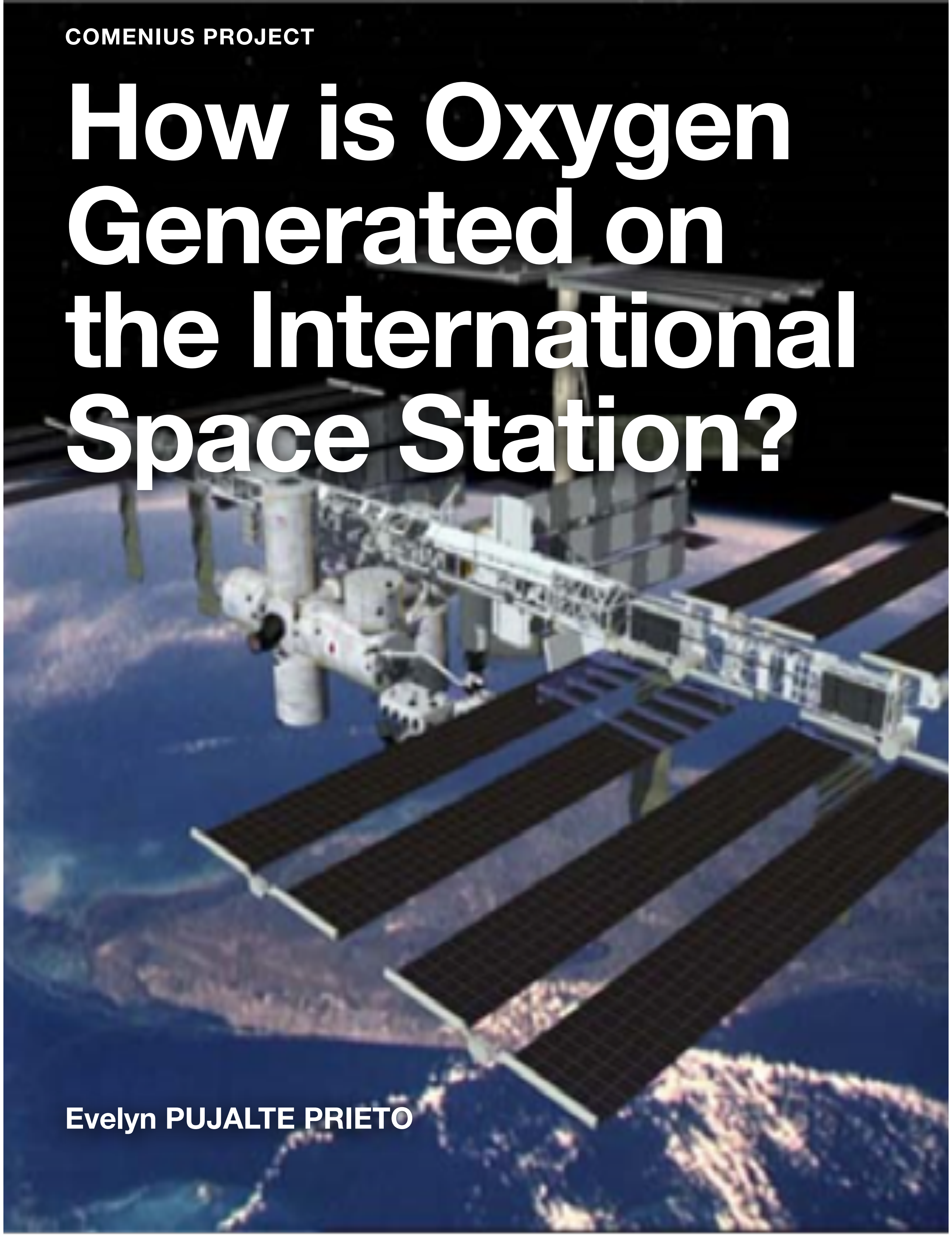
COMENIUS PROJECT

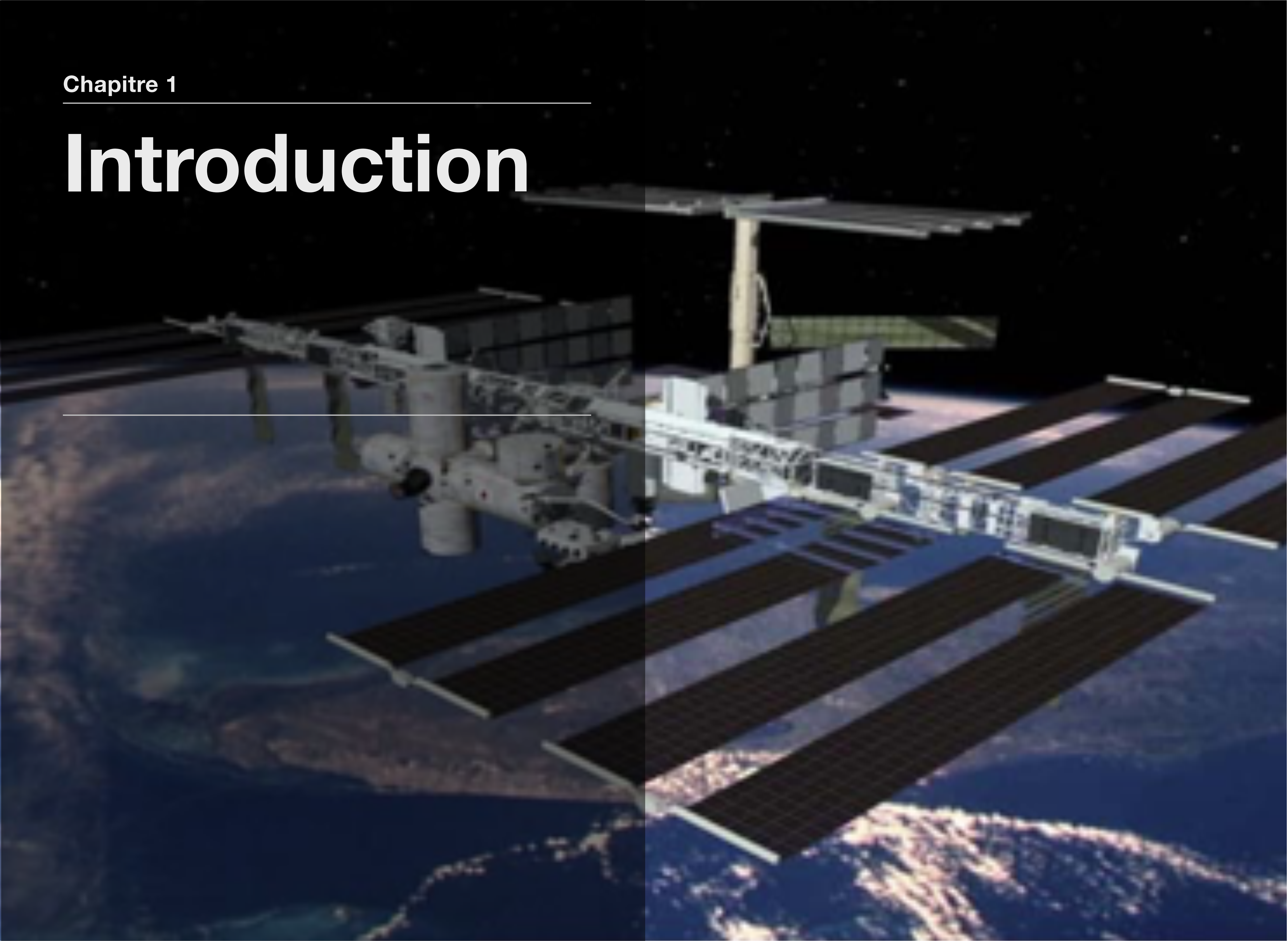
How is Oxygen Generated on the International Space Station?



Evelyn PUJALTE PRIETO

Chapitre 1

Introduction



The International Space Station (ISS) is a research laboratory being assembled in low Earth orbit. Construction of the ISS began in 1998 and is scheduled for completion in 2011.

Crews aboard the ISS conduct experiments in biology, chemistry, physics, medicine and physiology, as well as in astronomical and meteorological observations. An international crew, typically consisting of six members, resides on the ISS for approximately six months at a time.

Maintaining a permanent human presence on the ISS requires a well-organized and precise life support system a part which is the Oxygen Generator System (OGS)

The comfort of the crew on the ISS is very important since they may live in space for long periods of time.

The Environmental and Thermal Operating Systems (ETHOS) flight controller manages the systems which help provide a clean, safe and comfortable living area for the crew, including the monitoring of air and water onboard the International Space Station (ISS).

The ETHOS flight controller plans the appropriate amounts of oxygen (O2) and nitrogen (N2) required for the crew to live and work in an environment similar to that on Earth (78% nitrogen, an inert gas, Oxygen 21% and various other gases, like carbon dioxide, methane and argon make up the rest together with water vapor (which is usually around 1%).

The amount of each oxygen and nitrogen in the ISS cabin atmosphere has to be monitored carefully as well. The exact mixture of these two gases is important.

The Oxygen Generation System produces oxygen for breathing by the crew and laboratory animals, as well as for replacement of oxygen lost due to experiment use, airlock depressurization, module leakage and carbon dioxide venting.

