

Manual



T101 RFC Set



T105 HyRunnerBasic



T107 HyRunner



T109 HySpeedster

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Your Duties as a Supervisor

These Operating Instructions are intended for the responsible supervisor.

- Read the Operating Instructions before using the equipment. Observe the instructions and keep them on hand.
- Pay particular attention to the General Safety Precautions (**see Page 6**).
- This product may be set up and operated only under the supervision of the person responsible.

Objective / Introduction

The development of new energy sources will be one of the main tasks of the 21st century, as energy requirements increase, resources of coal, oil and gas decline, and climate change accelerates. Hydrogen technology is particularly important in this regard. Fuel cells allow electricity to be produced directly from hydrogen and oxygen. Their only waste product is water.

In turn, the fuel for these fuel cells can be produced by a process called electrolysis, which uses electricity (e.g. from solar cells) to split water into hydrogen and oxygen. Together, these two technologies form the solar hydrogen cycle.

The cells contained in our sets can do both: generate electricity and produce hydrogen. They allow all stages of the solar hydrogen cycle to be clearly explained through simple experiments. They outline a simple principle, which works on small and large scales, and in doing so conserves resources and helps the environment. No wonder then that all experts in fuel cell technology predict excellent prospects for the future.

This manual explains the design, setup and operation of the Tutorial RFC set, as well as the Tutorial HyRunner Basic, Tutorial HyRunner and Tutorial HySpeedster cars. You will also find suggestions for using the equipment in the classroom.

Our team wishes you exciting experiments and interesting insights into the future of energy supply.

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Wasserstoff-Energie-Systeme GmbH

Intended Use

The equipment described in this manual allows the principles of PEM fuel cells (PEM = proton exchange membrane) and PEM electrolyzers to be demonstrated, and appropriate measurements to be taken. The equipment has been developed for teaching and demonstration purposes only.

Any other use is prohibited.

WARNING!

The hydrogen (H_2) and oxygen (O_2) used in fuel cells can be dangerous if handled improperly. In order to avoid any risks you must follow the recommended safety precautions when using the equipment.

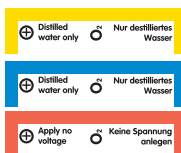
All steps for the H_2/O_2 and H_2 /Air modes of operation are explained using the Tutorial RFC set (T101) as an example. They can be carried out in the same manner with the Tutorial HyRunner (T107) and Tutorial HySpeedster (T109) cars. However, the Tutorial HyRunner Basic (T105) car has an air-breathing cell and is therefore only suitable for H_2 /Air mode.

h-tec cells are clearly color-coded according to their function.

yellow: reversible fuel cell (RFC), which can also be used as an electrolyser

blue: electrolyser

red: fuel cell



General Safety Precautions

- The units may only be set up and operated by a responsible supervisor.
- **WARNING!** Not suitable for children under 12 years!
- Read the Operating Instructions before setting up the fuel cell. Follow them during use and keep them readily available for reference.
- The equipment may only be used with the h-tec solar modules provided for the purpose (h-tec Solar Module Basic, Item No. 2086; Solar Module Tutorial, Item No. A113; Solar Module Tutorial Double, Item No. A118), h-tec batterybox (BatteryBox, Item No. A115) or h-tec plug-in power supplies (h-tec Power Supply, Item No. 2033).
- Wear protective goggles.
- Equipment and gases must be used and stored out of the reach of small children.
- Plug-in power supplies can be dangerous - they are not toys!
- Disconnect the unit from the plug-in power supply and the solar module before cleaning with liquids.
- Unless instructed to the contrary by the manual, do not reverse or short-circuit the connecting terminals.
- The units must not be operated when empty. Always ensure that they contain sufficient water. Pay attention to the water level marks.
- Remove flammable gases, vapours or liquids from the area surrounding fuel cells and electrolyzers. The catalytic materials involved may cause spontaneous ignition.
- Hydrogen and oxygen may escape from the units. Operate the units in well-ventilated rooms to ensure that the gases do not accumulate and form explosive mixtures.
- The units may only be operated in display cases if adequate ventilation is guaranteed under all circumstances. The operator is responsible for ensuring this.

- Remove from the vicinity of the units anything that could ignite the hydrogen (e.g. open flame, materials that can become charged with static electricity, substances with a catalytic action).
- Remove from the vicinity of the units all substances that could spontaneously ignite in increased oxygen concentration.
- Do not smoke.
- Hoses, plugs and gas tanks are used for pressure compensation. They must not be fixed or secured with clamps, adhesive, etc.
- Only use the gas storage tanks associated with or supplied with the units. Never connect alternative gas storage tanks.
- The units may only be operated at room temperature and ambient pressure.
- Minimum separation distances must be observed when using solar modules and artificial lights. These are: 30 cm between h-tec solar modules and the h-tec Videolight, and 50 cm in the case of the h-tec Spotlight. When using lights from other manufacturers, observe the minimum distance specified by them.
- **WARNING!** The surface of solar modules can get very hot during extended operation.
- Tell your students about any potential dangers and carefully supervise experimentation.
- h-tec accepts no responsibility for injuries or damage sustained in the event that these Safety Precautions are not followed.

