A guidebook for sustainability in laboratories

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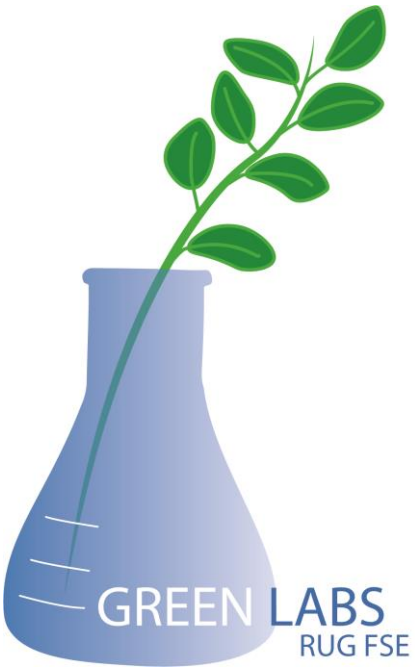
Version 1.1
Green Labs RUG – December 2023
Faculty of Science and Engineering, University of Groningen



This guidebook aims to improve lab users' everyday practices to become more sustainable. Specifically, this guidebook provides practical suggestions on how to effectively use lab instruments and resources and on how to acquire data. We provide advice to labs covering disciplines such as biology, chemistry, computational science, engineering, life sciences, materials sciences, medicine, pharmacy, and physics. As every lab is different, it may occur that alternative measures are required, advice may be outdated or not applicable, and sometimes laboratories may not be able to comply with measures of other laboratories.

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Contents

Safety statement:

When making improvements to procedures and protocols around sustainability management, safety for people and the environment inside and outside the university always have priority. Always consider safety before making final decisions about sustainable management.

In most cases sustainable approaches and safety align. However, if you have questions about safety and possible trade-offs, consult the safety protocols on your local Faculty of Science and Engineering (FSE) Health, Safety, and Environment (HSE) website or consult an HSE staff member. If in doubt or if you notice any potential hazards as a result of implemented procedures, please contact the person responsible for the implemented procedure and/or a HSE staff member to assess the situation.

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1. Sustainable management of chemicals

Responsible and sustainable management of chemical substances is a critical aspect when it comes to making laboratories greener. Plan and carry out experiments in ways that avoid unnecessary waste production, are reproducible, and that data generated is valuable to save materials and costs. This way repetitions of experiments can be minimized.[1]

Concrete actions:

- Avoid generation of surplus quantities:
    - Purchase the smallest possible quantities of chemicals sufficient for each experiment.
    - Conduct reactions in smallest scale possible (*i.e.* rightsizing experiments) and check for their success before upscaling.
    - Minimize the number of physical experiments by conducting appropriate literature research beforehand and possibly *through* computational modelling and simulations, where applicable.
    - Provide detailed information on reaction conditions, procedures and data to enhance reproducibility.
        - Record and share negative results to avoid unnecessary reproduction attempts in group meetings and supporting information of an article.
    - Only prepare the quantities that are actually needed (*e.g.* do not prepare an additional liter of eluent for a flash column from which the product might have already eluted before analyzing TLCs).
    - Implement an online chemical search and location system (so-called inventory) for the institute and regularly maintain its content. Make sure that chemicals are findable and accessible.
    - Share surplus chemicals with other labs/group members (*via* a chemical inventory & sharing system such as the Stratingh Institute for Chemistry's GROS system).
    - Consult the chemical search system if the compound needed is already available at the institute before ordering a new one.

- Eliminate (the need for) hazardous chemicals or substitute with less harmful alternatives whenever possible (**Figure 1** and **Table 1**):
    - Particularly focus on the use of sustainable solvents (these can often be easily substituted without affecting the reaction outcome).[2–5]
    - Substitute the chemical or change the procedure so the substance is no longer needed (*e.g.* use an alternative synthetic route). There is a tool for checking how green your protocol is: www.sigmaaldrich.com/NL/en/services/software-and-digital-platforms/dozn-tool
    - Possible aspects to consider: boiling point, chemical stability, corrosiveness, and toxicity.

BOX 1: Selecting better solvents!

Consider using the ACS solvent selection tool: www.acs.org/content/acs/en/greenchemistry/research-innovation/tools-for-green-chemistry/solvent-tool.html

Further tried and tested solvent lists:

- Unified Solvent Selection Guides: https://doi.org/10.1186/s40508-016-0051-z
- GSK: https://doi.org/10.1039/C0GC00918K
- Pfizer: https://doi.org/10.1039/B711717E
- Sanofi: https://doi.org/10.1021/op4002565
- AstraZeneca: https://doi.org/10.1021/acs.oprd.6b00015
- Massachusetts Institute of Technology (MIT): https://ehs.mit.edu/green-chemistry/
- Millipore Sigma: https://www.sigmaaldrich.com/deepweb/assets/sigmaaldrich/product/documents/115/677/greener_solvent_alternatives.pdf

The Toxics Use Reduction Institute (TURI) provides a solvent database to find solvents that are realistic for your application based on safety, efficiency, and affordability.

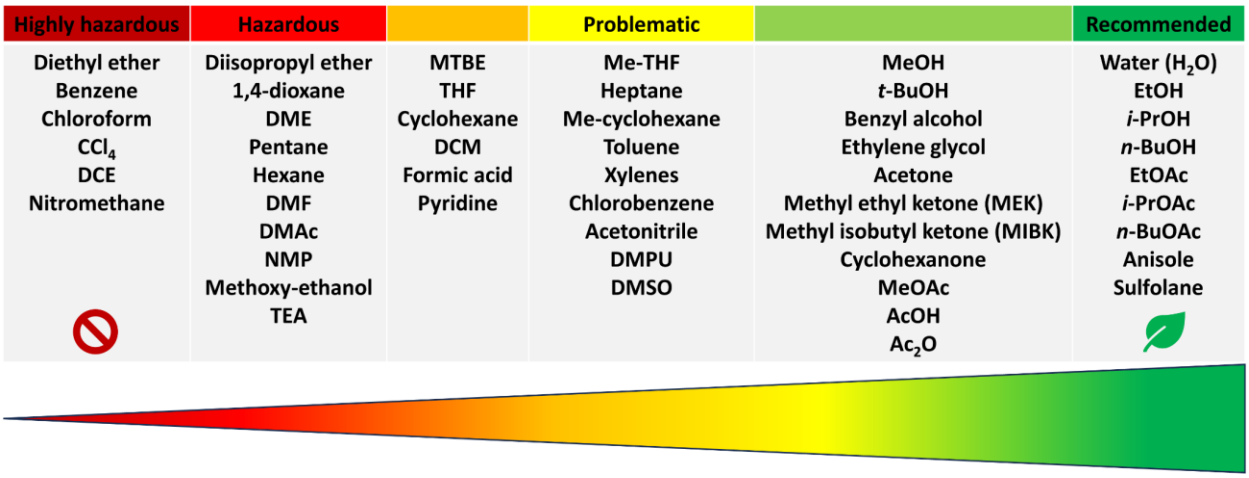


Figure 1: Ranking of solvents with respect to their sustainability.[6]

Table 1. Greener solvent guide for substitution of problematic solvents.[6–11] Chemicals marked in red indicate hazardous (where * marks highly hazardous compounds), yellow indicates problematic and green recommended with regard to safety and sustainability.

Undesirable Solvents	Alternative
Pentane, Hexane(s)	Heptane
Dimethyl formamide (DMF), dimethyl acetamide (DMAc), *N*-methylpyrrolidinone (NMP), DMSO	Acetonitrile, Cyrene, Cyclopentyl methyl ether (CPME), dimethyl carbonate
Tetrahydrofuran (THF), Methyl tert-butyl ether (MTBE)	2-Methyltetrahydrofuran (2-MeTHF), CPME
Di-isopropyl ether or diethyl ether*	2-MeTHF or tert-butyl methyl ether, CPME
Dioxane or dimethoxyethane	2-MeTHF or tert-butyl methyl ether, CPME
Chloroform*, dichloroethane* or carbon tetrachloride (CCl_4)*	Dichloromethane (DCM)
Pyridine (as a base)	Triethylamine (Et_3N)
Dichloromethane (DCM) (in extractions)	Ethyl acetate (EtOAc), MTBE, toluene, 2-MeTHF
Dichloromethane (DCM) (in chromatography)	EtOAc/heptane, 3:1 EtOAc/EtOH, *tert*-butyl acetate, *sec*-butyl acetate, ethyl isobutyrate, methyl pivalate[12–15]
Benzene*	Toluene
Acetone	Ethyl lactate

- Consider the optimization of your purification process: an extraction, distillation, or recrystallization process can be faster, less expensive and less solvent consuming than a column chromatography.

- Consider the optimization of the synthesis by applying the *12 Principles of Green Chemistry*.[16–24] Try to find biobased building blocks and synthesize the desired compound in a catalytic reaction in a sustainable solvent.[25,26] Prevent waste by designing and executing the experiments with high technical standards (**Figure 2**).[27–29]

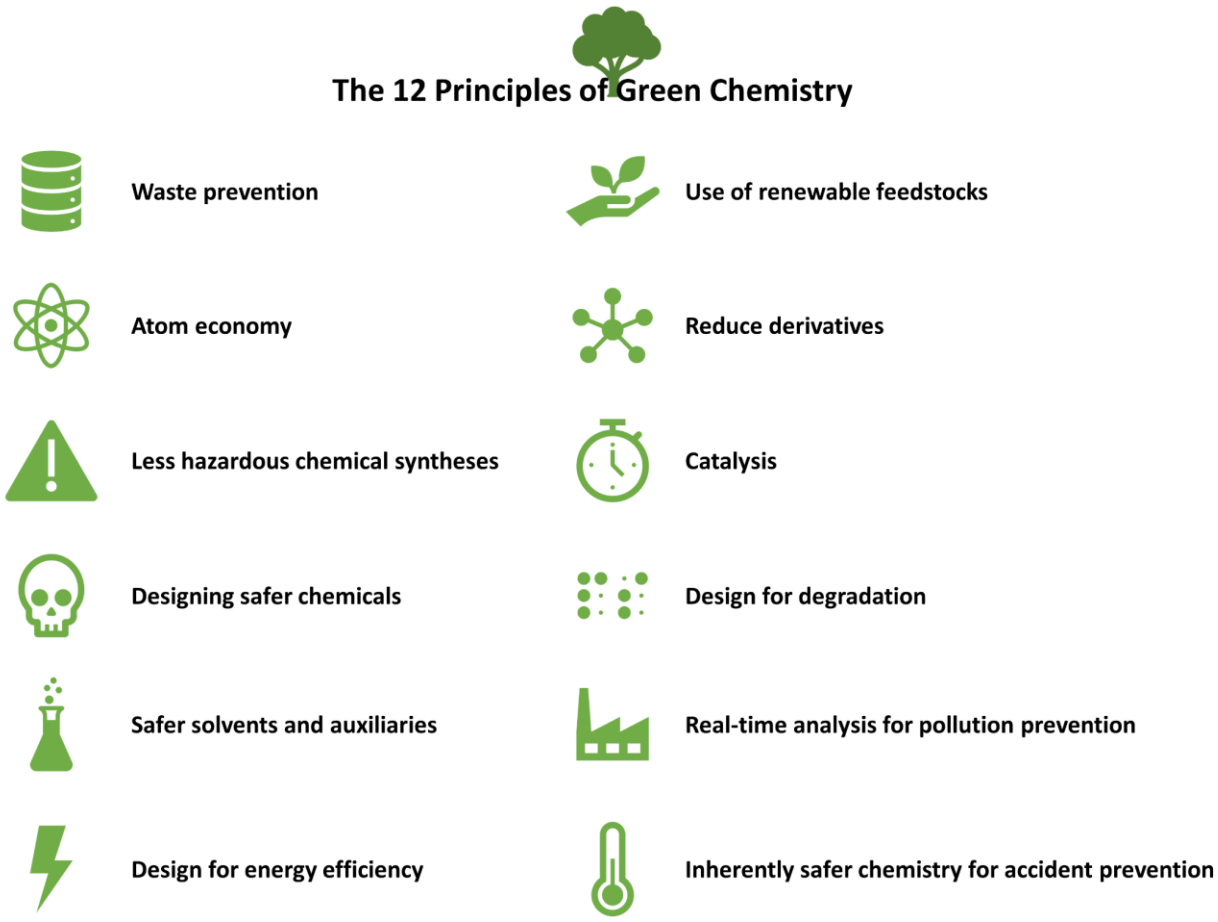


Figure 2: The *12 Principles of Green Chemistry* to improve chemical syntheses.[16,17]

- When analyzing reactions *via* nuclear magnetic resonance (NMR) consider consulting the "*NMR chemical shifts of emerging green solvents, acids, and bases for facile trace impurity analysis*".[11] This way impurities can be identified with ease, especially when using sustainable solvents. An online tool can be found at http://www.nmrimpurities.com, where chemicals are labeled with respect to their sustainability and hazardous character.