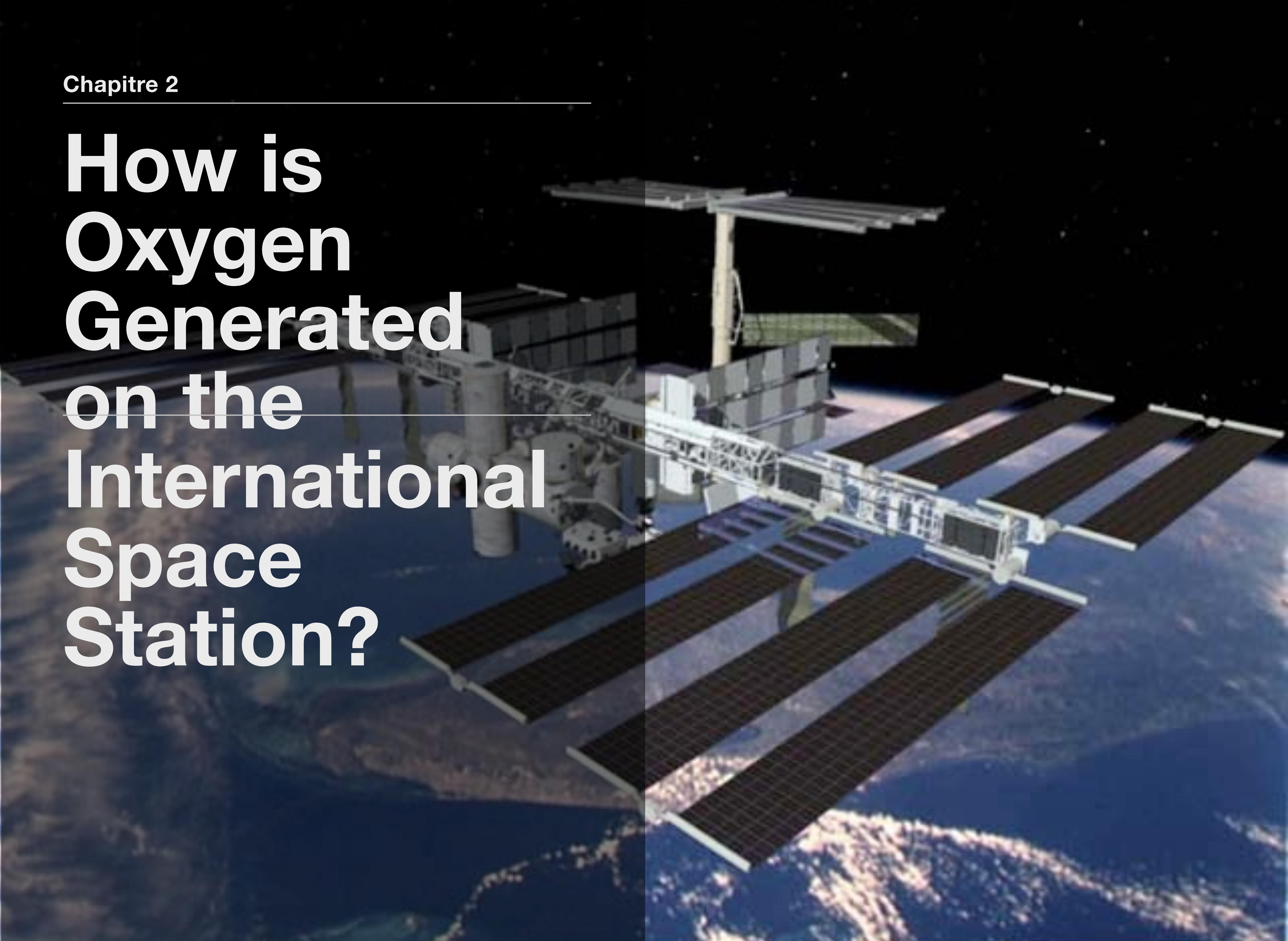
Mockup of the Oxygen Generation System Rack

The Oxygen Generation System provides up to 9 kg of oxygen per day during continuous operation and a normal rate of about 5.5 kg of oxygen per day during cyclic operation.