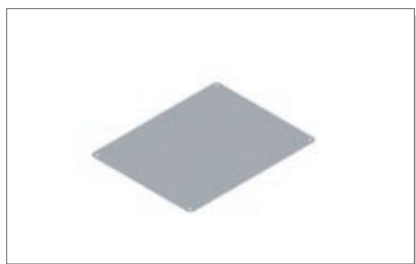
Individual Components (depending on set)



Solar Module Tutorial - Item No. A113
(for single cells)



Solar Module Tutorial Double - Item No. A118
(for double cells)



Experimentation Plate (Baseplate) -
Item No. A112



Chassis Vehicle Plate - Item No. A107

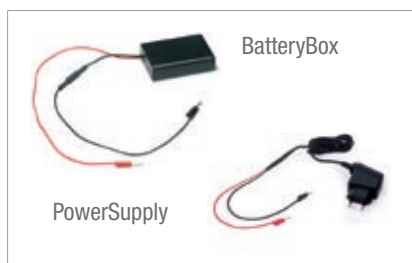
Water Bottle 100 ml - Item No. A125

Water Bottle 250 ml - Item No. A126
(with filler tip)



BatteryBox - Item No. A115

PowerSupply (Plug-in power supply) -
Item No. 2033

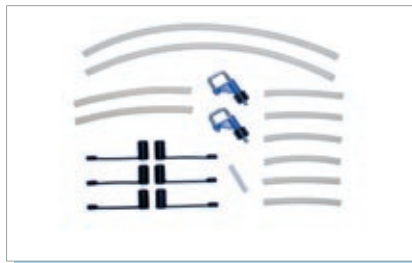


Ventilator Fan Tutorial - Item No. A105



TubeSet - Item No. A120

Cap (for gas connector) - Item No. A123

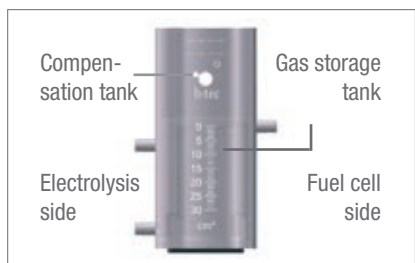




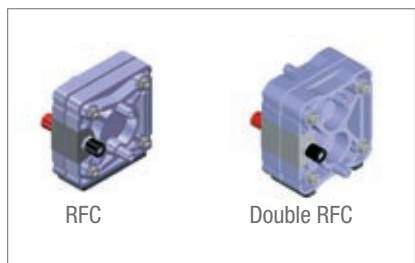
Stopper (for sealing air inlet) - Item No. A124
Cable (2 mm) - Item No. A130/A131



Adapter (2 mm to 4 mm safety sockets) -
Item No. A122



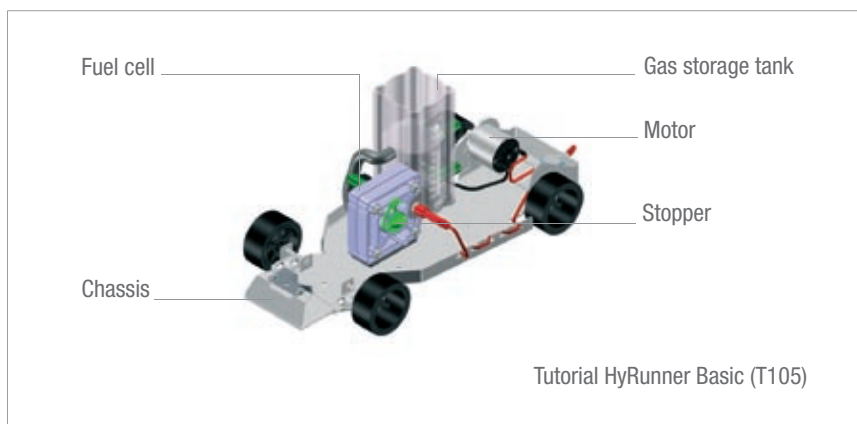
Gas storage tank Storage 30 - Item No. A103



Reversible Fuel Cell (RFC)
RFC H_2/O_2 /Air - Item No. R103
or
Double RFC H_2/O_2 /Air - Item No. R104

Tutorial HyRunner Basic (T105)

The Tutorial HyRunner Basic is a working model of a hydrogen fuel cell car with a reversible fuel cell. Hydrogen can be manufactured and stored with the cell via the application of electrical current from an external power supply (electrolysis). The charging time is approximately 7 min with the battery box, and approximately 9 min with the basic solar module and sunlight. Running time is approximately 8 min. The reversible fuel cell is operated in air-breathing mode (**H₂/Air mode**, see Page 19).



