to be somewhat higher (at least in the short term), manufacturers already have some experience with using SF_6 free solutions and they are performing tests on their new equipment that in principle should alleviate the other concerns related to space constraints and reliability."

"Manufacturer representatives reported additional investment costs after industrialisation in the range between 5% to 20%, with some conditional exceptions down to 0% and up to 30%. Of course, for new alternatives, cost information is based on manufacturers' claims and at this stage they can only provide indicative figures expected after full upscaling of manufacturing."

<u>ESB Response (shown in standard format)</u>

Costs from manufacturers are speculative at the moment and only consider the equipment cost itself while there are potentially much greater costs associated with installation and operation of new technologies. It is difficult for technology adopters to be able to perform any complete lifecycle or economic analysis, particularly as other key factors are not known and have not been considered to compare against SF_6 switchgear; for example life expectancy, costs of maintenance, technical training and additional handling/quality analysis equipment as well as other internal costs and times for homologation (time to adopt and develop processes for best practice management, specific company standards, policies and procedures).

Aside from the initial cost of the non-SF_6 switchgear, the operational costs (handling expertise and equipment, fault response/end of life considerations) could escalate with adoption of multiple non-SF_6 technologies. This could lead to a lack of operational expertise at critical points of the grid, overutilization of company resources and incomplete maintenance of switchgear. In addition, solutions using specific new manufactured gases might pose the problem of dependence (or even monopoly) on the supplier, which is not acceptable on an industrial level for a distribution system operator.

Importantly, the availability of alternative technologies and therefore the investment decisions of owners/operators differ between voltage levels, for the reasons pointed out above (various applications, operational and technical requirements, costs and environments).

Utilities should be encouraged to use non-SF_6 switchgear where it is economic and technically feasible for a particular application on an individual basis. This could be enacted using incentives to promote the use of non-SF_6 technologies in electrical equipment.

ESB is involved in international working groups, researching and funding installation of non-SF_6 switchgear to develop experience in this area.

Premature replacements would incur additional costs to the whole electricity system (and in the end to customers) and would be questionable from a climate protection point of view as it would involve producing new devices earlier than technically necessary and , increased energy use for additional production processes and CO_2 emissions. Apart from that, earlier replacement of existing switchgear is not feasible for technical reasons: It is not possible to carry out many replacement projects at the same time and in the same grid area because of grid restrictions. And additional testing is required to facilitate "swapping" SF_6 filled equipment with alternatives.

Older MV Switchgear at 10 and 20 kV (e.g. air, resin etc) was used before SF_6 switchgear but was comparatively large and bulky. In contrast SF_6 allows for considerably smaller switchgear and hence a considerably smaller packaged substation. Secondary substations have been built around switchgear in densely populated areas where space is limited – to the point there is no physical room to replace SF_6 switchgear with others of larger footprint/dimensions. Such types of MV Substation are the norm in continental Europe.

Should restrictions be put in place for SF_6 MV Secondary Switchgear without an alternative of the same dimensions or smaller, it would result in significant additional costs including replacement of the whole of the existing substation with a larger modular one to accommodate new larger equipment (existing cable connections dictate the site location and cannot be moved) and the purchase of the additional land beyond the curtilage of the ESB site (from the adjacent household/landowner) to accommodate this new substation. This would cost multiples of the entire cost of the modular substation. Other ancillary costs need to considered including labour, civils, and delays involving planning permissions (loss of space to developers in new projects is an additional premium to be considered outside of utility costs). ESB has over 20,000 such substations which rapidly increases costs which will ultimately be borne by electricity consumer. These additional considerations require a detailed study, taking into account the economic, technical and environmental issues which has not currently been carried out for the non-SF_6 MV Secondary Switchgear.

MV Secondary Switchgear (10/20kV) contains small amounts of SF_6 (typically 0.7-2.5kg as per EcoFys Report) and comes pre-filled from the factory in hermetic 'sealed for life' units, which have leakages rates of <0.1% per IEC 62271-1. At end of life ESB has very well-defined processes and systems for decommissioning, recovering SF_6 gas and retiring assets in compliance with waste legislation and best practice. It is unreasonable to impose restrictions/change-outs on SF_6 sealed units as it is not cost effective; the amount of SF_6 emissions prevented is miniscule, the complexity of a change out of SF_6 equipment for non-SF_6 equipment is impractical and costs are orders of magnitude above the equipment costs alone.