VIDEO 1 . ESA_EDU_2008-09-12_ES_

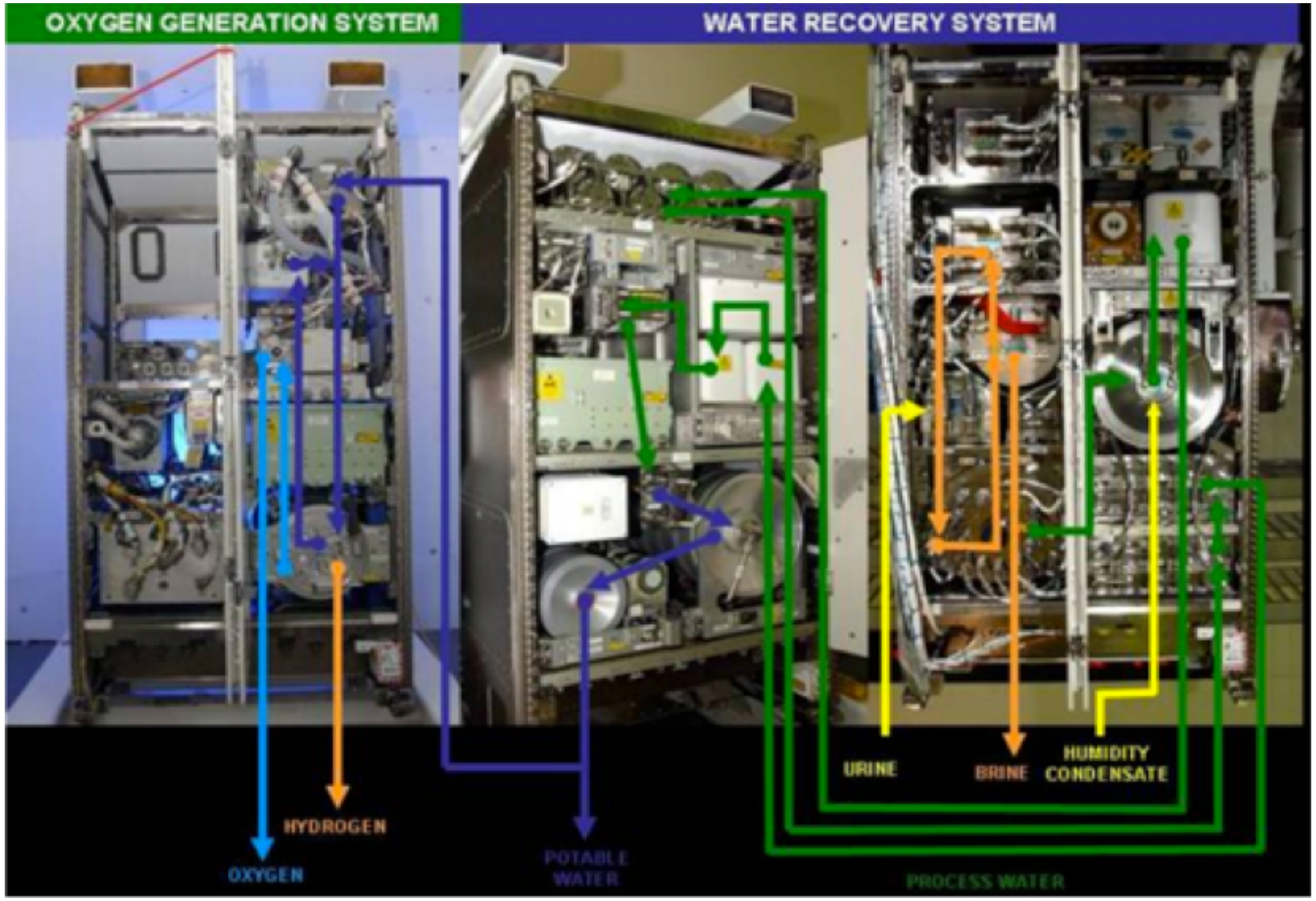
Chapitre 2

How is Oxygen Generated on the International Space Station?

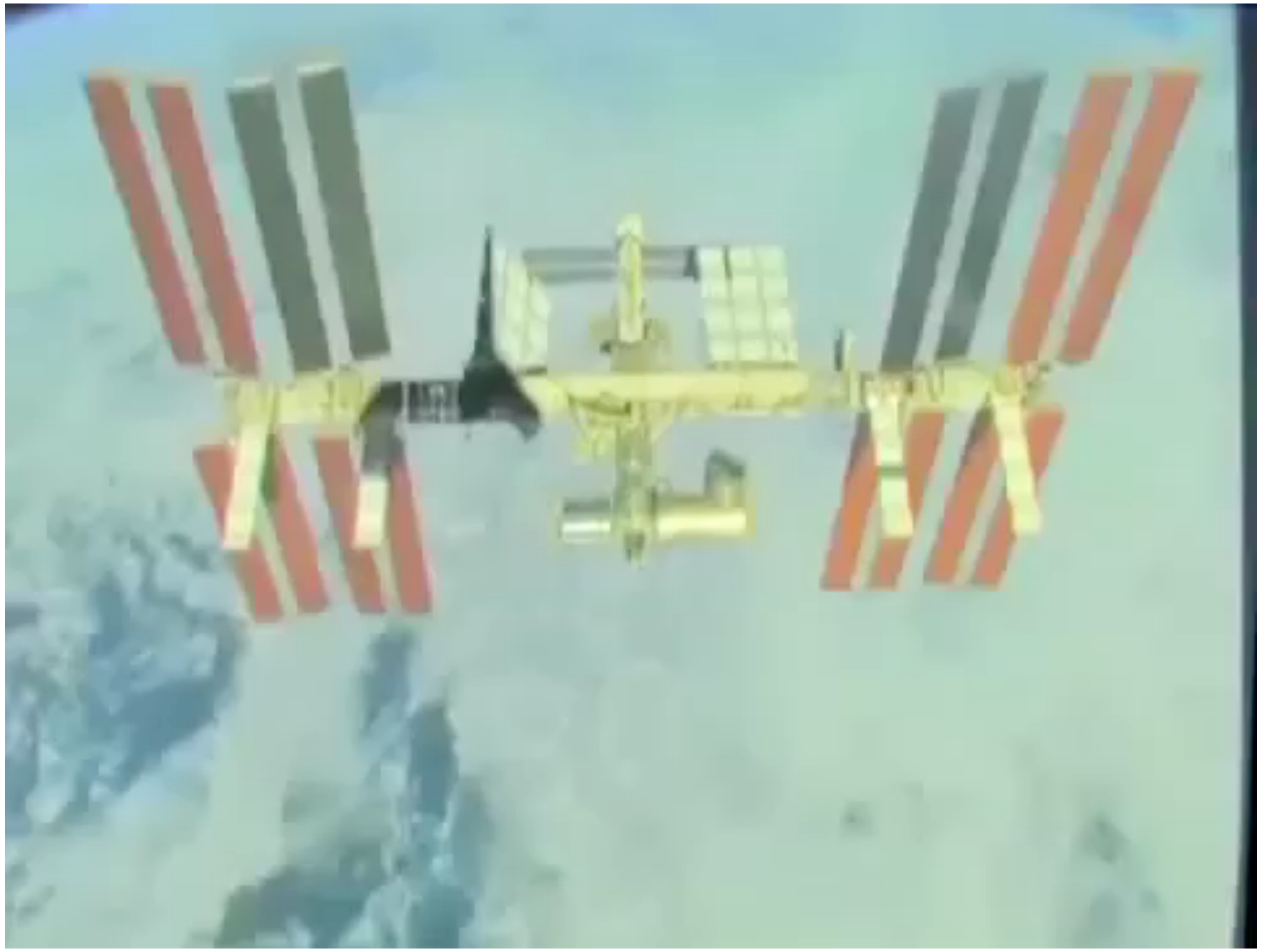


The ETHOS flight controller monitors the equipment on the ISS which collects wastewater (i.e., condensation and urine) and recycles it into clean drinking water and oxygen. This is done through the Regenerative Environmental Control and Life Support System (Regen ECLSS) – one of the most complex systems on the ISS.