Tutorial HyRunner Basic com-

prises:

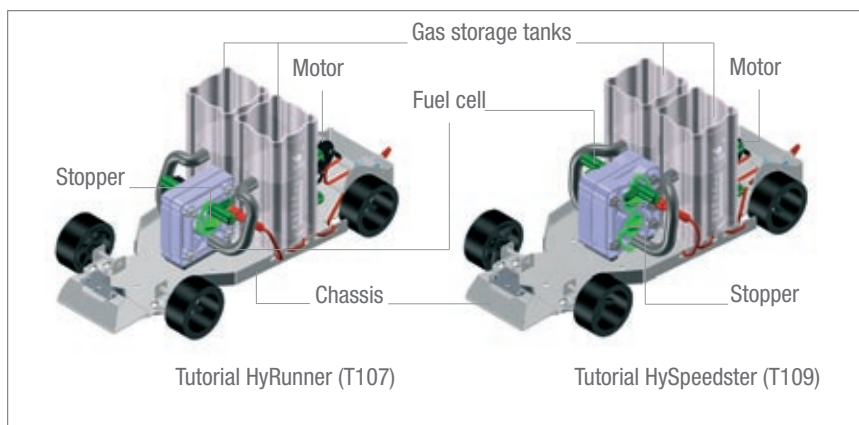
- 1x RFC cell H₂/O₂/Air
- 1x Gas storage tank Storage 30
- 1x Solar Module Tutorial
- 1x BatteryBox with 2 mm connecting cables (Batteries not included)
- 1x Chassis
- 1x Tube
- 3x Caps
- 2x Cable 2 mm or 2x Adapter from 2 mm to 4 mm safety plug if necessary
- 1x Water Bottle 100 ml
- 1x Protective goggles
- 1x Textbook

Tutorial HyRunner (T107), Tutorial HySpeedster (T109)

Tutorial HyRunner and Tutorial HySpeedster are working models of hydrogen fuel cell cars with a reversible fuel cell RFC H_2/O_2 /Air and two gas storage tanks. Hydrogen can be manufactured and stored with the cell via the application of electrical current from an external power supply. The following charging times may be expected:

Charging times with...	Tutorial HyRunner	Tutorial HySpeedster
PowerSupply	approx. 4 min.	approx. 2 min.
BatteryBox	approx. 7 min.	approx. 8 min.
Solar Module Tutorial and sunlight	approx. 9 min.	—
Solar Module Tutorial Double and sunlight	—	approx. 14 min.

The running time is approximately 8 min for the Tutorial HyRunner and 4 min for the Tutorial HySpeedster. The reversible fuel cell can be operated in either oxygen-breathing or air-breathing mode (H_2/O_2 mode see Page 16, H_2 /Air mode see Page 19).



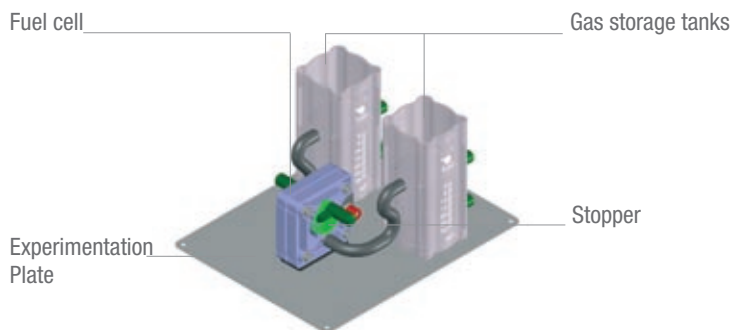
Tutorial HyRunner and Tutorial HySpeedster each comprise:

- 1x RFC cell H_2/O_2 /Air or 1x Double RFC cell H_2/O_2 /Air (respectively)
- 2x Gas storage tank Storage 30
- 1x Solar Module Tutorial or 1x Solar Module Tutorial Double (respectively)
- 1x BatteryBox with 2 mm connecting cables (Batteries not included)
- 1x PowerSupply
- 2x Cable 2 mm or 2x Adapter from 2 mm to 4 mm safety plug if necessary
- 1x Chassis
- 2x Tubes
- 6x Caps
- 1x Water Bottle 100 ml
- 1x Protective goggles
- 1x Textbook

Tutorial RFC Set (T101)

The Tutorial RFC Set is a modular solar hydrogen system. It consists of a reversible fuel cell RFC H_2/O_2 /Air, two gas storage tanks and a black baseplate. The set is used for producing, storing and using hydrogen and oxygen. The reversible fuel cell can be operated in either oxygen-breathing or air-breathing mode (**H_2/O_2 mode see Page 16, H_2 /Air mode see Page 19**). The following charging times may be expected:

Charging times with...	Tutorial RFC Set (T101)
PowerSupply	approx. 4 min.
BatteryBox	approx. 7 min.
Solar Module Tutorial and sunlight	approx. 9 min.