- Prevent the release of hazardous chemicals into the atmosphere/environment:
    - Never dispose of hazardous chemicals in the sink.
    - Replace damaged containers and storage units immediately. Use secondary containment, wherever possible.
    - Prevent spilling.
    - Do not let elution fractions from chromatography columns evaporate overnight inside the fume hood (remember that this is released into the atmosphere) but concentrate them with a rotary evaporator and dispose of the solvent as chemical waste.
    - Keep containers with volatile substances closed as much as possible (this applies to solvent canisters as well as to waste canisters) as long as safe to do so and use vented caps, where applicable.

- Ensure correct storage and handling of chemicals (remind people to familiarize themselves with the properties of compounds before handling) to prevent avoidable degradation and related generation of waste.

- Label chemical containers clearly and in a consistent manner (ideally including a molecular structure/IUPAC name) which is not only relevant for safety but also for adequate storage (avoid degradation), disposal, use by other group members (prevent disposal due to lack of identifiability), for better data management, and ultimately for better reproducibility of research.

- Keep your inventory updated regularly (verify that the inventory matches the actual stock present during lab cleaning, at least once per year) and ensure that chemicals are stored at the designated locations to prevent unnecessary purchases when chemicals that are present in the group cannot be found by other members.

- Regularly check the state and quality of stored chemicals. Dispose of chemicals in an adequate manner according to regional safety and environmental standards (see also **Section 2**), if necessary.

2. Waste management

2.1 Chemical waste

Important aspects of chemical waste are *reduction of the amount/volume* generated, *prevention of release* into the environment, and *elimination or substitution* of hazardous chemicals for more environmentally friendly and less toxic alternatives.

Concrete actions:

- Ensure correct separation of waste streams. For this, utilize a clear waste flow chart.

- Keep waste containers closed with lids except when adding waste, make sure the waste containers are closed at the end of the day. Keep waste containers in secondary containers and in a dedicated fume hood. Corresponding lid adapters are available from:
  - https://scat-europe.com/en/products/safety-funnels/overview/
  - https://scat-europe.com/en/products/accessories/thread-adapters/?p=3
  - https://www.fishersci.nl/shop/products/nalgene-safety-waste-funnel-systems-2/11764434
  - www.thermofisher.com/order/catalog/product/6379-0004
  - https://www.thomassci.com/scientific-supplies/Safety-Waste-Funnel
  - https://www.fishersci.nl/shop/products/marco-safety-funnel-lid-v2-0-18/16822130
  - https://www.fishersci.nl/shop/products/safetywasteset-v2-0/16669085

  An alternative can be to put a small round bottom flask or plastic water bath balls (**Figure 19**) inside the waste funnel. This way solvent evaporation is kept at a minimum, while still offering the possibility to dispose liquid waste (**Figure 3**).

Figure 3: Funnels with lid to prevent solvent evaporation from waste canisters (left). Use of a round bottom flask to improve solvent loss by evaporation, which can serve as alternative to funnels with a lid (right). Another alternative to the round bottom flask is the plastic balls used to cover water baths in rotary evaporators (see **Section 4**), which can also be placed in a funnel to prohibit solvent loss by evaporation.

- Old stackable jerry cans/solvent flasks (*e.g.* ethanol or acetone) should be taken out of the inventory system by sending an email to the logistics department and any labels fully removed, to reuse them as waste cans (**Figure 4**). ***Note***: use appropriate adapters to mount the funnels. Such adapters can be 3D printed.

Figure 4: Reuse of solvent bottle (*e.g.* ethanol or acetone) and repurposing it as waste canister to avoid ordering new waste canisters for disposal. For safety, one needs to remove the previous label and stickers and add the respective waste label.

- Reduce quantities of stored/purchased chemicals, when possible, to avoid the generation of waste as a consequence of aging/degradation and amount:
    - Order the smallest quantity of chemicals required for your research.
    - Share chemicals with other labs (*e.g.* surplus amounts) or group members (*e.g.* shared NMR solvents per lab).

- Substitute hazardous chemicals for less harmful alternatives whenever possible (see **Section 1**).

- As vacuum pumps for high vacuum often should or cannot be switched off overnight, improve sustainability aspects of the cold trap:
    - When utilizing cold traps for vacuum pumps, avoid the use of pure liquid nitrogen.
    - Frozen isopropanol is the preferable choice with a melting point of – 89°C and is sufficient for almost all cases, while not condensing oxygen. Frozen acetone has worse freezing properties and a less green solvent character.[2]

- Consider improving your high-pressure liquid chromatography (HPLC) purification by using HPLC columns with smaller inner diameter to reduce solvent consumption and waste creation. See also **Section 1** again to evaluate greener chromatography solvents such as ethyl acetate / ethanol mixtures or heptane.

- Reuse cartridges for automated flash column chromatography systems up to 5x (reverse phase up to 100x) as suggested by the supplier.

- Depending on the company and solvent provider, there are returnable solvent containers such as stainless-steel drums and barrels, which are cleaned and reused to minimize plastic and glass waste. Try to implement such a system within your facility (*e.g.* Supelco/Merck).

- Ensure proper labeling of chemical containers (disposal of unknown substances does not only increase the risk of accidents but also hampers adequate quenching/disposal).

- Install and share laboratory dishwashers to reduce solvent amounts needed for cleaning of glassware (include guidelines, so they are run only when full and use an environmentally friendly program with fewer cycles).

- Replace the drying agent in your lab with a less harmful alternative such as silica gel containing an orange iron salt instead of the more commonly used blue cobalt dichloride, which is toxic and carcinogenic.
  https://www.sigmaaldrich.com/NL/en/product/mm/101969

- Consider reusing solvents collected by evaporation in a rotary evaporator for cleaning.

- Use brushes for cleaning glassware to reduce the amount of solvents needed for cleaning.

- For the generation and applications of gases, an on-demand hydrogen generator can replace cylinders and reduce risks, while providing hydrogen from deionized water.

2.2 Plastic waste

The 3 biggest contributors to the plastic waste of laboratories are:[30]

1. Syringes and pipet tips;

2. Personal protective equipment (*e.g.* gloves);

3. Sample storage containers (*e.g.* tubes).[31]

Improve your plastic management *via* the **Reduce-Reuse-Recycle** principles (see below).[32–34] *"The most sustainable plastic is the plastic you do not use."*[35]

Reduce:

Purchase

- Buy in bulk when possible, and consider combining orders with other groups.
- Choose products with reduced plastic content and/or packaging.
- Reduce the number of suppliers and prioritize local shipments, thereby reducing the number of deliveries (which reduces packing material as well as shipping-related CO_2 emission).
- When ordering, ask for a Life Cycle Assessment (LCA) and check the provided '*ACT. Label*' by *My Green Labs* to buy the most sustainable piece of equipment (https://actdatabase.mygreenlab.org/).

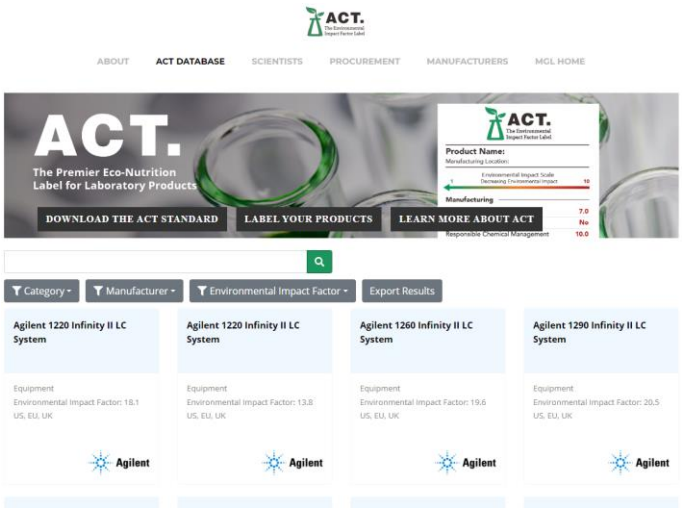


Figure 5: ACT (Accountability, Consistency, and Transparency) Environmental Impact Factor Label around manufacturing, energy and water usage, packaging and end-of-life.[36]

Laboratory

- Educate people on when to use certain products with lower environmental impact over other products, for example, the use of volumetric pipettes/graduated cylinders instead of plastic syringes.
- Only wear gloves when needed. Despite being disposable, they can be re-used several times and it is a good practice to do so, if safety considerations warrant it.
- Choose aliquot fractions and volumes wisely to reduce the number of required tubes/containers and to avoid unnecessary waste.
- Have a box with centrifuge counter-weights in order to avoid the need to prepare new ones every time.
- Use glassware instead of plastic whenever possible (**Figure 6**).[37]
    - An example would be the replacement of plastic weighing boats with weighing paper or by directly weighing the chemical into the reaction flask. One may also repurpose the paper found on the back of parafilm or using glass funnels (https://uk.vwr.com/store/product/543428/weighing-boats-pyrex or http://andersonscientific.co.uk/product/weighing-boat-10ml-pyrex/)
    - Replace plastic serological pipettes with glass serological pipettes (*e.g.* https://www.fishersci.com/shop/products/pyrex-reusable-color-coded-glass-serological-pipets-8/p-164703 or https://www.sigmaaldrich.com/NL/en/product/aldrich/cls708610)
    - Replace plastic petri dishes with glass petri dishes.
    - Glass equipment can be cleaned and reused easily, consider using glassware cleaner for stubborn stains, deposits, and silicones (https://www.sigmaaldrich.com/NL/en/product/aldrich/328693). Laboratory dishwashers also help in cleaning glassware effectively.
    - Replace plastic spreaders for E. Coli transformation with glass or metal spreaders sterilized with ethanol and flame.
- If there is no suitable plastic-free replacement possible:
    - Choose the smallest option (*e.g.* smallest pipet or container) to minimize plastic use.
    - Check if you can reuse the item, see next section *Reuse*.

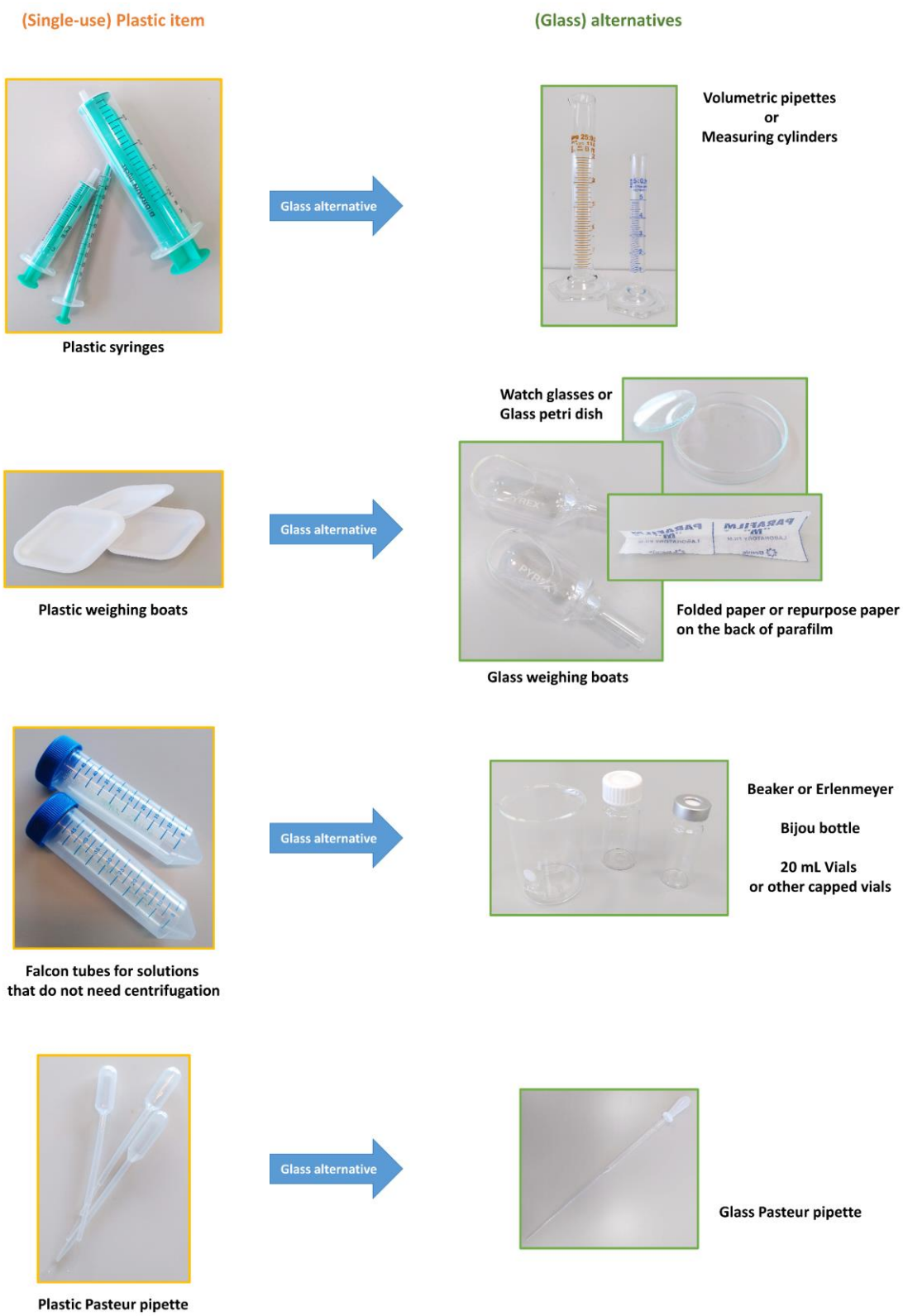


Figure 6: (Single-use) plastic items and their (glass) alternatives to reduce plastic waste.