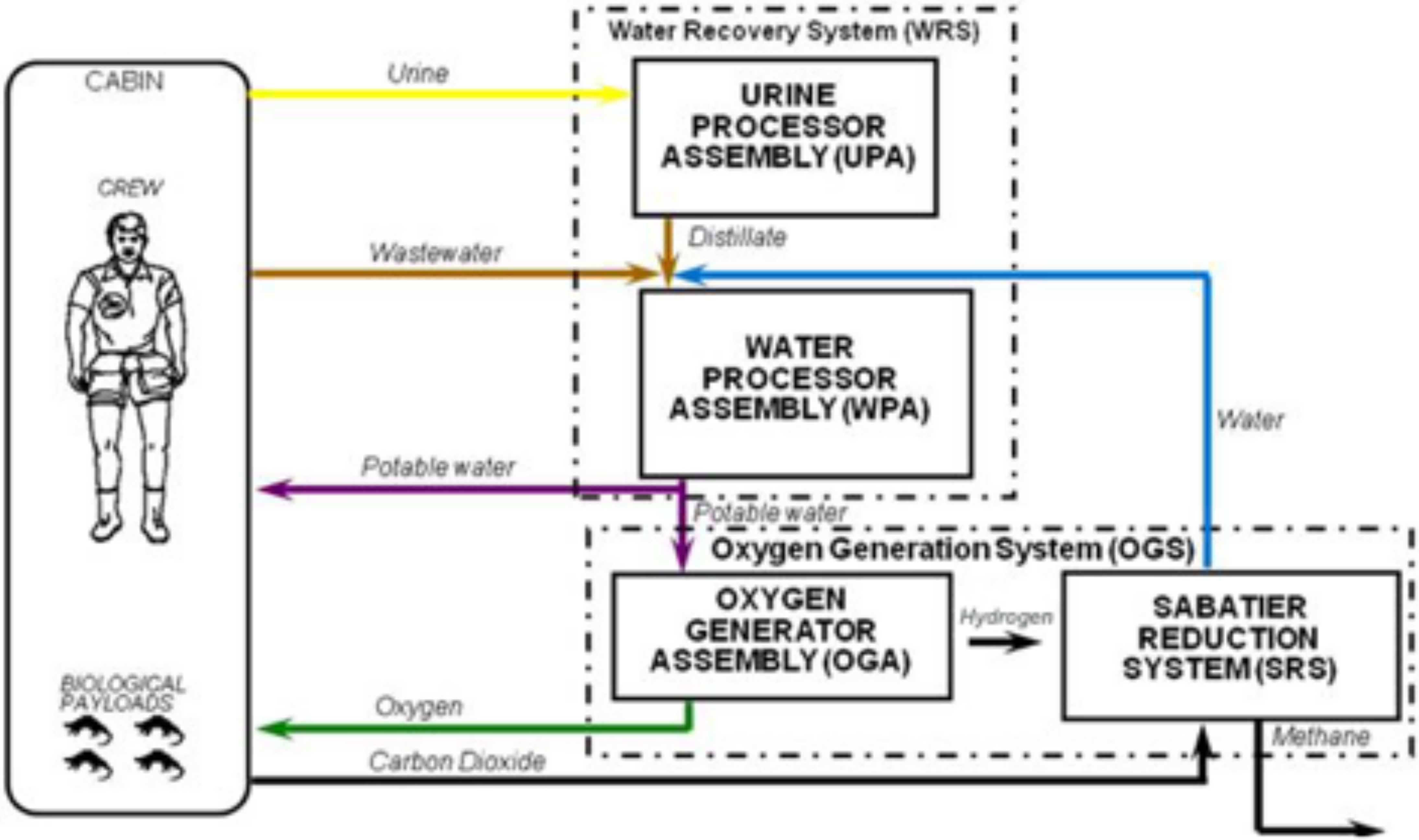
Image 2.1 International Space Station Regenerative ECLSS



VIDEO 2 . Environmental Thermal Operating Systems



Simplified scheme of Regenerative ECLSS



•The **UPA** distills (heats) the collected urine to evaporate and extract the water (H_2O), which is fed into the WPA.

•The **WPA** mixes the distilled water with the moisture collected from the air conditioners. Then, the system purifies the mixture before it is used for drinking or for making oxygen (O_2) in the OGS.

•The **OGS** creates oxygen from water by electrolysis (the break-down of water into oxygen gas and hydrogen gas by electrical current). The **OGA**, the major component of the OGS, produces both oxygen (O_2) for the crew to breathe, and hydrogen (H2) which is sent to the Sabatier Reactor. The Sabatier Reactor uses the leftover hydrogen and the excess carbon dioxide (CO_2) exhaled by the crew to create water and methane gas (CH_4).

•The water is then fed back into **OGS** (making a complete circle of water recycling on the ISS) and the methane gas is released out of the ISS into space.

•When the O_2 output of the **OGS** does not meet the demand of the crew, additional resources of O_2 are supplied by the Russian oxygen generator -Elektron , pressurized oxygen tanks or from a resupply vehicle.