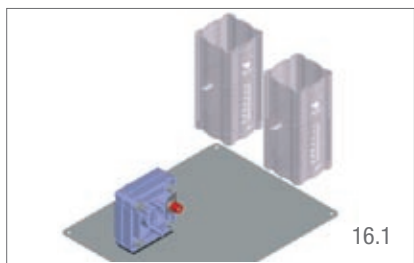


Tutorial RFC Set (T101)

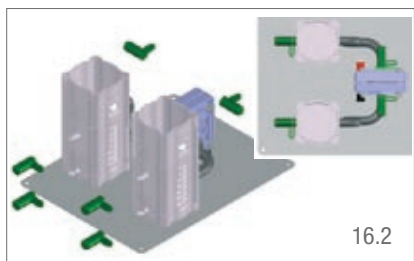
Tutorial RFC Set comprises:

- 1x RFC cell $\text{H}_2/\text{O}_2/\text{Air}$
- 2x Gas storage tank Storage 30
- 1x Solar Module Tutorial
- 1x BatteryBox with 2 mm connecting cables (Batteries not included)
- 1x Ventilator Fan Tutorial
- 1x Experimentation Plate
- 1x TubeSet
- 6x Caps
- 2x Cable 2 mm or 2x Adapter from 2 mm to 4 mm safety plug if necessary
- 1x Water bottle 100 ml
- 1x Protective goggles
- 1x Textbook

H₂/O₂ mode - Setup



1. Place the two gas storage tanks and the reversible fuel cell on the baseplate or chassis (**Fig. 16.1**).

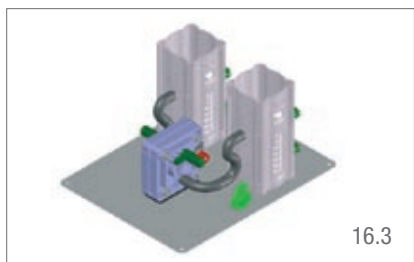


2. Using a hose, connect the bottom connectors of the reversible fuel cell to the connectors on the fuel cell side of the storage tanks (**Fig. 16.2**).

3. Fit caps to the connectors on the electrolysis side of the gas storage tanks (**Fig. 16.2**).

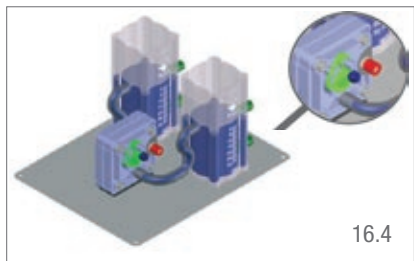
4. Fit caps to the top gas connectors of the fuel cell (**Fig. 16.2**).

5. Make sure that the stopper for sealing the air inlet on the cell is fitted (**Fig. 16.3**).



6. Fill both storage tanks with distilled water up to the top mark of the compensation tank.

7. Open the upper caps on both sides of the cell. Air will escape from the gas storage tanks and from the cell and the cell will be flooded. The process is complete when water comes out of the top gas connectors (**Fig. 16.4**).



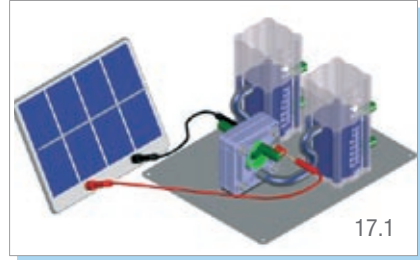
Note

The rising water level can easily be seen in the labyrinth inside the cell. If air bubbles form, they may interfere with the system. Allow the process to run until you see no more air bubbles.

8. Re-cap the gas connectors.

H₂/O₂ mode - Gas production

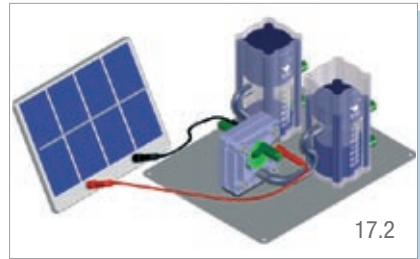
1. Use the cables to connect a voltage source (solar module, plug-in power supply or battery box) to the appropriate terminals on the fuel cell. When doing so, make sure that the polarity is correct (red = „+“, black = „-“). The cell will begin to produce hydrogen and oxygen in a 2:1 ratio (**Fig. 17.1**).



Note

If the lighting is not sufficient, you can use a powerful halogen spotlight (h-tec 75 W spotlight), or use the included battery box as an alternative to the solar module.

2. Oxygen is produced on the positive side of the cell, and hydrogen on the negative side. The gases collect in the gas storage tanks and displace the water there into the compensation tanks (**Fig. 17.2**).