Reuse:

- Reuse pipette tip boxes and fill them with bulk tips.
    - Refillable racks/refill tips (certified with the *ACT. Label*) can be a great option to make refilling and replacement efficient and convenient:[38]
        - https://www.mygreenlab.org/blog-beaker/sustainable-pipetting-how-to-reducing-plastic-usage-in-the-lab
        - https://www.fishersci.nl/shop/products/refillable-racks-eclipse-refill-tips-5/p-7194067
        - https://beta-static.fishersci.com/content/dam/fishersci/en_EU/suppliers/labcon/Eclipse_Brochure.pdf
        - https://www.mt.com/gb/en/home/products/pipettes/pipette-tips/pipette-tip-packaging-options/terrarack/TR-200F.html

- Reuse empty solvent canisters as waste canisters after taking them out of the inventory system (do not put a new label over the first one, but fully remove the original label – see also **Figure 4**).

- Return your polystyrene foam box/cooler to reduce waste sent to landfills. Evaluate if your provider participates in a polystyrene cooler return program and send it back after delivery of your chemical: https://www.sigmaaldrich.com/NL/en/services/support/recycling/polystyrene-cooler-return-program

  The University of Groningen has separate bins for the collection of Styrofoam/expanded polystyrene (EPS) boxes, which are recycled. Polystyrene boxes can also be reused as ice boxes for cold storage and transport. Furthermore, polystyrene materials are useful for safe storage of glass equipment.

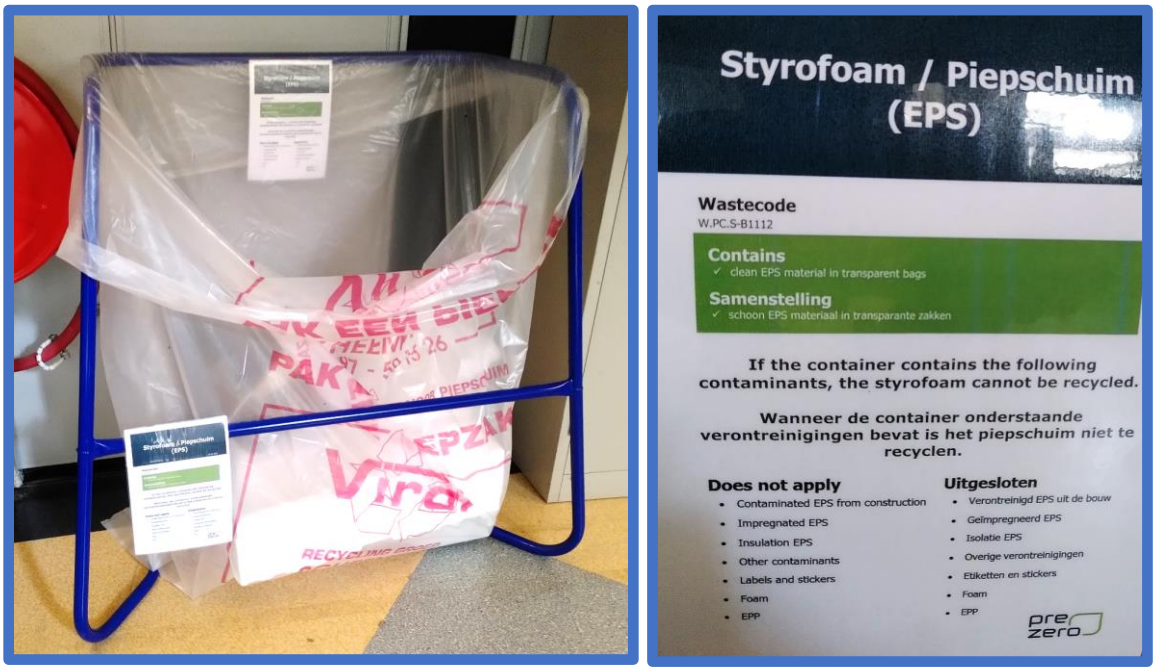


Figure 7: Reuse polystyrene boxes for cold storage and transport. If no further purpose is required, dispose in the designated bins.

However, a better solution is to replace expanded polystyrene coolers with alternatives made of paper and starch. This way a recyclable insulated shipping container made from cardboard is used. https://www.sigmaaldrich.com/NL/en/services/support/recycling/greener-cooler

- Reuse plastic items when possible:
    - Determine if the item can be cleaned sufficiently for the purpose.
    - Determine how to clean the item to maintain the quality of the product (*e.g.* a laboratory dishwasher may be too hot for certain plastics).
    - Be mindful that cleaning a product may also be costly (water use, electricity, among other things).
    - If the cleaning cannot guarantee the continued performance of the item as needed for experiments, the item may be used for pilot experiments or student practicals.

- Reuse cooling packs of deliveries to fill unused space in a fridge or freezer, this way the cold air circulation and thus energy loss is minimized.

  Examples of equipment that could potentially be decontaminated, cleaned and reused:
    - 96-wells plates
    - Non-filter pipette tips (*via* a pipette tip dishwasher)[39,40] https://gcbiotech.com/product-category/supplier/grenova/ http://grenovasolutions.com/
    - Tissue cups
    - 15/50 mL Falcon tubes
    - Autoclavable petri dishes
    - Drosophila embryo collection plates
    - Multi-channel pipette boats
    - DNA extraction columns
    - Filter tip boxes that cannot be refilled, may be reused with a different purpose, for example sample storage and organization both in labs and offices, after appropriate decontamination.

Recycle:

The University of Groningen introduced a new waste policy to better separate waste:
https://www.rug.nl/society-business/facility-services/afvalbeleid
https://www.rug.nl/about-ug/profile/facts-and-figures/duurzaamheid/beleid/afval

There are modular bins for paper, plastic, organic waste, coffee cups, and residual waste. While these bins are not present in the labs, CLEAN packaging material (*i.e.* not chemically/biologically contaminated) from the lab such as plastic and paper should also be collected in the normal recycling bins (**Figure 8**).

Figure 8: Implemented recycling system at the University of Groningen for the separation of paper, cardboard, plastic, organic waste, coffee cups and other waste. Non-contaminated waste from the lab (*e.g.* wrapping and packaging materials of syringes or vials can be disposed of in these containers).

The Green Labs team is in the process of implementing additional waste streams to **recycle pipette tips, plastics and gloves**.[41,42] One option towards a circular economy for single-use plastics could be provided through LabCycle (https://labcycle.org/).

Whereas **pipette tips** are best to be reused as often as possible and then being cleaned *via* a pipette tip dishwasher (https://grenovasolutions.com/tipnovus-4-2/), **syringes** and **falcon tubes** should be investigated to be cleaned in an autoclave.

For **protective clothing**, **safety glasses**, **and glove recycling** the local team should investigate solutions with external companies; options available in the Netherlands include:

- US: https://www.terracycle.com/en-US/ and for NL: https://www.terracycle.com/nl-NL
- https://www.terracycle.com/en-US/collection-programs?query=glove (US)
- https://www.terracycle.com/de-DE/collection-programs?query=handschuhe (GER)
- https://zerowasteboxes.terracycle.nl/collections/recyclingoplossingen-voor-industriele-locaties/products/persoonlijke-beschermingsmiddelen-zero-waste-box (NL)
- https://www.terracycle.com/en-GB/brigades/gloves (UK and NL)
- https://investor.kimberly-clark.com/news-releases/news-release-details/kimberly-clark-professionaltm-expands-rightcycletm-programme
- http://www.kimtech.eu/solutions/sustainability-rightcycler
- https://www.kcprofessional.com/en-us/solutions/rightcycle-by-kimberly-clark-professional

Figure 9: Possible recycling option for gloves and other single-use plastics through Terracycle towards furniture or tools.

Furthermore, the distillation of solvents such as washing acetone is recommended and should be investigated for the possibility of **acetone and solvent recycling**.[43] An acetone recycling program can be of interest in teaching labs/undergraduate labs especially. If necessary, purity can be measured *via* ^{1}H-NMR. Solvent recycling saves a considerable amount of money, not to mention savings on disposal costs of hazardous waste.[44] Further information: https://www.colorado.edu/ecenter/greenlabs/solventrecycling

For life sciences and biological labs many alternatives exist to reduce the plastic consumption.[45] **Liquid media** can be obtained for example in bigger bags (50L) to replace a plastic volume of 10 kg: https://recycling.pan-biotech.de/reduce-en/
If **PET cell culture bottles** are still required, they can be recycled as well: https://recycling.pan-biotech.de/recyceling-en/
The consumption of **serum** can be significantly reduced or replaced by serum-free systems: https://recycling.pan-biotech.de/replace-en/

Alternative and biobased products are already offered by *e.g.* Eppendorf, such as pipette tips and falcon tubes (both certified with the *ACT. Label*):

- https://www.eppendorf.com/nl-en/lab-academy/lab-solutions/eppendorf-consumables-biobased/
- epT.I.P.S.® BioBased (https://www.eppendorf.com/nl-en/eShop-Products/Liquid-Handling/Pipette-Tips/epTIPS-BioBased-p-PF-7756363)
- Eppendorf Tubes® BioBased (https://www.eppendorf.com/nl-en/eShop-Products/Laboratory-Consumables/Tubes/Eppendorf-Tubes-BioBased-p-PF-4440301)

2.3 Glass waste

Discarded vials, test tubes, and Pasteur pipettes are the biggest contributors to glass waste in chemical laboratories. Considerate use and (partial) reuse of such frequently employed disposables can help to reduce the total amount of laboratory waste.

Concrete actions:

- 1.5 mL vials with inserts can be reused without the inserts.

- Reuse NMR tubes whenever possible (and be cognizant of how to properly store and dry NMR tubes).

- Reuse test tubes for fraction collection of column chromatography instead of disposal, after rinsing when lightly contaminated. Wash test tubes after column chromatography while they are still wet which makes them easier to clean.

- Rinse capillaries for TLC spotting and reuse them.

- Repair and/or recycle broken glassware such as round bottom flasks, adapters, and others. Often universities have a technical department including a glass-blowing workshop, where glassware can be repaired easily.

2.4 Paper and cardboard waste

Reduce the amount of paper used in your laboratory by implementing an electronic lab journal (see also **Section 5**). Avoid printing of articles, slides, protocols, and notes; in short: anything that will be disposed after a short period of time. Prioritize working digitally *via* appropriate project management tools and laboratory wikis and share those files online with each other. This way commenting and version control is efficient and produces less paper waste. Read online literature as PDF document rather than print. Comply with national and university data management regulations and adhere to FAIR principles (https://www.go-fair.org/fair-principles/).

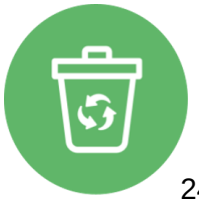
Concrete actions:

- Implement an electronic lab journal:
  Mbook: https://mestrelab.com/software/mbook/
  ELabJournal: https://www.elabnext.com/products/elabjournal/

- Reduce the number of printed copies PhD theses, articles, and notes.

- Prioritize working digitally. Share and access files online for feedback and updates.

- Reduce the daily amount of single-use coffee cups by bringing your own mug to the office.



2.5 Old or broken laboratory equipment

If devices and equipment are broken or indicate a defect, contact the responsible person or technician to repair and maintain the device. Most minor and many major errors can be fixed by the technicians, the workshop of the university, or by contacting the supplier/manufacturer.

Older devices and equipment are often deprecated and discarded, despite still being functional. Considerations such as low energy efficiency, lack of lab space, or lack of experienced users (former users finishing and moving on) play significant roles in such decisions. Because most devices are still functional, they could be donated to education or other research groups within and outside of the institute. Such donated equipment could particularly benefit groups with less funding. Next to academic research and educational labs, high schools and secondary schools could benefit from such devices.

Concrete actions:

- Fix defects and errors in devices early and make use of specialized technicians, workshops, or servicing companies to repair the equipment before discarding it.