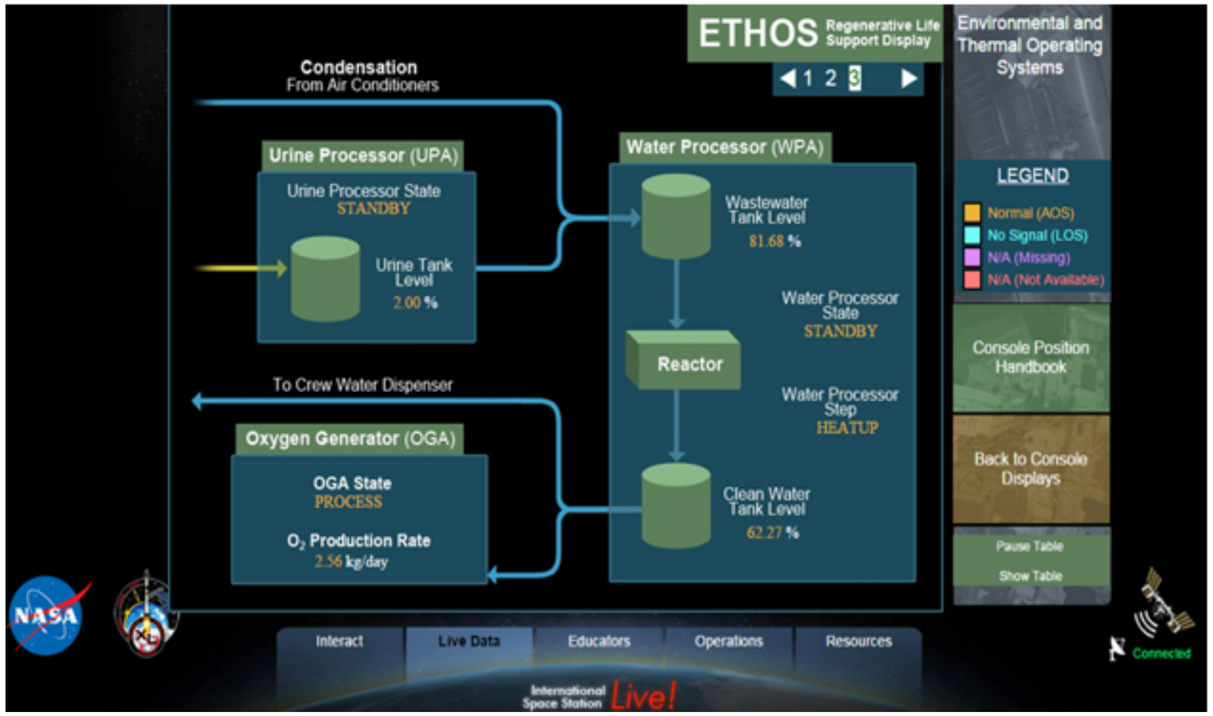
Astronaut Daniel W. Bursch, Expedition Four flight engineer, works on the Elektron Oxygen Generator in the Zvezda Service Module on the International Space Station (ISS).

Image courtesy of NASA

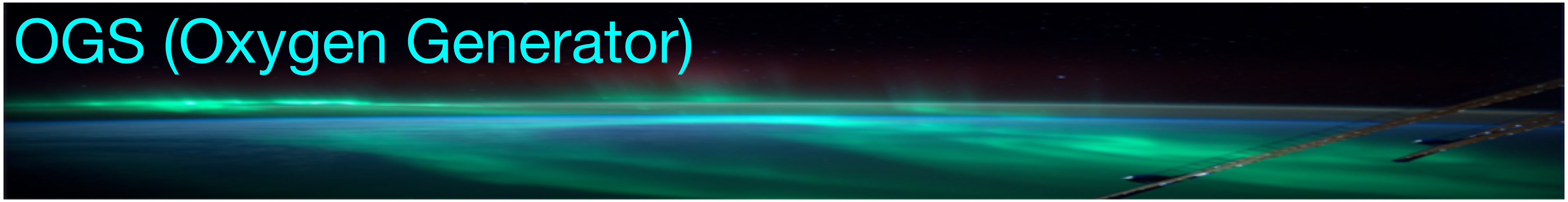
ETHOS Console Displays

A wireless signal sends data from the ISS to the Mission Control Center. This data is updated on the ETHOS console displays. The current atmosphere, oxygen and water production of the ISS modules is displayed on the consoles. The ETHOS flight controller checks the data on the console displays to make sure everything is working as expected.

To view these display, return to the ISSLive! website at http://spacestationlive.jsc.nasa.gov. To obtain all the live data streaming from the ISS to the ETHOS console display, select “Resources,” and then select “Space Station Data”.



OGS (Oxygen Generator)



The OGS produces breathable oxygen for the crew by converting wastewater from the ISS into oxygen and hydrogen through the process of electrolysis.

To learn more, explore the 3D ISS Mission Control Center by accessing Explore Mission Control under the Interact tab on the ISSLive! website at http://spacestationlive.nasa.gov

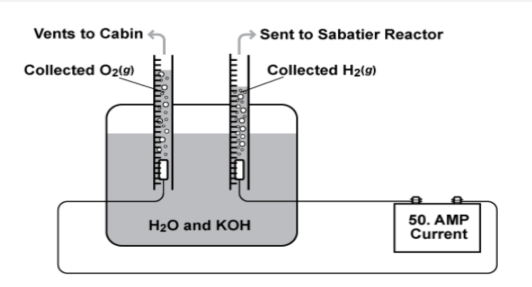


Diagram depiction of the electrolysis process used in the OGS system in one of multiple electrolytic cells .