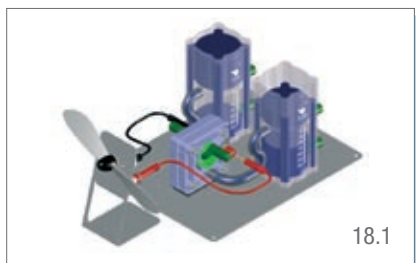


H₂/O₂ mode - Gas storage

When the gas storage tanks are full, excess gas will escape in the form of bubbles.

H₂/O₂ mode - Gas consumption

1. Remove the current source and connect an electric load (ventilation fan or the motor of the Tutorial HyRunner/Tutorial HySpeedster). The cell will use the gas to generate current, along with water and small amounts of heat (**Fig. 18.1, Page 18**).

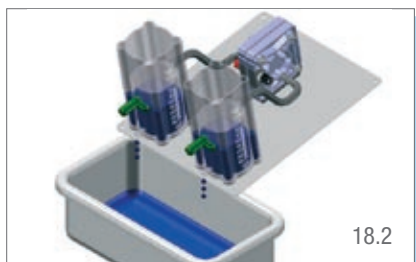


2. The gas level drops. If the gases are used up, the cell will draw water and the electric load (e.g. the motor) will stop.
3. Re-connect the solar cell or battery box. Gas production will start again.

Note

Make sure that the oxygen side of the cell is sufficiently moist. Re-flood the cell if necessary.

Running time with...	Duration
Fan Tutorial	approx. 30 min.
Tutorial HyRunner	approx. 8 min.
Tutorial HySpeedster	approx. 4 min.



Emptying the storage tanks (at the end of operation)

1. Remove the caps from the fuel cell.

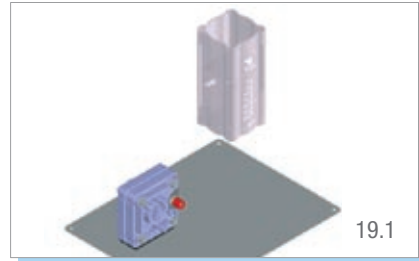
Note

If you are using the Tutorial HyRunner or Tutorial HySpeedster, remove the storage tank and the cell from the chassis before emptying.

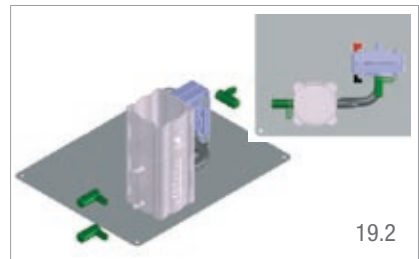
2. Hold the gas storage tanks over a collecting tray and remove the bottom caps from the tanks. The water will run out (**Fig. 18.2**).

H₂/Air mode - Setup

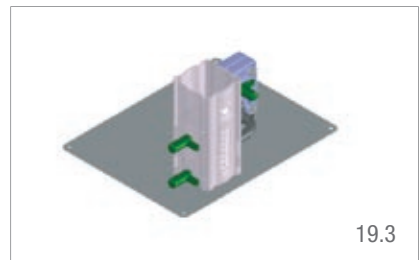
1. Place a gas storage tank and the cell on the baseplate or chassis (**Fig. 19.1**).
2. Using a hose, connect the bottom connector of the fuel cell on the hydrogen side to the connector on the fuel cell side of the gas storage tank (**Fig. 19.2**).
3. Fit caps to the connectors on the electrolysis side of the gas storage tank (**Fig. 19.2**).
4. Fit a cap to the top gas connector on the hydrogen side of the fuel cell (**Fig. 19.2, 19.3**).
5. Fill the gas storage tank with distilled water up to the top mark of the compensation tank.
6. Open the top cap on the hydrogen side of the cell. Air will escape from the gas storage tank and from the cell and this side of the cell will be flooded. The cell is flooded when water comes out of the top gas connector (**Fig. 19.4**).
7. Re-cap the gas connector on the hydrogen side.



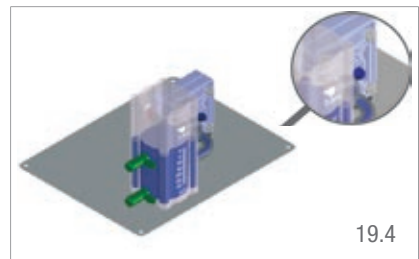
19.1



19.2



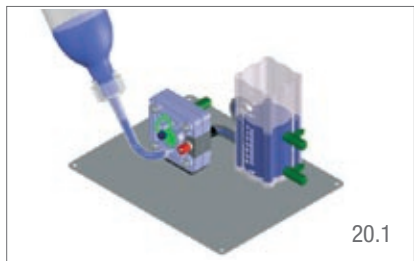
19.3



19.4

Note

The rising water level can easily be seen in the labyrinth inside the cell. If air bubbles form, they may interfere with the system. Allow the process to run until you see no more air bubbles.