- Organize a second-hand device and lab equipment market place to donate/sell/exchange old equipment locally or regionally. There are free online marketplaces for redistributing resources legally and conveniently within the university: https://www.warp-it.co.uk/

- There are certified refurbishing companies if local options are unfeasible:
    - https://www.labexchange.com/en/index.html
    - https://shop.labexchange.com/en/
    - https://www.labmakelaar.com/
    - https://www.unigreenscheme.co.uk/
    - https://equipsent.org/
    - https://s-a-le.nl/used-laboratory-equipment/
    - https://www.agilent.com/en/product/certified-pre-owned-instruments
    - https://rheaply.com/
    - https://rheaply.com/circular-economy/

2.6 Used lab coats

One underestimated issue are lab coats. Most wet labs utilize 100% cotton lab coats, which are washed and reused over the course of several years. However, as soon as staff departs the lab, lab coats often stay behind, they are washed and cleaned for reuse, but end up in a cabinet. Before buying new lab coats for every new member or student, prioritize reusing clean and washed lab coats from previous laboratory members. Also, students, who just started their studies often need to buy lab coats themselves, so it may be even better to donate old lab coats to first year students.

Concrete actions:

- Reuse and wash lab coats
    - throughout a single research project.
    - from former lab members for new arriving staff.
    - and donate clean lab coats to undergraduate students.

Figure 10: Often old lab coats of previous staff are left behind in institutes, which are cleaned and washed. Reuse them as much as possible for new arriving members or donate to first year students.

3. Water

Preserving water resources is a crucial aspect when it comes to laboratory sustainability. Water has to be cleaned, transported, stored and cleaned again before being returned to the environment. Next to the limited amount of fresh water, those actions require energy and have a significant carbon footprint.[46]

Concrete actions:

- Autoclaves use vast amounts of water to sterilize equipment, reagents and waste. They are the biggest water consumers in a laboratory. One cycle can use up to 228 liters of water. There are water-saving devices to retrofit autoclaves with.[46]
    - Autoclaves should only be run at full capacity.
    - Turn off the autoclave over night to save water and energy.
    - Retrofit autoclaves with water-saving devices.
    - Consider replacing older equipment with research grade autoclaves to save 93% water and reduce energy consumption.

- Utilize low-flow aerators in all faucets (*i.e.* taps) of the laboratory, but also restrooms and kitchens. This way water flow is reduced from 15 liters per minute to 5.7 liters per minute while maintaining the desired pressure.

Figure 11: Aerators for faucets, which should be used in all taps of the laboratory, restrooms, and kitchens to save water.

- Single pass cooling should be avoided to preserve water resources. Replace water-cooled condensers with air-cooled or Vigreux condensers (air-cooled condensers work the best for solvents with boiling points >50 °C; *e.g.* https://www.asynt.com/product/asynt-condensyn-air-condenser/).
    - Depending on the type and specifications of air-cooled condensers, use of low boiling point solvents such as dichloromethane (DCM) may be possible: https://heidolph-instruments.com/Knowledge-Blog/Buyers%20guides/Buyers-Guide/Buyers-Guide-Findenser-2020-EN.pdf
    - Utilize closed-cycle cooling systems in combination with liquid-cooled condensers for solvents with a low boiling point, instead of traditional water cooling. If water cooling is needed, circular systems or thermostats are the optimal choice.

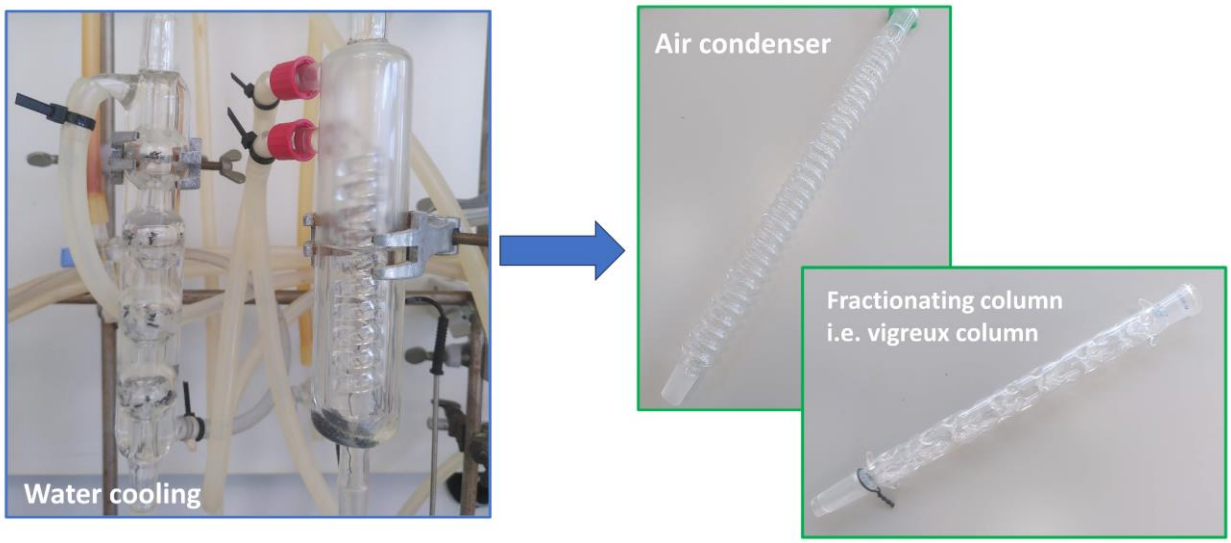


Figure 12: Replace water-cooled condensers with air-cooled or Vigreux condensers.

- Use water wheels (*i.e.* 'paddle wheel flow meters') to monitor flow and avoid unnecessary fast flow (circular system preferred).

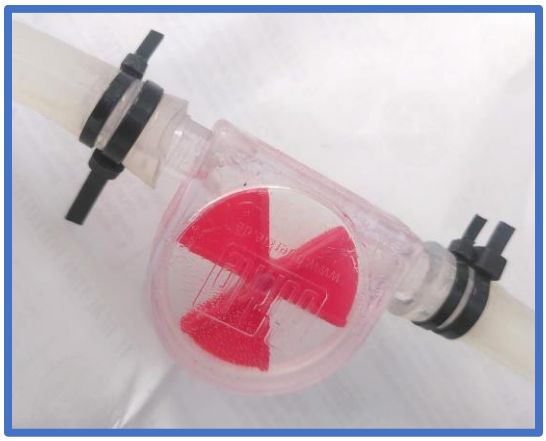


Figure 13: Paddle wheel flow meters or water wheels to monitor flow of cooling liquid.

- Replace water vacuum aspirators with regular vacuum pumps. Utilizing water vacuum aspirators for 2 hours per day wastes more than 227000 liters annually, corresponding to the annual water usage of 750 people. Regular vacuum pumps reach higher vacuum and have better performance.[47]

- When using ice, use minimum amount necessary. Do not fill cooling baths, or styrofoam boxes up to the top unless strictly necessary.
    - Use cooling blocks for tubes instead of ice (see for example these PCR tube cooling blocks: https://online-shop.eppendorf.nl/NL-en/Temperature-Control-and-Mixing-44518/Accessories-44520/PCR-Cooler-PF-55940.html or https://www.coleparmer.com/p/corning-coolrack-microcentrifuge-tube-and-pcr-plate-cooling-blocks/72104.

- Glassware does not always need to be washed (in the dishwasher) after use, it could be used multiple times for the same substance.

- Only run dishwashers when they are full. Use dishwasher programs with fewer cycles if possible.

- When cleaning glassware and washing dishes do not leave the faucet running, while walking away, stay close to a running water source.

- Be mindful about the purity grade of water needed for the procedure. As purification processes are not running at 100% efficiency. Making 1 liter of deionized water takes about 3 liters of water. Utilize purified water only when needed.

- Check for leaks near autoclaves, ice machines, thermostats, water cooling equipment, faucets and taps. Report these leaks immediately to save not only water resources but keeping laboratory equipment intact.

- When Milli-Q grade water is needed for experiments, consider utilizing equipment for its generation with a reduced environmental impact in energy, waste, and water (*e.g.* Milli-Q® IQ 7003/05/10/15 systems from Sigma-Aldrich/Merck, https://www.sigmaaldrich.com/NL/en/technical-documents/technical-article/analytical-chemistry/wet-chemical-analysis/milli-q-iq7003-7005)

4. Energy

Simple interventions can lead to considerable savings of up to 50% in energy consumption for wet labs.[48,49] Involvement and education of lab members is essential: group members will be more motivated to save energy if the managers themselves indicate that this is an important goal for the group.[50] Moreover, people may not always be aware of the impact that simple actions can have. Talk to them about the laboratory's mission to reduce energy usage and how they can contribute. Many of our staff members and students are very climate aware and will be eager to help![51]

As laboratory spaces are expensive to build and to maintain because of ventilation, the optimal and safe use of existing laboratory space should be the first priority.[52,53] Optimize the lab space as efficiently as possible by repurposing and sharing underutilized fume hoods with other laboratories. Make sure laboratory space is not unused or overcrowded. Scientists from different research groups should evaluate shared spaces for similar laboratory processes and designate space based on its function.[54]

Concrete actions:[52] *ordered by impact*[55]

- Keep fume hoods closed as much as possible, and close the sash completely at the end of the day. Variable air volume fume hoods automatically reduce the air flow when the sash is lowered, which saves energy. Fume hoods consume 3 to 3.5 times more energy than ultra-low temperature freezers and are the single most-energy intensive service in laboratory buildings.[32]
  Whether it saves energy or not, a closed sash is safer than an open one (**Figure 14**).

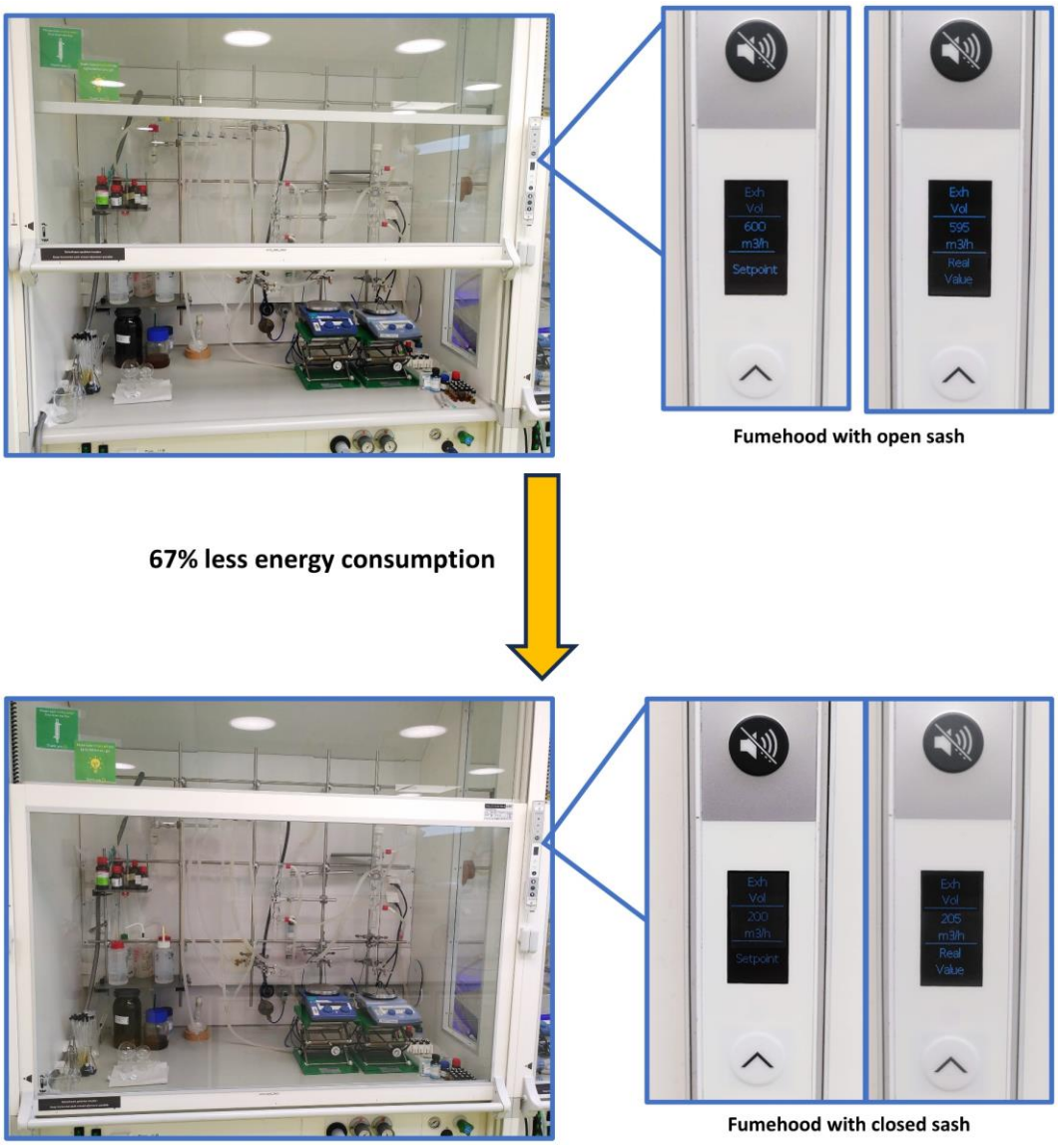


Figure 14: Keep fume hoods closed as much as possible. Each fume cupboard consumes as much energy as 2-3 houses annually. Stickers can remind users to close them after usage.[56]

In new laboratories fume hoods are often equipped with a light sensor and an automated closing system. Here the sash closes automatically after 5 minutes. However, lab users should check regularly on the light sensors ensuring they are still functional to keep the automated closing system running. This automated closing system should stay enabled at all times and not be turned off. Any issues should be reported to facilities management immediately.