For a simple 10% increase in the cost of an MV Ring Main Unit (RMU) costing €5000, the emissions reduction would be 0.1% pa or 3% over 30 years. Emissions on disposal are negligible (Fig Z1 p(ii) Final Report) and on production are less than a sixth of the ongoing emissions.

This means that for MV RMU's containing 0.7 – 2.5kg SF_6 with lifetime emissions of 0.021 – 0.075kg SF_6 or 504 – 1,800kg Co_2Eq (say 1,150kg CO_2 Eq), the cost of abatement (if there were no further costs whatsoever) would be €500 or €0.43 /kg CO_2 Eq corresponding to €430/t Co_2Eq.

In the 2011 report it was considered that €347 /t CO_2 Eq was excessively high for abatement costs for MV Switchgear, and this figure is higher again.

For MV Primary Switchgear, size is also a significant factor as urban development will prevent expansion of the substation buildings and the existing substation is limited in dimensions for switchgear as busbars and infrastructure is designed in a predetermined configuration (10/20/33kV switchgear will have been set out to maximise the number of outlets that can fit into the switch-room). If any SF_6 equipment had to be replaced with non-SF_6 switchgear that wasn't absolutely identical it would involve replacing the whole busbar (and overhauling the associated civil infrastructure) which would be inordinately expensive. This expense would arise not only for the purchase of multiple CB's but because it is not generally possible to simply rewire a switchboard in an existing station as the station loads are substantial and must continue to be fed.

Accordingly it is more practical (but still costly) in such situations to replace the switchgear with a modular switch room completely equipped with new switchgear and associated protection relays, develop a new concrete plinth, dig new cable trenches and then joint and divert each MV cables from the old board to the new board. Typically there is at least 10 such circuit breakers per station and the resultant costs involved are around €200,000+ for 10/20 kV switchgear (or higher if above 20kV).

Arc proof fault safety tests are an additional external item required for RMU cabinets and considered for primary MV equipment installed in modular buildings; these tests ensure the safety of the enclosure in combination with the installed switchgear after an arc/fault event. They are specific to the individual type of switchgear and enclosure, and these tests must be performed in complex and individual laboratory tests.

In addition, the number and capacities of technical laboratories for these tests are very limited. Due to the change in technology and the changing behaviour under fault conditions, this means that non-SF_6 MV Switchgear replacing MV SF_6 Switchgear would require a new Type Test covering the new combination for the packaged substation. For these reasons, the installation of these new technologies takes much more time and with additional cost than a mere replacement of the switchgear.

These additional considerations require a detailed study, taking into account the economic, technical and environmental issues which has not currently been carried out for the non-SF_6 MV Switchgear.

Briefing Paper Comment (shown in italics):

The period of time needed for commercial availability of alternatives and market penetration…………………*"may however be around 2 years for standard applications in primary distribution (MV switchgear in substations) and the most common RMU configurations, whereas other applications may need a few additional years for market readiness."*

ESB Response (shown in standard format)

Currently, no mature industrial non-SF_6 switchgear exists on the MV switchgear market with demonstrated technical and economic performance over a number of years equivalent to SF_6 filled equipment. The alternative concepts currently proposed all have drawbacks that are difficult to reconcile with the expected functions, the level of security and safety that any network operator is entitled to expect. In addition, the return to old technology (e.g. vacuum, etc.) would significantly impact on the current levels of performance, the overall economic analysis for new equipment and maintenance requirements.

As outlined above, the alternative solutions for medium-voltage switchgear (MV) for 24 kV and 36 kV secondary substations will require further development and sufficient testing time of several years to have a robust track record based on qualification tests and demonstrating the reliability of the alternative solutions with regard to the expected functions.

Some limited equipment is available as vacuum switchgear, for example ring main units at 10 and 20kV are readily available however SF_6 gas is still required for insulation in this equipment. Vacuum circuit breakers are available up to approx. 40kV as indoor metalclad switchgear but only in limited numbers (ESB have limited experience).