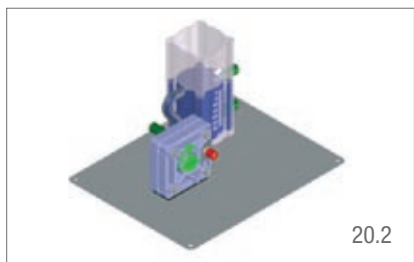


20.1

8. Fit the included filler tip on the water bottle.

Note

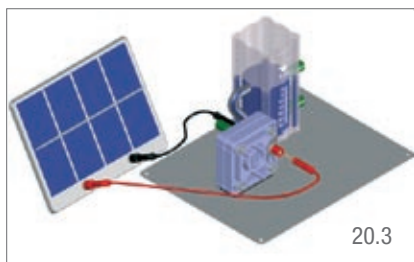
Before flooding the cell, fit the stopper so that the water will be well distributed in the cell.



20.2

9. Connect the water bottle to the bottom connector on the oxygen side of the cell and flood this side as well (**Fig. 20.1**).
10. Disconnect the water bottle. The cell is now ready for use (**Fig. 20.2**).

H₂/Air mode - Gas production



20.3

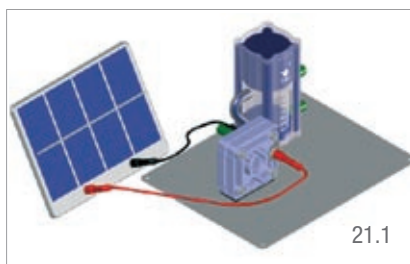
1. Remove the stopper. If you are using the Tutorial HySpeedster, remove both stoppers.
2. Use the cables to connect a voltage source (solar module, plug-in power supply or battery box) to the terminals on the fuel cell.

When doing so, make sure that the polarity is correct (red = „+“, black = „-“). The cell will begin to produce hydrogen and oxygen in a 2:1 ratio (**Fig. 20.3**).

Note

If the lighting is not sufficient, you can use a powerful halogen spotlight (h-tec 75 W spotlight), or use the included battery box as an alternative to the solar module.

3. Oxygen is produced on the positive side of the cell, and hydrogen on the negative side. As the cell is operated in fuel cell mode with atmospheric oxygen, only the hydrogen will be collected in the gas storage tank. It displaces the water there into the compensation tank (**Fig. 21.1**). The process runs until the water on the oxygen side of the cell is used up.

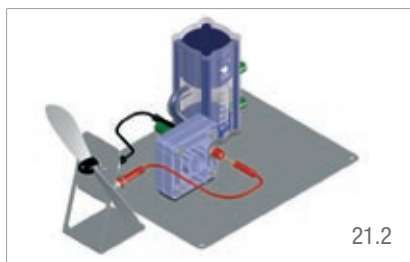


H₂/Air mode - Gas storage

When the gas storage tank is full, excess gas will escape in the form of bubbles.

H₂/Air mode - Gas consumption

1. Remove the current source and connect an electric load (ventilation fan or the motor of the Tutorial HyRunner Basic/Tutorial Hy-Runner/Tutorial HySpeedster). The cell will use the produced gas together with the atmospheric oxygen to generate current, along with water and small amounts of heat (**Fig. 21.2**).



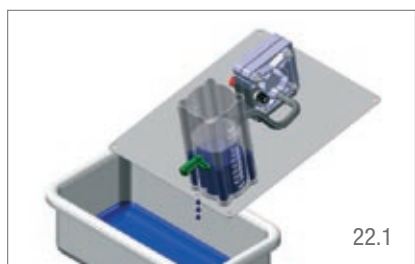
When operating with atmospheric oxygen, the power of the cell is somewhat lower than when operating with pure oxygen.

2. The gas level drops. If the hydrogen is used up, the cell will draw water and the electric load (e.g. the motor) will stop.
3. Re-connect the solar cell or battery box. Gas production will start again.

Note

Make sure that the oxygen side of the cell is sufficiently moist. Re-flood the cell if necessary.

Running time with...	Duration
Fan Tutorial	approx. 50 min.
Tutorial HyRunner Basic	approx. 14 min.
Tutorial HyRunner	approx. 14 min.
Tutorial HySpeedster	approx. 8 min.



Emptying the storage tank

(at the end of operation)

1. Remove the caps from the fuel cell.

Note

If you are using the Tutorial HyRunner Basic, Tutorial HyRunner or Tutorial HySpeedster, re-move the storage tank and the cell from the chassis before emptying.

2. Hold the gas storage tank over a collecting tray and remove the bottom cap from the tank. The water will run out (**Fig. 22.1**).

Experimental Guidelines

The h-tec textbook contains detailed experimental instructions for calculating characteristics and efficiencies of the cells, as well as extensive background information on hydrogen technology. Below, you can find some brief suggestions for how you can use the equipment in the classroom to clearly demonstrate the basic principles of hydrogen technology.