Figure 15: a) Ensure that the light sensors are functional at all times. b) Do not change the settings of the fume hood to keep the automated closing system enabled.

In some cases, an automated system exists to lower the air flow of the fume hood even further overnight (**Figure 16a**). While complying with safety rules and not interfering with experiments, it should be considered to turn off fume hoods overnight.

Figure 16: a) Some fume hoods automatically reduce airflow overnight. b) Sometimes due to air pressure and heating requirements of the building some fume hoods need to stay on during the night. c) Depending on the manufacturer there is also the possibility to manually turn off the fume hoods.

- Increasing the temperature of a –80 °C freezer to **–70 °C** reduces its energy consumption up to 30%.[57–61]
    - https://www.freezerchallenge.org/resources.html
    - https://www.etcc-ca.com/reports/ultra-low-temperature-freezers-opening-door-energy-savings-laboratories
    - https://doi.org/10.1504/WRSTSD.2013.050786

Figure 17: Increase the temperature of a –80 °C freezer to –70 °C to save energy. An ultra-low temperature freezer consumes as much energy as a household annually.[56]

Further actions:[32]

- Conduct maintenance *i.e.* cleanup of the freezer and defrosting twice per year.
- Ensure that door seals are not blocked by excess ice or frost, and close securely.
- Clean filters from dust accumulation every 3 months as it increases energy consumption by 14%-25%.
- Have proper spacing for the freezer (*i.e.* distance to wall) and assess the ambient temperature of the room.
- Open and close the doors quickly (less than 30-45 seconds) to avoid frost buildup and a rise in temperature.

- Keep an updated inventory list of samples inside the freezer and regularly sort out unneeded samples.

- Turn off ovens that are not in use.
  - Only turn ovens on when you need them, it usually takes 30 minutes to heat up from 25°C to 100°C.
  - Run the oven on a timer and avoid operating overnight.
  - Operate at minimum temperatures necessary.
  - Do not use the oven as storage facility for glassware.

- Increase the regular freezer temperature from –25 °C or –20 °C to **–15 °C**.

- Routinely defrost freezers to clean off ice and old samples during semiannual lab cleaning. Ice and overfull drawers or shelves hamper the air circulation and increase energy consumption.

- Turn off heaters for warm water at the laboratory water sink, when warm water is not used frequently.

- Switch off laboratory equipment when not in use:
  - Always consider safety!
  - Switch off unused water baths, cooled centrifuges, lighting, thermostats, pH-meters, balances, heating plates, *etc*.
  - Implement a stoplight sticker system (see *appendix*) to indicate when to turn off equipment and when to keep on (*e.g.* for instrument performance or safety reasons). Make use of multiplugs or power strips for convenience and if safe to do so.
  - Share equipment and devices with other lab members and staff from the institute.
  - Computers should be turned off at the end of the day. For convenience, they can be programmed to turn off automatically after work (see manual in *appendix*). Furthermore, you can set the computer to go into sleep mode after the computer has not been used for a certain time (settings → system → power&sleep → set after how many minutes the PC goes to sleep).

- Power strips/multiplugs with switches are recommend as this can additionally reduce energy consumption by preventing wattless currents when the switch is set to “off” (see **Figure 18**). Built-in surge protection can protect equipment from power spikes.
- Time switches (*i.e.* outlet timers) can be used on equipment that can be switched off during the night and does not require shut down (*e.g.* https://ap.lc/S88hD). This way, before the laboratory members arrive in the morning, the equipment is cooled down/heated up again without any downtime for experiments during the day.

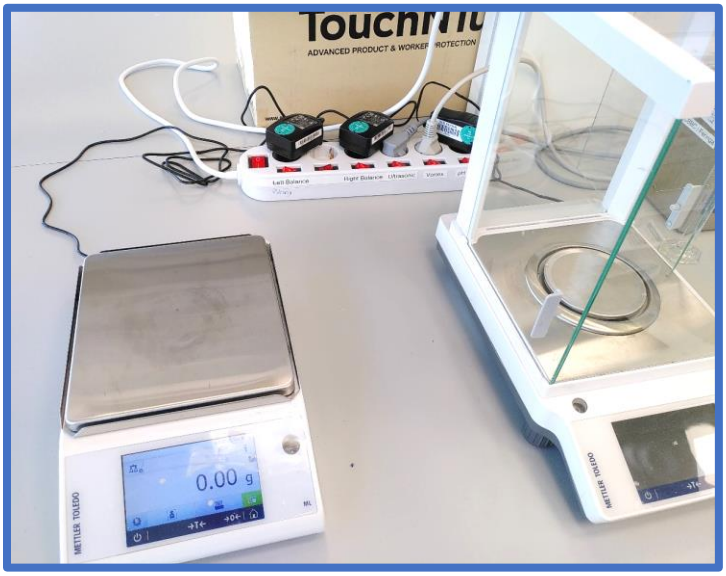


Figure 18: Utilize multiplugs as much as possible to have equipment switched on only when necessary or make turning off equipment convenient for the end user.

- Ensure water baths have a cover. For instance, use plastic water bath balls for rotary evaporators to cover the open water (**Figure 19**). They prevent heat loss, evaporation (up to 90%), reduce oxygen input, reduce odors and levels of algae growth in the water. (https://www.asynt.com/product/water-bath-balls/ or https://www.sigmaaldrich.com/NL/en/product/aldrich/z743209)
    - Avoid running the rotary evaporator overnight, unless required.

Figure 19: Plastic balls in the water bath of a rotary evaporator to prevent energy loss in form of heat.

- If experiments allow, turn down/off the laboratory thermostat and/or air conditioning during and at the end of the day. The same applies to heaters in offices.

- Set the fridge temperature to 7°C, instead of a lower temperature.

- Check if all equipment is turned off at the end of the day/before the weekend.

- Use posters and stickers to remind people to turn off equipment, computers, and lights when they leave the lab. Utilize an ´end of day´ checklist.

- Make sure that the light is switched off at the end of the day. In many laboratories, light can be dimmed even throughout the day. The same applies for fume hood lighting.

- When equipment is replaced, make sure to choose sustainable new equipment:
    - Choose electrical equipment with low energy demand. Especially freezers and fridges have become much more energy friendly in recent years. Leverage the information contained in the energy labels to determine whether an appliance has good sustainability properties (https://www.energielabel.nl/apparaten). Ask for a Life cycle assessment (LCA) and check the provided '*ACT. Label*' by My Green Labs to buy the most sustainable piece of equipment (https://actdatabase.mygreenlab.org/).[62]
    - Replace oil baths with metal heating blocks.
        - https://us.vwr.com/store/product/4698629/vwr-modular-heating-blocks-for-standard-test-tubes
        - https://www.coleparmer.com/p/accessories-for-ika-synthesis-packages/64812
        - https://www.ika.com/en/Products-LabEq/Dry-Block-Heater-pg909/DB-58-4470200/
        - https://www.fishersci.ca/shop/products/heidolph-heat-on-blocks-14/p-4371463
        - https://www.coleparmer.com/i/ika-h-135-107-block-100-ml-3-1-x-3-1/0467207
        - https://www.getmedonline.com/ika-db-5-7-single-heating-block-4470100.html
        - https://www.labgearusa.com/reaction-blocks-for-heating-and-stirring-round-bottom-flasks/

Figure 20: Metal heating block as efficient and safe replacement for oil heating baths.

- Replace oil pumps with scroll or screw pumps (see **Section 2.1** for cold trap improvements).
    - https://www.vacuubrand.com/us/page1501.html
    - https://shop.vacuubrand.com/en/screw-pump-vacuu-pure-10c-vp-9177.html
    - https://shop.vacuubrand.com/en/screw-pump-vacuu-pure-10-vp-9179.html

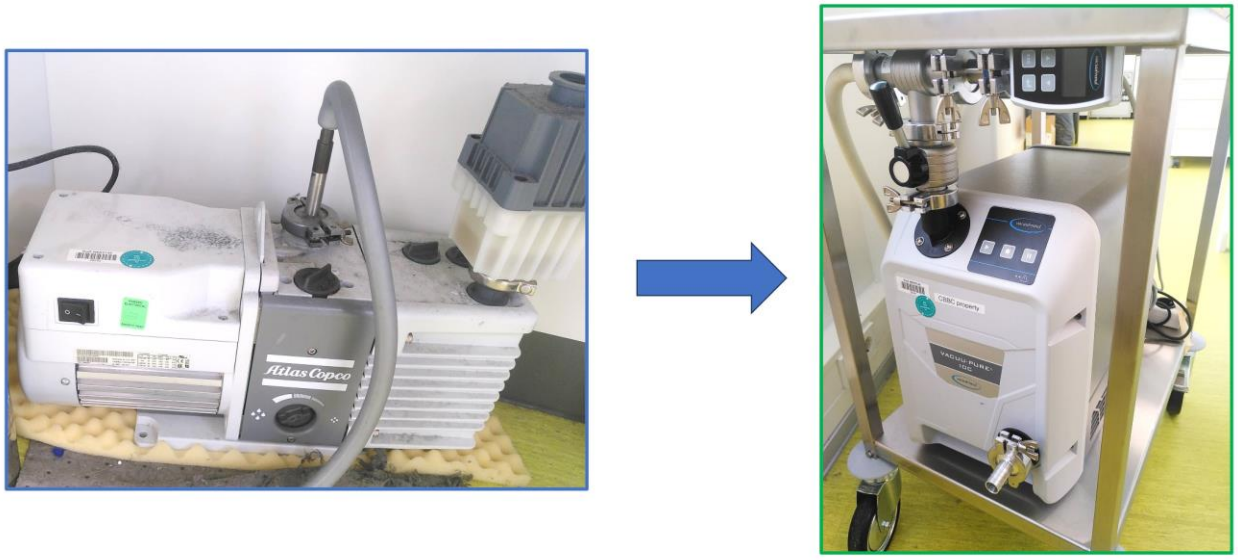


Figure 21: Screw pumps as replacement for oil pumps. For cold traps utilize frozen isopropanol instead of liquid nitrogen or frozen acetone. It is the preferable choice with a melting point of – 89°C, sufficient in almost all cases, and has better freezing and environmental properties.

5. Research data handling and internet usage

Data management is subject to national and university regulations. Every researcher is required to have filled in a data management plan before starting experimental work. Data management should meet FAIR standards: Findable, Accessible, Interoperable, and Reusable.[63] Should questions arise, get in contact with your data steward or a representative from the university´s Digital Competence Center (DCC, https://www.rug.nl/digital-competence-centre/?lang=en). The use of an electronic lab journal is strongly recommended: observations and conclusions can be combined with all analytical data such as yield, NMR, IR or HRMS spectra, linked to previous literature, and all experimental data remains traceable and transparent even after staff have left the university.

Concrete actions:

- Implement an electronic lab journal:
  Mbook: https://mestrelab.com/software/mbook/
  ELabJournal: https://www.elabnext.com/products/elabjournal/

- Opt for energy efficient devices.

- Use the search engine Ecosia (https://www.ecosia.org/), which is powered by renewables only, to support planting trees while looking up information on the internet.

- Switch online meetings to audio only to reduce emissions by up to 96%.[64]

- Evaluate the necessity for online meetings and replace with asynchronous alternatives such as project management tools or email where appropriate.

- Clean out your digital inbox on a regular basis, to avoid unnecessary storage in data centers and thus energy consumption.

- Sign up for the newsletter of the Green Office or Green Labs team of your institution.