The period of two years suggested is completely inadequate for both utilities and manufacturers. A minimum of ten (10) years is required for manufacturers to gear up to produce alternative non-SF_6 switchgear in the quantities required for commercial production, provided production models are tested and available. This time is required, to expand production and retool factories and reduce existing stocks of SF_6 switchgear (as now rendered unsaleable) should any restrictions be put in place. Utilities in Europe purchasing alternatives would require time for development of new specifications, extended time for tender and procurement processes, to physically alter/replace switchgear itself and make changes to designs in which the switchgear is used. Additionally, any projects already underway either need to continue or be altered, although altering these projects has consequences for customers in terms of both cost and delay.

A realistic time scale would be 10-15 years for commercial availability and market penetration given the factors above (even though it has been noted that it is not cost effective to use non-SF_6 switchgear at MV level, given increased costs and low emission rates).

If new technologies are installed in pilot projects over the different voltage levels in the early 2020s, manufacturers and ESB will be able to gain experience by the end of the decade. Once alternatives are available on the market in a sufficient number, from different manufacturers (competitive market) and for reasonable prices, and ESB have trained their staff on handling the new technologies and established the necessary life-cycle processes, they will be able to buy and use these new technologies.

In particular, the EU Procurement Directive needs to be met to allow for tendering and procurement of non-SF_6 equipment based on established international standards and market experience; this involves specific measurable market experience and definitive agreed international criteria to be able to compare equipment and ensure the product is proven and reliable for its lifetime and to avoid risks to security of supply.

In any case, a transition phase for existing SF_6 switchgear has to be granted until their end of life cycle is technically reached.

2 HV & EHV Switchgear

Switchgear for voltages above 36 kV

Briefing Paper Comment (shown in italics):

"Pilot installations for voltages up to 145 kV have been successfully implemented and operated using the different gases and gas blends. According to manufacturers, several hundred bays already have been ordered. Implementation of different technology approaches is expected in the next two years. Also live tank breakers have been presented and piloted successfully by several manufacturers. For offshore wind power plants, GIS for 72.5 kV has been commercially introduced. Substantial growth is expected (more than 1000 orders already placed)."

"SF_6 free switchgear for 245 kV and 420 kV is under development. Depending on voltage and functionality (substation, live tank circuit breaker, dead tank circuit breaker), for various components scheduled development periods are 2 to 5 years."

"In general, the concepts are an extension of existing designs using higher pressures and / or adapted blends of substances."

"Thus, from a technical point of view it is feasible to use SF_6 free solution for some uses in the HV voltage segment already now."

ESB Response (shown in standard format)

Alternative products are still significantly more expensive than SF_6 devices, or they don't even exist for particular voltages and applications. If incentives are provided for the extra costs in comparison to SF_6 technologies, ESB is willing to install these more climate-friendly technologies in pilot projects in order to gain experience and to incorporate them in future grid extension strategies.

Costs from manufacturers are speculative at the moment and only consider the equipment cost itself while there are potentially much greater costs associated with installation and operation of new technologies. It is difficult for technology adopters to be able to perform any complete lifecycle or economic analysis, particularly as other key factors are not known and have not been considered to compare against SF_6 switchgear; for example life expectancy, costs of maintenance, technical training and additional handling/quality analysis equipment as well as other internal costs and times for homologation (time to adopt and develop processes for best practice management, specific company standards, policies and procedures).

Aside from the initial cost of the non-SF_6 switchgear, the operational costs (handling expertise and equipment, fault response/end of life considerations) could escalate with adoption of multiple non-SF_6 technologies. This could lead to a lack of operational expertise at critical points of the grid, overutilization of company resources and incomplete maintenance of switchgear. In addition, solutions using specific new manufactured gases might pose the problem of dependence (or even monopoly) on the supplier, which is not acceptable on an industrial level for a distribution system operator.

Also, the size of the alternative switchgear should be noted in case the replacement of the SF_6 is considered. In city network areas, the size needs to be compact, and it can become very costly to switch from SF_6 switchgear to a larger alternative solution. There is no long-term experience with the alternatives, meaning there is no knowledge about how the technical characteristics of the alternatives and long term technical performance changes over time.