The OGS converts water collected from a variety of sources within the ISS (e.g. urine, wastewater, and condensation) into hydrogen (H2) and oxygen (O2) through the process of electrolysis. Potassium hydroxide (KOH) is used as an electrolyte creating a solution that is 30% KOH. When a current is then placed on the solution, oxygen and hydrogen are produced.

The electricity is generated by the station's solar panels.

Electrolysis of Water

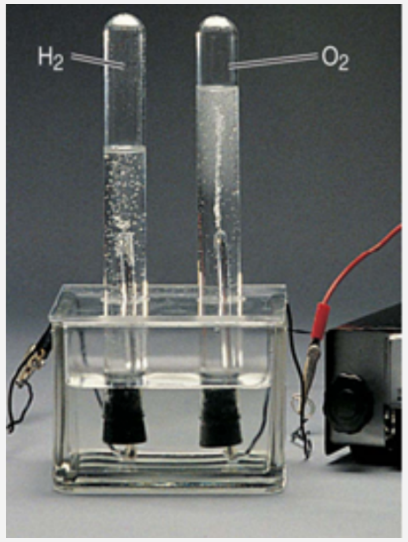
The suffix -lysis comes from the Greek stem meaning to loosen or split up. Electrolysis literally uses an electric current to split a compound into its elements.

In the electrolytic cell, anode is the positive electrode where oxidation takes place. Cathode is the negative electrode where reduction occurs

By itself, water is a very poor conductor of electricity. We therefore add an electrolyte to water to provide ions that can flow through the solution, thereby completing the electric circuit. The electrolyte must be soluble in water. It should also be relatively inexpensive. Most importantly, it must contain ions that are harder to oxidize or reduce than water.

According to the equations for the two half-reactions, the overall reaction of the electrolysis of water is:

$$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$$



Note the difference between the volumes of H2 and O2

VIDEO 3. Water Electrolysis.wmv

Chapitre 3

ACTIVITY

Visit the ETHOS console display in the 3D Mission Control Center environment to answer the following questions.

http://spacestationlive.nasa.gov

1) Question:

a) **Write the balanced equation for the electrolysis of water. Calculate the value of the standard cell potential, E°, for the reaction using the information from the table below.**

Anode reaction: $2\ H_2O \Longrightarrow O_2 + 4\ H^+ + 4\ e^-$ **Eo red = 1.23 V**

Cathode reaction: $2\ H_2O + 2\ e^- \Longrightarrow H_2 + 2\ OH^-$ **Eo red = - 0.83 V**

b) **Determine the moles of electrons needed to produce one mole of oxygen**

c) **What is the oxidization number of oxygen before the reaction occurs? What is the oxidation number of oxygen (O_2) after the reaction occurs?**

2) Question:

According to the ISSLive! Website , calculate the amount of O_2 required (in liters) to sustain the size of the current crew per day at 298 K and 1 atm.

Each crewmember consumes approximately 0.90 kg of O_2 per day.
To determine the number of crewmembers currently onboard the ISS, view the OPS Planner console from the Mission Control Center or Crew Activities Timeline, under the Live Data tab.

3) Question:

Calculate the amount of water need to produce the current output of O_2 (3'6 kg)

4) Question:

a) How much oxygen is produced according to Website?

b) Calculate the amount of H_2 gas produced from the O_2 required using the new data

5) Question: ***Based on the above information and calculations:***

a) Calculate the number of moles of carbon dioxide produced on the ISS per day by the crew that can be used for the production of water. ***(The average carbon dioxide output for any person per day is approximately 1.0 kilogram (kg).)***

b) Write a balanced equation for the reaction between carbon dioxide and hydrogen gas that occurs in the Sabatier Reactor.

c) Determine the limiting reagent between the carbon dioxide and hydrogen gas.

d) Calculate the amount of water in kilograms (kg) that can be produced per day at the current rate

6) Question:

Using the data above, calculate the amperage necessary for the production of O_2 (5kg)

7) Question:

How many cells are operating in the system?

Chapitre 4

Teacher

1) Question:

a) Write the balanced equation for the electrolysis of water. Calculate the value of the standard cell potential, E°, for the reaction using the information from the table below.

Anode reaction: $2\ H_2O \implies O_2 + 4\ H^+ + 4\ e^-$ Eo red = 1.23 V

Cathode reaction : $2\ H_2O + 2\ e^- \implies H_2 + 2\ OH^-$ Eo red = - 0.83 V

Oxidation half-reaction (anode): $2\ H_2O \rightarrow O_2 + 4\ H^+ + 4\ e^-$ E^o_{red} = 1.23 V
Reduction half-reaction (cathode): $2\ (2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-)$ E^o_{red} = - 0.83 V

Cell reaction: $6\ H_2O \rightarrow O_2 + 2H_2 + \boxed{4H^+ + 4OH^-} \rightarrow 4H_2O$

The overall reaction : $2\ H_2O\ (l) \rightarrow O_2\ (g) + 2H_2(g)$ $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ = -2'06V

Negative value of E^o_{cell} indicates that the process is not spontaneous, you need an external power source.

b) Determine the moles of electrons needed to produce one mole of oxygen

According to overall redox reaction to produce one mole of oxygen we need to electrolyze 2 moles of water, and 4 moles of electrons are required.

c) What is the oxidization number of oxygen before the reaction occurs? What is the oxidation number of oxygen (O_2) after the reaction occurs?