6. Dry labs and computational science

In a dry lab, experiments are performed using data, algorithms, and computational resources. When it comes to dry labs and environmentally sustainable computational science, a coordinated approach is needed. Here the GREENER principles by Lannelongue and co-workers can serve as a great starting point.[65–67]

Concrete actions:[68,69]

- Identify the hardware used in the dry lab:
    - Get in contact with the IT department and include them as much as possible to determine the number of servers and type of clusters used, as well as the specifications of the computational facility (location, power usage effectiveness (PUE), carbon usage effectiveness (CUE), *etc.*).
    - Make an inventory of all the hardware currently maintained and used for simulations:
        - Measure the energy consumption of your hardware during both computer simulations and idle times.
        - Consider whether newer hardware would reduce energy consumption significantly.
    - Create an overview of all the high-performance computing facilities used for simulations:
        - Determine what type of computations are performed on what type of equipment.
        - Ask the management of the high-performance computing facilities to provide information on power usage effectiveness (PUE) and energy source.
        - Consider moving some of the computations to different computing facilities based on energy source and energy usage of the corresponding facilities.
    - Investigate the efficiency of the computational resources, older hardware is typically less energy efficient. Running energy efficient software on old hardware is detrimental to the overall energy efficiency.
    - Use sustainability metrics to quantify the level of sustainability of the high-performance computing (HPC) facilities and identify areas of improvements.[70]

- Create an overview of all the third-party simulation software used in the group:
    - Determine what type of computations are performed with what type of software.
    - Identify what software is running in the dry lab, and ensure it is up to date and uses the latest, most efficient libraries and dependencies.
    - Determine the hardware utilization of the corresponding computations and record them as well.
    - Consider whether alternative simulation software is more efficient and sustainable but provides equivalent results.

- Create an inventory of all large datasets stored and used by the group and their corresponding storage locations.
    - If the large dataset can be regenerated readily, consider only storing the information required for its regeneration.
    - Consider whether alternative storage locations are more efficient for the dataset.

- Quantify the carbon footprint of computations:
    - Utilize: https://www.green-algorithms.org/
    - Optimize the use of computing resources needed (*e.g.* number of cores, running time, and data center efficiency).
    - Evaluate if the temperature of the air conditioning (*i.e.* set point temperature) in server rooms can be increased, to reduce active cooling.
    - Reduce the carbon intensity by considering the location and production methods of the energy (*e.g.* wind and solar *vs.* nuclear, gas or coal).
    - Educate new students and staff about the energy efficiency of software, algorithms, and code. Introductory materials on sustainability should be available to all new students and staff who utilize the dry lab.

- Improve training and implement sustainable policies for reducing energy consumption, renewing hardware, and storing data.
    - Computer power management settings, such as sleep timeout, and computer monitor brightness should be reviewed. Also include Dynamic voltage and frequency scaling (DVFS) in this review.
    - Large data sets should be identified and deduplicated to reduce storage requirements and energy consumption.
    - Make use of checkpointing, when possible, to minimize the number of repeated simulations or analysis steps.
    - Provide access to low-carbon computing facilities and dynamically shift jobs from data centers across multiple locations to where wind and solar generate excess electricity.[71–74]

- Utilize and apply principles of open science as much as possible.[75]

- Include carbon footprints in cost-benefit analyses, as well as in the Life Cycle Assessment of new hardware purchases.

- Create a second-hand IT-market place to share/donate/sell equipment and hardware before throwing it away. There are free online marketplaces for redistributing resources legally and conveniently within the university: https://www.warp-it.co.uk/

- There are certified refurbishing companies if local options are unfeasible:
    - https://www.unigreenscheme.co.uk/
    - https://rheaply.com/
    - https://rheaply.com/circular-economy/

7. Life sciences and *in vivo* models

Lab users should critically assess the use of animal testing in their research to reduce animal suffering and environmental impact. For ethical and sustainability reasons, the number of animals used for experiments should be reduced.[76] It has been demonstrated, that the number of animals used in control groups can be reduced by half without losing statistical power, if historical control groups are included in the studies.[77]

Animal models often fail to mimic clinical disease adequately and human subjects have been harmed in clinical testing of drugs that were deemed safe by animal studies.[78–81] Moreover, the success rate from animal model-based studies to clinical evaluations can be as low as 10% or less.[78–85] In fact around 92% of the drugs tested in animals as preclinical step, fail to pass to the clinical stage.[86]

In view of sustainability, resources should therefore be invested in developing alternatives to animal models. Alternatives such as *in silico* modelling,[87] *in vitro* assays,[82] organ-on-a-chip technology,[88] omics and mathematical biology, as well as high-throughput screening[89] should be considered. This way complementary information for a complete picture of the potential response of an organism to a chemical stressor is obtained.[87,90]

8. Training and implementation

We encourage laboratory and research managers to share this document with all group members and spread the information proactively.[91]

Education is an important first step towards "greener" labs, as many people are willing to implement new, more sustainable measures. Many researchers, however, may not know how to do so or may not be aware of the impact that their actions have on the environment.[56,92] In addition, it must be benevolently considered that humans are creatures of habit who are prone to fall back into old patterns. For this reason, following the path towards sustainable wet and dry laboratories is tackled best in a team spirit by mutual encouragement and respect, especially in the early stages until new procedures have been internalized.

A guidebook can only provide generalized procedures and recommendations. As the specific experiments and procedures can differ greatly from laboratory to laboratory, the general information provided here must be adapted to the very individual situation given in your research environment.

- Include this document in your laboratory introduction. Adapt safety introductions for starting staff to include training on sustainability.
- Send around the link to this document to all current users (it will be updated regularly).
- Organize a meeting with all group members and laboratory users to brainstorm which specific actions can be taken in your environment. They might have even more ideas than we did.[93]
- This guidebook can also be a great opportunity to educate new incoming students to achieve a paradigm shift over the upcoming years towards a Green Lab culture. Include it in the introduction procedure of research as well as teaching labs.
- Establish a laboratory culture and mindset, where environmental sustainability is expected and normalized.[94]
- Adapt the document and create your own guide specifically designed for your laboratory situation, which explains to researchers which products can be replaced or reused. A template for this can be found in **Appendix 2**.

9. Green conferencing, meetings and travel

Attending conferences and meetings has a significant impact on the environment.[95,96] In fact, the travel-related footprint of one conference is equivalent to the annual footprint of 1000 laboratories.[97]

The University of Groningen has implemented a policy for sustainable travel within Europe: always take the train for journeys up to nine hours (https://www.rug.nl/about-ug/profile/facts-and-figures/duurzaamheid/nieuws/sustainable-new-travel-policy?lang=en). We recognize the importance of networking during conferences, which is more 'enjoyable' in person.

Concrete actions:

- Attend conferences and meetings online whenever possible and make use of electronic communication.
- Prioritize the attendance at local conferences.
- Go by train whenever possible. There is good infrastructure for trains and night trains in Europe – moreover, the university allows you to buy first class tickets, when you use international trains. There are several great tools to find and book trips across countries to reach conferences:
  https://www.chronotrains.com/en
  https://www.night-trains.com/europe/
  https://www.eurostar.com/
  https://www.eurail.com/en/get-inspired/trains-europe/night-trains
  https://www.interrail.eu/en,
  https://www.omio.com/
  https://www.nsinternational.com/en
- When you must go by airplane, you can compensate for your carbon dioxide by using websites like https://www.atmosfair.de/en/, that allows you to contribute (depending on your flight) to sustainable projects and research on sustainable jet fuels.
- Try to book direct flights to your destination; layovers increase the carbon footprint of your trip (https://ecopassenger.org/).

10. Accreditation frameworks and auditing

While implementing the recommended changes it can be highly rewarding and motivating to join one of the several accreditation frameworks for sustainability in laboratories. This way group members do not need to reinvent the wheel on *how* to make their labs more sustainable. Following the criteria of these accreditation frameworks provides resources as well as specific actions to achieve an improved laboratory. Regular audits ensure that research practices stay as green as possible and a ranking system (*e.g.* bronze, silver gold) is creating not only engagement but also a competitive mindset within your institution. This way greener lab practices are spreading more quickly and the focus on environmental impact could inspire new students to join our university and your research group. Consider applying for these accreditation programs to accelerate progress:

- ***L**aboratory **E**fficiency **A**ssessment **F**ramework* (*LEAF)*[98–100]
  https://www.ucl.ac.uk/sustainable/leaf-laboratory-efficiency-assessment-framework

- The *My Green Lab* certification[101]
  https://www.mygreenlab.org/green-lab-certification.html

- GES 1point5[102]
  https://apps.labos1point5.org/ges-1point5

- GreenED Framework for Environmentally Sustainable Emergency Medicine and Health Care[103,104]
  https://greened.rcem.ac.uk/

- Green Impact[105]
  https://greenimpact.nus.org.uk/

- Framework for building sustainability and green building rating system: LEED (Leadership in Energy and Environmental Design)
  https://www.usgbc.org/leed

11. Networks, schemes, resources, and education

Networks:

Green Your Lab
http://greenyourlab.org/

Sustainable European Laboratories
https://sels-network.org/

Max Planck Sustainability Network
https://www.nachhaltigkeitsnetzwerk.mpg.de/

Green Labs NL
https://www.greenlabs-nl.eu/

Laboratory **E**fficiency **A**ction **N**etwork (LEAN)
https://www.lean-science.org/

Green Labs Austria
https://greenlabsaustria.at/

Sustainable Labs Canada
https://slcan.ca/

Labos 1point5 (France)
https://labos1point5.org/

Green Labs Portugal
https://greenlabs.pt/

Irish Green Labs
https://irishgreenlabs.org/

Non-Profit:

International Institute for Sustainable Laboratories (I^2SL)
https://i2sl.org/

My Green Lab
https://www.mygreenlab.org/

Schemes:

Laboratory **E**fficiency **A**ssessment **F**ramework (LEAF)
https://www.ucl.ac.uk/sustainable/leaf-laboratory-efficiency-assessment-framework

My Green Lab certification
https://www.mygreenlab.org/green-lab-certification.html

Resources:

Royal Society of Chemistry report: Sustainable laboratories.
https://www.rsc.org/policy-evidence-campaigns/environmental-sustainability/sustainability-reports-surveys-and-campaigns/sustainable-laboratories/

Wellcome report: Advancing environmentally sustainable health research.
https://wellcome.org/reports/advancing-environmentally-sustainable-health-research

CaRe 2021: Catalogue of Recommendations for Sustainability in the Max Planck Society.
https://doi.org/10.17617/1.mpsn.2021.01

Sustainability in Science Wiki:
https://sustainability.wiki.gwdg.de/

Allea report: Towards Climate Sustainability of the Academic System in Europe and beyond
https://allea.org/portfolio-item/towards-climate-sustainability-of-the-academic-system-in-europe-and-beyond/

Education:
Beyond Benign
https://www.beyondbenign.org/

Open resources and blogs:
Labconscious
https://www.labconscious.com/

Assessing and comparison of energy usage, emissions and practices of a lab:
Laboratory Benchmarking Tool
https://lbt.i2sl.org/

Podcast:
The Caring Scientist: Mission Sustainable
https://podcasters.spotify.com/pod/show/caring-scientist

Green Chemistry:
American Chemical Society and the ACS Green Chemistry Institute
https://www.acs.org/greenchemistry.html

United Nations Industrial Development Organization (UNIDO)
https://www.unido.org/our-focus-safeguarding-environment-resource-efficient-and-low-carbon-industrial-production/green-chemistry

Green Chemistry Teaching and Learning Community (GCTLC)
https://gctlc.org/

Products:

Merck and Sigma-Aldrich: Sustainable lab products, solutions & services for responsible science.
https://www.sigmaaldrich.com/NL/en/campaigns/sustainable-chemistry

Starlab: Sustainable product alternatives
https://www.starlabgroup.com/GB-en/sustainability-uk.html

Glove recycling possibilities:

- https://www.terracycle.com/en-US
- https://zerowasteboxes.terracycle.nl/collections/recyclingoplossingen-voor-industriele-locaties/products/persoonlijke-beschermingsmiddelen-zero-waste-box
- https://www.terracycle.com/en-GB/brigades/gloves
- http://www.kimtech.eu/solutions/sustainability-rightcycler

Pipette tip washer
https://gcbiotech.com/product-category/supplier/grenova/
http://grenovasolutions.com/