Products using SF_6 for insulation and as circuit breaker switching gas have reached a high degree of maturity; products and components are highly standardised, leading to competition among manufacturers, and lower purchase and maintenance costs. The SF_6 high voltage switchgear used today is highly performant and reliable. The industry possesses long and intense experience (more than 50 years) with this technology, enabling a high level of know-how and safe handling with regarding maintenance processes.

Alternatives in comparison have not yet reached market maturity. Experience of suitable non-SF_6 switchgear is even more limited, functional requirements are higher and the consequences of any reliability issues greater. Three technologies are currently in a testing phase: one solution based on atmospheric gases as insulation medium and vacuum for circuit breaker (up to 145 kV) and two alternative synthetic gases (as insulation and switching media).

In particular, the EU Procurement Directive needs to be met to allow for tendering and procurement of non-SF_6 equipment based on established international standards and market experience; this involves specific measurable market experience and definitive agreed international criteria to be able to compare equipment and ensure the product is proven and reliable for its lifetime and to avoid risks to security of supply.

In a similar fashion to MV, HV equipment will require a minimum of ten (10) years for manufacturers to gear up to produce alternative non-SF_6 switchgear in the quantities required for commercial production, provided production models are tested and available. This time is required, to expand production and retool factories and reduce existing stocks of SF_6 switchgear (as now rendered unsaleable) should any restrictions be put in place. Utilities in Europe purchasing alternatives would require time for development of new specifications, extended time for tender and procurement processes, to physically alter/replace switchgear itself and make changes to designs in which the switchgear is used. Additionally, any projects already underway either need to continue or be altered, although altering these projects has consequences for customers in terms of both cost and delay.

High voltage (HV and EHV) equipment requires additional developments to cover the entire voltage range (up to 400 kV). Here too, a robust track record based on several utilities/users is required before any evolution of the regulatory frameworks. Large scale market experience is required and additional studies, in particular toxicology studies (as noted in the MV section), to open up the market, carry out the development of equipment and allow for an extensive development of market experience of at least 10 years (robust track record).

When alternatives are available on the market in a sufficient number, from different manufactures (competitive market) and for reasonable prices, where the reliability is proven (with a critical mass of utilities to have established best practices) and ESB have trained their staff on handling the new technologies and established the necessary life-cycle processes, with full details of toxicological studies taking into account the risks to staff and the public after a high energy event. Therefore, more pilot projects have to be carried out at HV and EHV levels, allowing ESB and other users to get more experience, share knowledge on handling and recycling and to continuously feedback information to the OEM to improve products and processes, and develop best practice standards and specifications around this equipment.

SF_6 switchgear is preferred, but as an alternative vacuum switchgear and natural gases would be suitable once it is proven for an appropriate lifetime of 50 years to be considered reliable and mature technology. Also, it must be considered that like for like replacement be allowed in order to replace older SF_6 filled equipment where it is not technically or economically feasible to use non-SF_6 alternatives with its modern equivalent for increased gas tightness (for example greenfield sites already in progress or for use of new non-SF_6 switchgear with incompatible size/dimensions/ratings/functionality for brownfield sites). This would allow for an improved (lower) leak rate while retaining the operational capabilities SF_6 switchgear provides.

3 Instrument Technology Manufacturing

"As for MV, instrument transformers rely on epoxy as insulating medium, but SF_6 is used during manufacturing. The final products contain only very low residues of SF_6. Further emission reduction in the manufacturing process is possible. Complete replacement of SF_6 may be possible for a limited number of applications (lower insulation levels) in the next 5 years."

Restrictions on use must be based on a detailed study of emissions and the effects of any regulatory instruction; i.e. if the instruction is cost effective for the amount of emissions recovered and it is technically practicable and feasible using the same consideration as above for MV and HV equipment.

The considerations include:

- cost over the lifespan,
- technical performance of alternative for voltages, currents, humidity and temperature
- operation restrictions,
- environmental and health risks of new gases,
- market risks, track record & experience