The oxidation numbers are established by agreement: free elements or in its natural state receive the number of oxidation 0 .

Before : -2 ; After : 0

Oxygen is oxidized because it reduces its oxidation state

2) Question:

According to the ISSLive! Website , calculate the amount of O_2 required (in liters) to sustain the size of the current crew per day at 298 K and 1 atm.

Each crewmember consumes approximately 0.90 kg of O_2 per day.

To determine the number of crewmembers currently onboard the ISS, view the OPS Planner console from the Mission Control Center or Crew Activities Timeline, under the Live Data tab.

Assume 4 crewmembers onboard the ISS.

$$4 \times 0.9\,kg\ O_2 = 3.6\ kg\ O_2 / day \Rightarrow 3.6\,kg\ O_2\ \frac{1000\,g\,O_2}{1\,kg\ O_2} \cdot \frac{1\,mol}{32\,g\ O_2} = 112.5\ mol\ O_2 / day \Rightarrow$$

$$PV = nRT \Rightarrow V = 2749.05\ L\ O_2 / day$$

3) Question:

Calculate the amount of water need to produce the current output of O2 (3'6 kg)

$$3.6\ kg\ O_2 \cdot \frac{1000\ g\ O_2}{1\,kg\ O_2} \cdot \frac{1\ mol\ O_2}{32\ g\ O_2} \cdot \frac{2\ mol O_2}{1 mol O_2} \cdot \frac{18\ g\ H_2O}{1 mol\ H_2O} \cdot \frac{1\ kg\ H_2O}{1000 g\ H_2O} = 4.05\ kg\ H_2O$$

4) Question:

a) How much oxygen is produced according to Website?

According to ISSLive! website indicates 5.00 kg of oxygen gas production per day.

b) Calculate the amount of H_2 gas produced from the O_2 required using the new data

According to the overall equation: $2\ H_2O\ (l) \Rightarrow O_2\ (g) + 2\ H_2\ (g)$

$$5.00\ \frac{kg\ O_2}{day} \cdot \frac{1000\ g\ O_2}{1 kg\ O_2} \cdot \frac{1 mol\ O_2}{32 g\ O_2} \cdot \frac{2 mol\ H_2}{1 mol\ O_2} = 312.5\ \frac{mol\ H_2}{day}$$

5) Question: Based on the above information and calculations:

a) Calculate the number of moles of carbon dioxide produced on the ISS per day by the crew that can be used for the production of water. *(The average carbon dioxide output for any person per day is approximately 1.0 kilogram (kg).)*

For 4 crew members : $4 \times 1.0\ kg\ CO_2 = 4.0\ kg\ CO_2\ /\ day$

$$\frac{4.0\ kg\ CO_2}{day} \cdot \frac{1000\ g\ CO_2}{1\ kg\ CO_2} \cdot \frac{1\ mol\ CO_2}{44\ g\ CO_2} = 90.9 \Rightarrow 91\ mol\ CO_2\ /\ day$$

b) Write a balanced equation for the reaction between carbon dioxide and hydrogen gas that occurs in the Sabatier Reactor.

$CO_2\ (g) + 4\ H_2\ (g) \Rightarrow 2\ H_2O\ (l) + CH_4\ (g)$

c) Determine the limiting reagent between the carbon dioxide and hydrogen gas.

$$91 \text{ mol } CO_2 \cdot \frac{4 \text{ mol } H_2}{1 \text{ mol } CO_2} = 364 \text{ mol } H_2$$

Only 312.5 moles of hydrogen gas are produced , so hydrogen gas is the limiting reagent.

d) Calculate the amount of water in kilograms (kg) that can be produced per day at the current rate

$$312.5 \text{ mol } H_2 \cdot \frac{2\text{mol } H_2O}{4\text{mol } H_2} \cdot \frac{18 \text{ g } H_2O}{1\text{mol } H_2O} \cdot \frac{1\text{kg } H_2O}{1000\text{g } H_2O} = 2.81 \text{ kg water}$$

6) Question:

Using the data above, calculate the amperage necessary for the production of O_2 (5kg)

Calculate the amount of electric charge in coulombs (C) that passes through the solution in one of the electrolytic cells in the OGS in a 24-hour period.

$$\frac{5.00 \text{ kg}O_2}{\text{day}} \cdot \frac{1000 \text{ g } O_2}{1 \text{ kg}O_2} \cdot \frac{1\text{mol } O_2}{32\text{g } O_2} \cdot \frac{4 \text{ mol e}^-}{1\text{mol } O_2} \cdot \frac{96\,500 \text{ C}}{1\text{mol e}^-} = 60\,312\,500 \text{ C / day}$$

$$\frac{60\,312\,500 \text{ C}}{1 \text{ day}} \cdot \frac{1 \text{ day}}{24 \text{ hr}} \cdot \frac{1 \text{ hr}}{60\text{min}} \cdot \frac{1\text{min}}{60\text{s}} = 698 \text{ A}$$

7) Question:

How many cells are operating in the system?

A constant current of 50 A is applied to each electrolytic cell in the OGS system.

698 A / 50 A per cell = 13.96 or 14 cells operating