Tutorial RFC Set

- Use the equipment as an electrolyser to produce H_2 and O_2 in a ratio of 2:1.
- Compare the performance of the electrolyser (gas volume per unit time) when using the solar module with sunlight versus artificial light.
- Compare the running time of the fan in the different fuel cell modes (H_2/O_2 or H_2/Air). Recommended gas quantity: 5 cm^3 .

Tutorial HyRunner Basic

- Use the equipment as an electrolyser to produce H_2 .
- Compare the performance of the electrolyser (gas volume per unit time) when using the solar module with sunlight versus artificial light.
- Run the Tutorial HyRunner Basic as a fuel cell car using self-generated hydrogen.

Tutorial HyRunner / Tutorial HySpeedster

- Use the equipment as an electrolyser to produce H_2 and O_2 in a ratio of 2:1.
- Compare the performance of the electrolyser (gas volume per unit time) when using the solar module with sunlight versus artificial light.

- Run the Tutorial HyRunner or Tutorial HySpeedster as a solar car without a fuel cell by connecting the solar module directly to the motor.
- Run the Tutorial HyRunner or Tutorial HySpeedster as a fuel cell car using self-generated hydrogen in H_2/O_2 or H_2/Air modes.
- Compare the car's performance in different modes by measuring its speed or range.
- If you have two cars available, have a race based on time or distance to compare the types of cell (single or double cell) or operating modes (H_2/O_2 , H_2/Air , solar car).

Maintenance

The fuel cells we provide in our sets are maintenance-free. However, always remember:

- Use fresh, distilled water each time.
- Drain the water from the storage tanks after use.

Before putting the cell away:

- Continue operating the cell until the electric load (e.g. the motor) stops by itself. This will ensure that a little water remains in the cell and keeps the membrane moist.
- Close the caps and the stopper so that the water in the cell does not evaporate.
- Wipe the base plate and chassis dry in order to prevent water marks.

Technical Data

Tutorial RFC Set (T101)

Electrolysis mode:	5 cm ³ /min H ₂ 2.5 cm ³ /min O ₂ 1.16 W
Fuel cell mode:	H ₂ /O ₂ : 300 mW H ₂ /Air: 100 mW
Gas storage tank:	30 cm ³ H ₂ ; 30 cm ³ O ₂
Solar module:	2.0 V / 600 mA
Battery box:	4.5 VDC / 0.8 A
Electric load (fan):	10 mW
Cable length (single):	250 mm
H x W x D:	90 x 170 x 135 mm
Weight:	453 g

Tutorial HyRunner Basic (T105)

Electrolysis mode:	5 cm ³ /min H ₂ 1.16 W
Fuel cell mode:	H ₂ /Air: 100 mW
Gas storage tank:	30 cm ³ H ₂
Solar module:	2.0 V / 600 mA
Battery box:	4.5 VDC / 0.8 A
H x W x D:	100 x 115 x 260 mm
Weight:	593 g

Tutorial HyRunner (T107)

Electrolysis mode:	5 cm ³ /min H ₂ 2.5 cm ³ /min O ₂ 1.16 W
Fuel cell mode:	H ₂ /O ₂ : 300 mW H ₂ /Air: 100 mW
Gas storage tank:	30 cm ³ H ₂ / 30 cm ³ O ₂
Solar module:	2.0 V / 600 mA
Battery box:	4.5 VDC / 0.8 A
Plug-in power supply:	1.2 A
H x W x D:	100 x 115 x 260 mm
Weight:	651 g

Tutorial HySpeedster (T109)

Electrolysis mode:	10 cm ³ /min H ₂ 5 cm ³ /min O ₂ 2.33 W
Fuel cell mode:	H ₂ /O ₂ : 600 mW H ₂ /Air: 200 mW
Gas storage tank:	30 cm ³ H ₂ / 30 cm ³ O ₂
Battery box:	4.5 VDC / 0.8 A
Plug-in power supply:	1.2 A
Solar module:	4.0 V / 350 mA
H x W x D:	100 x 115 x 260 mm
Weight:	616 g

Fault Diagnostics

The cell only produces low power.

Cause:

- The cell has been stored for a very long time or is too dry. A cell with a dry membrane will lose power.

Solution:

- Continue operating the cell. The cell will moisten itself during operation and gradually return to full power.

The electric load (e.g. motor) connected to the cell does not work, despite hydrogen being present.

Cause:

- There is too much water in the cell. Water in the fuel cell leads to a rapid reduction in power. This condition can occur if the electrolyser runs in permanent operation for too long and pumps water to the hydrogen side of the fuel cell. With reversible cells, it is possible that the cell has

not been operated for long enough in electrolysis mode, so that too much water still remains in the cell.

Solution:

- Dry the cell by opening the connectors and blowing through the cell. In the case of reversible cells, change back to electrolysis mode.

No hydrogen is produced when the solar cell is connected.