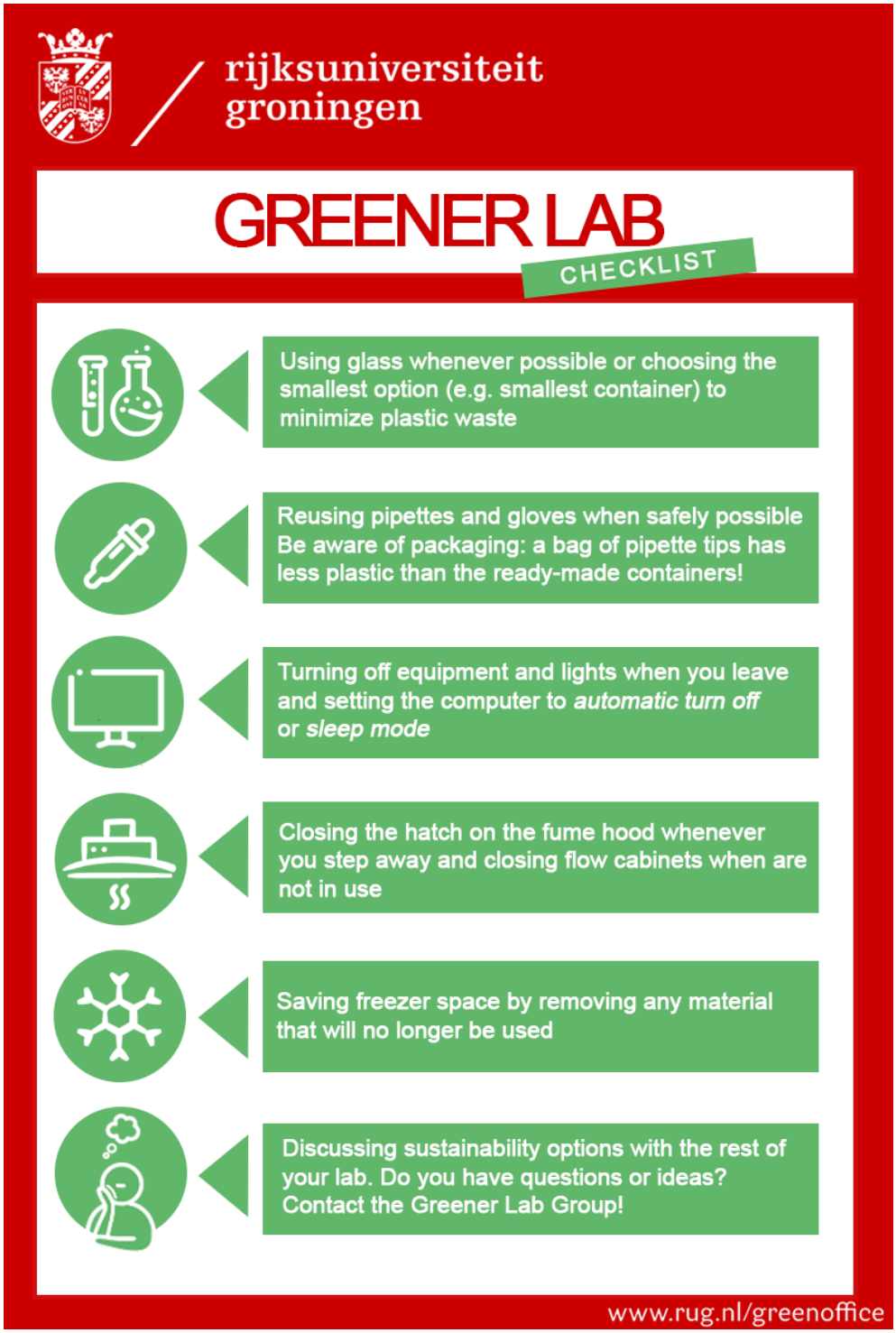
IKA Twister, replacing vortex mixers/magnetic stirrers/orbital shakers in one device
https://www.ika.com/en/Products-LabEq/Magnetic-Stirrers-pg188/TWISTER-SET-1-20027010/

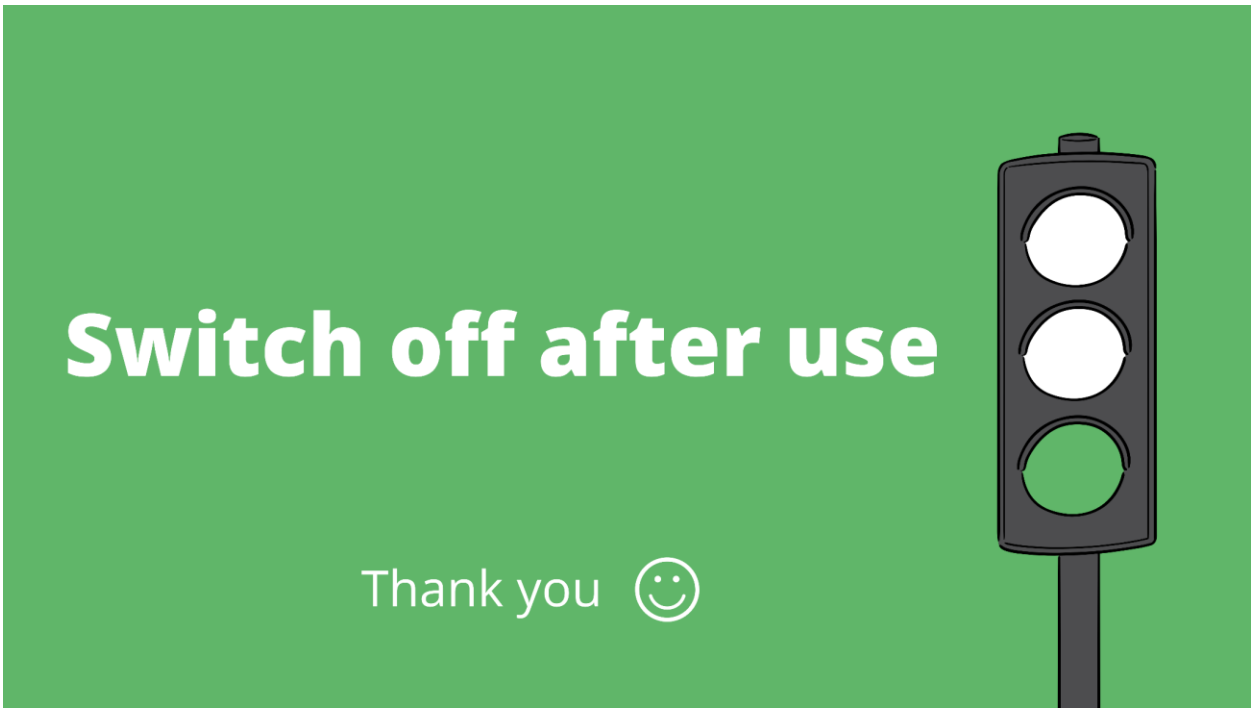
Bioplastic based products:
https://www.labcon.com/products.html

Biodegradable flasks:
https://crystalgen.com/catalogsearch/result/?q=biodegradable

Environmentally friendly thermometer:
https://us.vwr.com/store/product/4763398/vwr-enviro-safe-environmentally-friendly-liquid-in-glass-pocket-thermometers

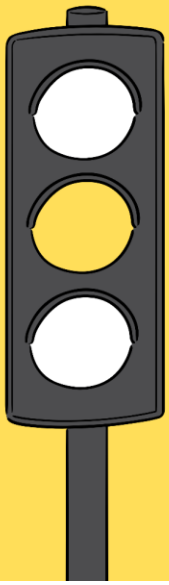
Appendix 1: Overview of available posters and stickers



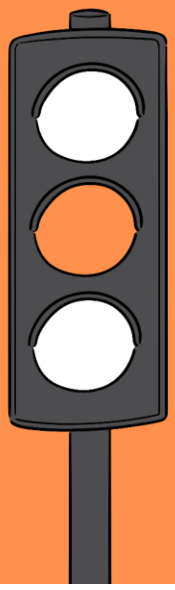


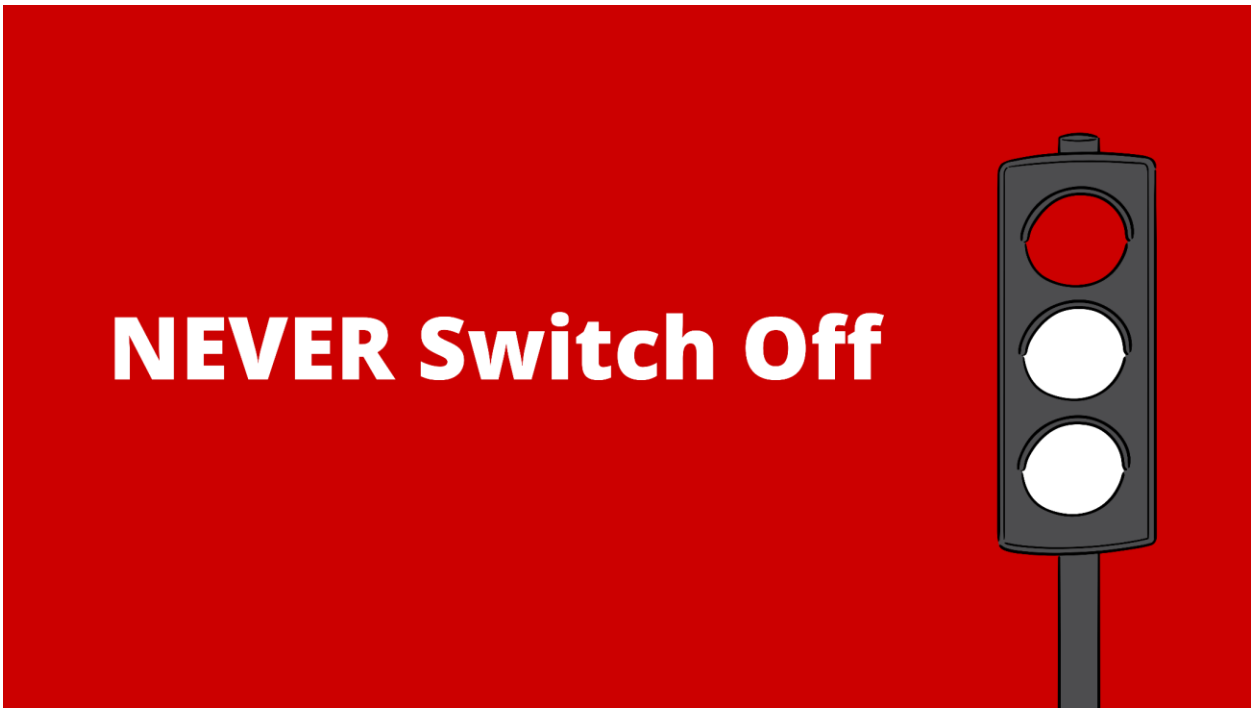
Switch off at the end of the day

Thank you ☺



ASK before switching off





Remember to close the fume hoods when leaving the station!

Thank you ☺

Switch off your computer before leaving the office!

Thank you ☺

Make sure to turn off the lights before you go!

Thank you ☺

Please save cooling water!
Slow down the flow

Thank you ☺

Please check the calendar:

Is someone using the machine after you?

YES
Leave it on!

NO
Switch it off!

Thank you ☺

Do not forget to help the UG recycle non-hazardous waste!

Thank you ☺

Appendix 2: Information sheet template

Every lab is different! Many different products are used or similar products have different requirements for how clean they need to be. It could help to create a simple list for (and together with!) your lab-users which products in your specific lab can be replaced or reused.

Reduce

Single-use product	**Procedure**	**Alternative**
Syringe	*Measure volumes*	*Volumetric pipette/ graduated cylinder*

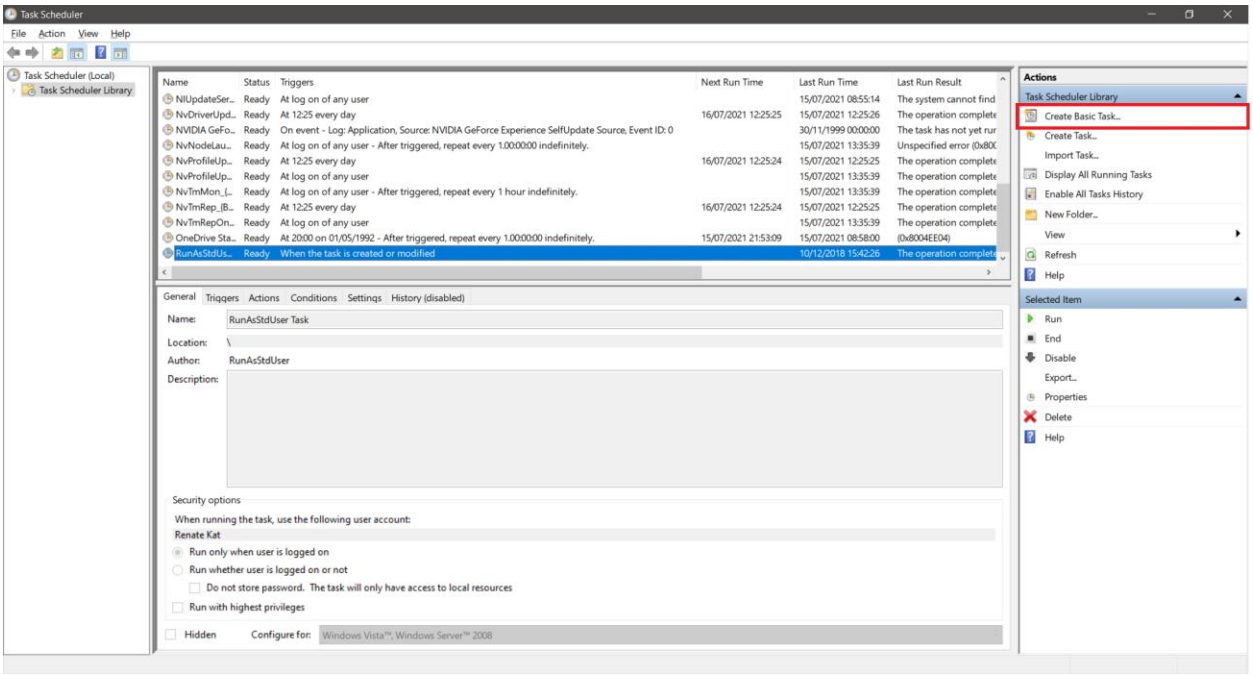
Reuse

Products that can be reused	**Instructions**
Test tubes	*Wash with acetone*
1.5 mL vials that have been used with insert	*Remove insert, reuse vial*