Cause 1:

- The light intensity is insufficient.

Solution 1:

- Check the power specifications designed for the light source. You need sufficient sunlight or halogen lamps with focused light such as the h-tec Videolight or h-tec Spotlight. Energy-saving lamps, fluorescent tubes, etc. are not suitable for the operation of solar modules.

Cause 2:

- You are using a double-cell electrolyser and running it with a solar module for single cells.

Solution 2:

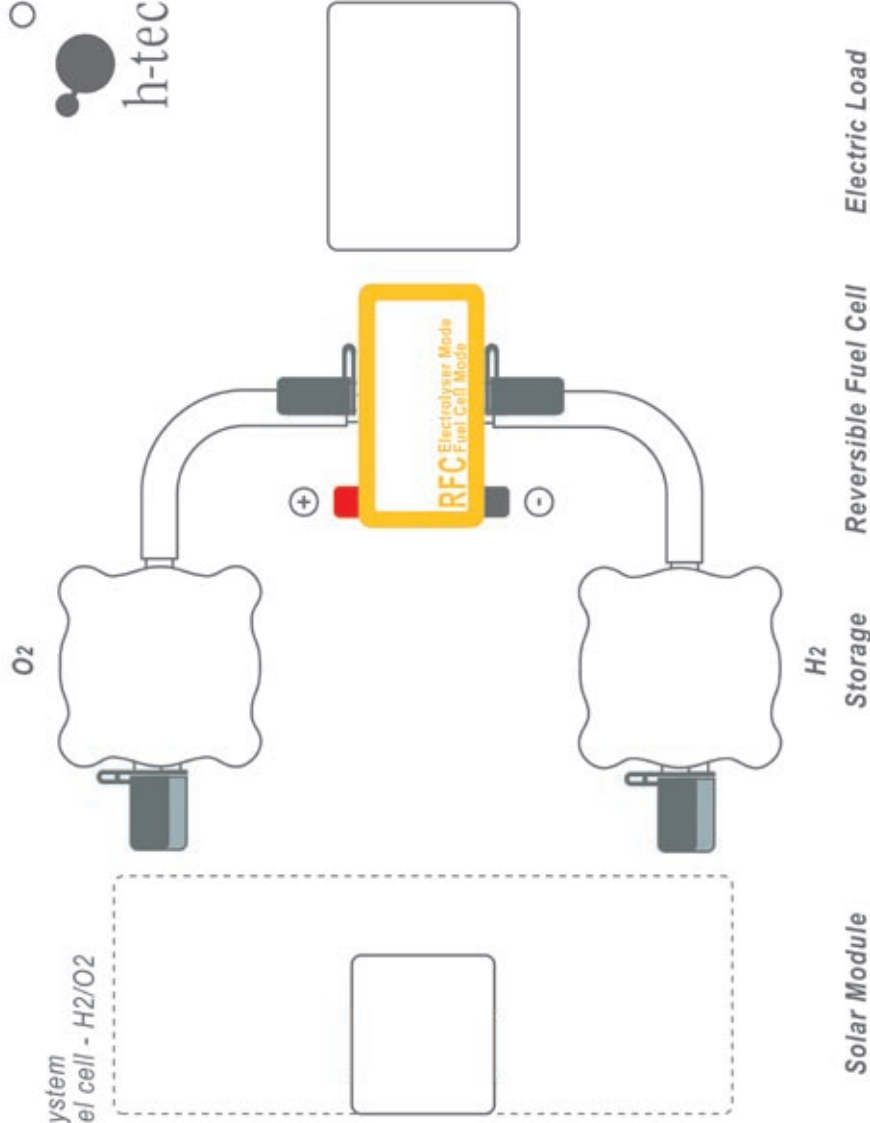
- Use the appropriate solar module - the Solar Module Tutorial Double.

The cell does not work despite being set up correctly.

Cause:

- You have not used distilled water. The cell is permanently damaged.

Solar hydrogen system
with reversible fuel cell - H₂/O₂



Notes

Notes

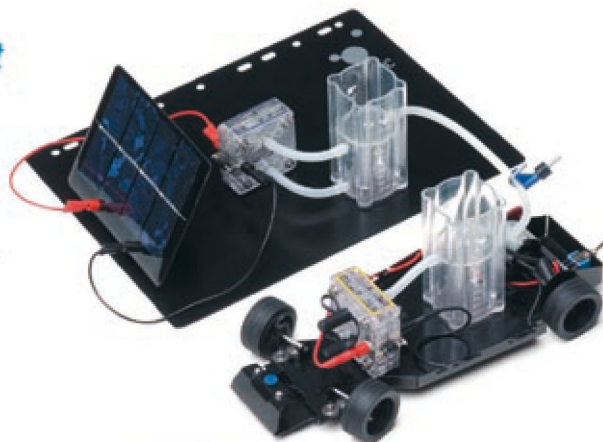
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