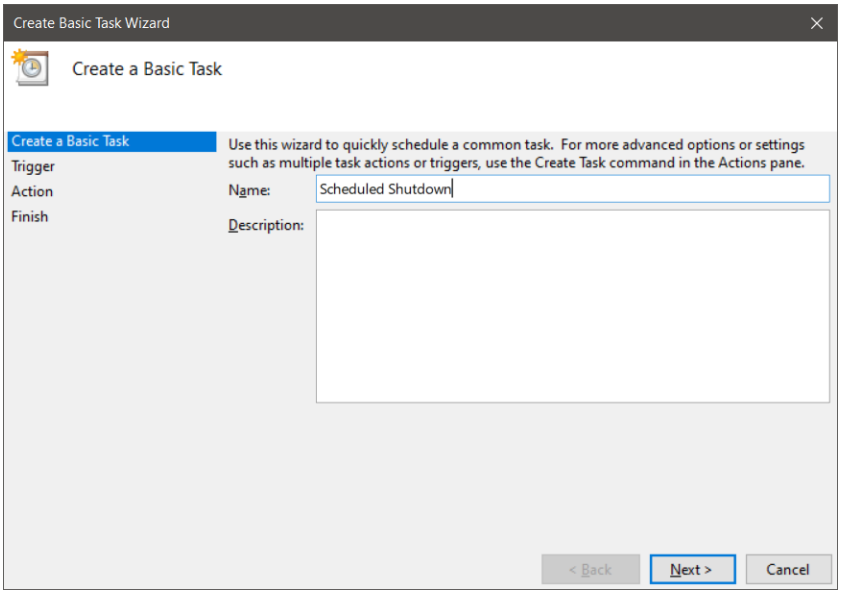
Appendix 3: Programmed shut down of Windows 11 personal computer

1. *Via* the search bar open the 'Task Scheduler'.

2. Click 'create a basic task'.

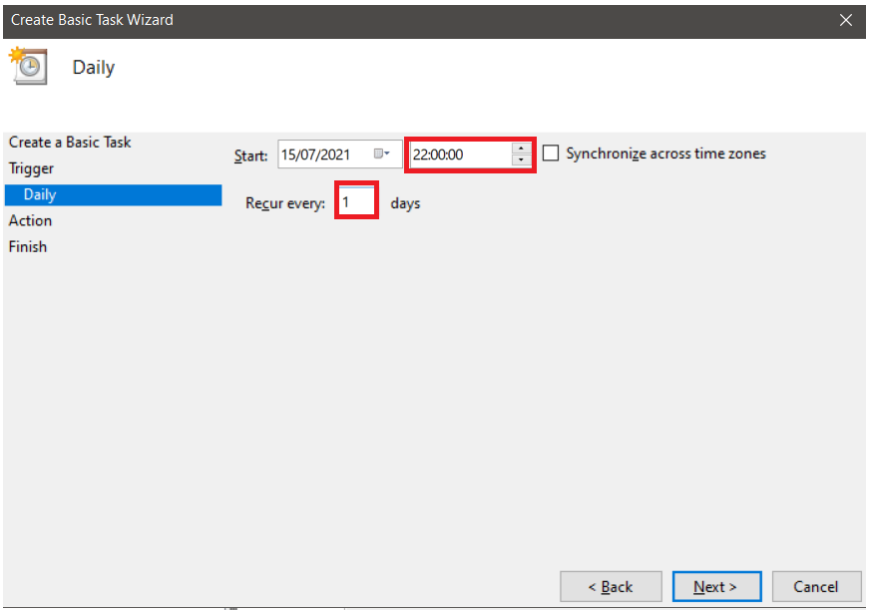


3. Give the task a name (*e.g.* 'scheduled shutdown'), then click Next.



4. Set the task to start Daily, click Next.

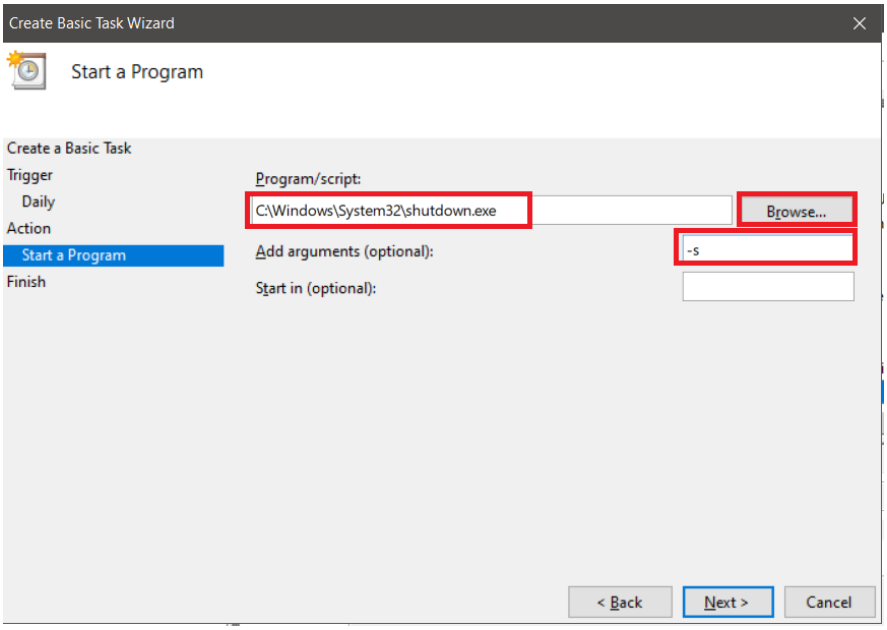
5. Set the time of shutdown (*e.g.* 22:00:00) and set it to recur every 1 day, click Next.



6. Select “Start a program”, click Next.

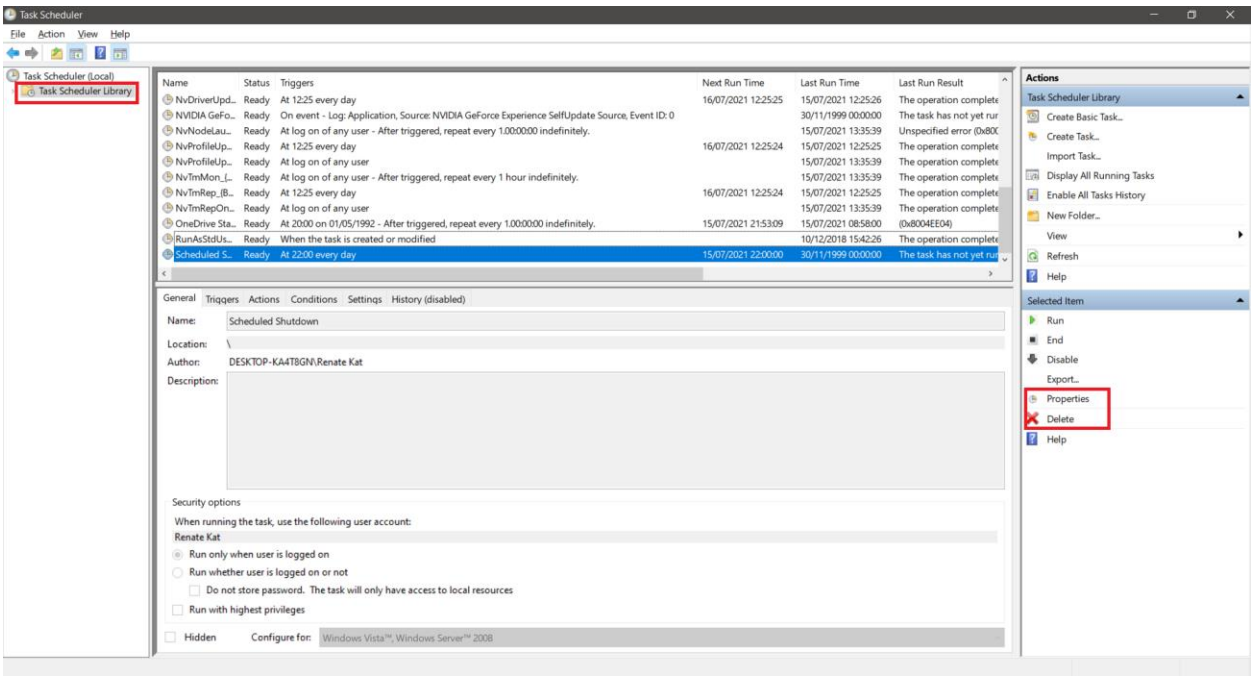
7. Click the Browse button and go to: “C:\\Windows\System32”, select a file called “shutdown”.

8. In the “Add arguments” field, add “-s”, click Next.

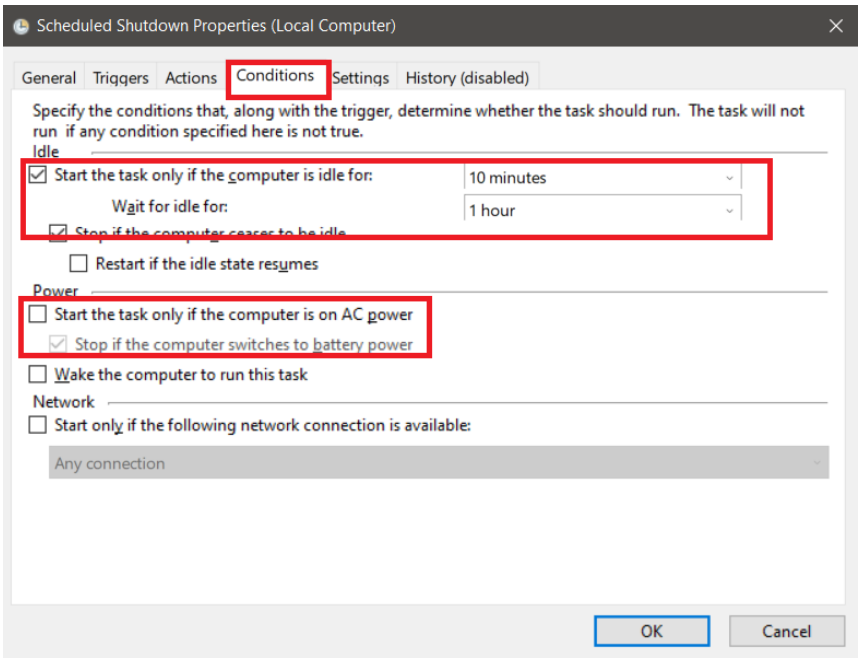


9. You can now check the setting and click “Finish”.

10. The task can now be found in the “Task scheduler Library”, if you select it, you can also find buttons to delete the task or see and change properties.



11. In the tab conditions, you can select that the task will only be executed when the computer is idle, and for how long it needs to be idle. For laptops it's important to unselect that the task will only be performed if the computer is on AC power.



Author Contributions

T.F., R.K., S.D.L., and T.C.B. conceptualized the project and coordinated it with the help C.M.D.R., N.E., M.B., B.S., R.R.W., I.M., T.B.G., P.F., R.P., and M.M.L..
T.F., R.K., S.D.L., and T.C.B. prepared the manuscript with input from C.M.D.R., N.E., M.B., B.S., R.R.W., I.M., T.B.G., P.F., R.P., and M.M.L.. All authors reviewed the manuscript.

Conflicts of interest

The authors declare no competing interests. There is no affiliation to any company and product recommendations are based on variety and region.

Acknowledgements

We thank the entire Green Labs RUG team, the Green Office of the University of Groningen and Green Labs NL for supporting sustainable lab practices. In particular we thank G.P.R. Schaeffer, D. Lijdsman, E.W. Zinkstok, E.M. Klop, T. Canrinus, N. N. H. M. Eisink, F. Trigka, R. Tarozo, D. Gerlach, J. L. Sneep, P. Nauw, S. R. Bonsing-Vedelaar, E. Zhemchuzhnikova, K. Horlings, L. A. A. Giannini, M. Farley, S. B. Beil, M. Heinemann, and V. Andrikopoulos. We thank M.B. Blikmans-Middel for guidance and advice in the context of Open Educational Resources. We thank Maaike M. Weber and Francine Nijp for designing logos, posters and stickers. Furthermore we thank the Health Safety and Environment department for critical assessment and discussions.

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