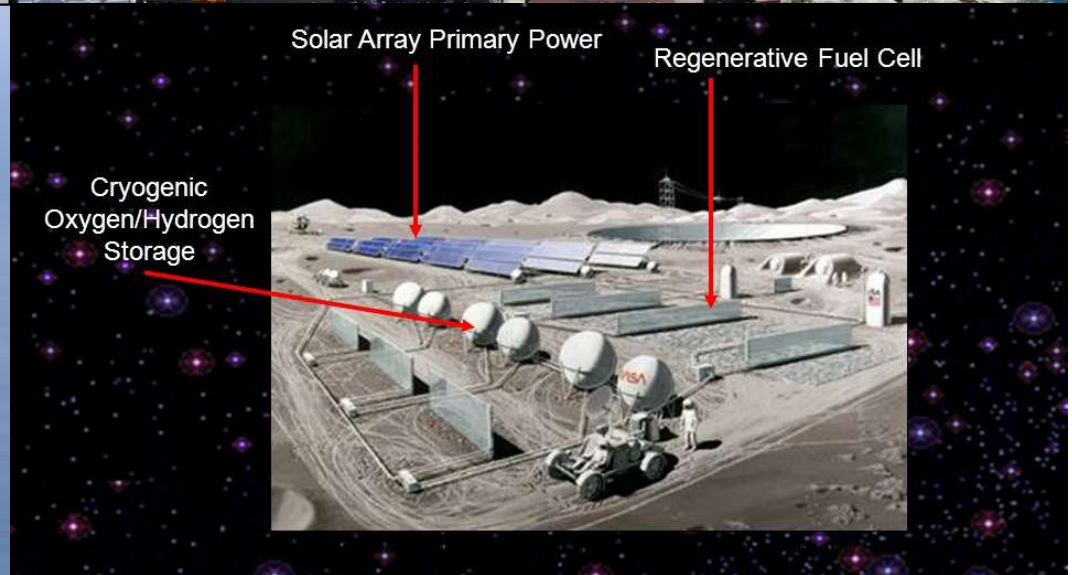
# Development of Regenerative PEMFC system for HALE Aircraft

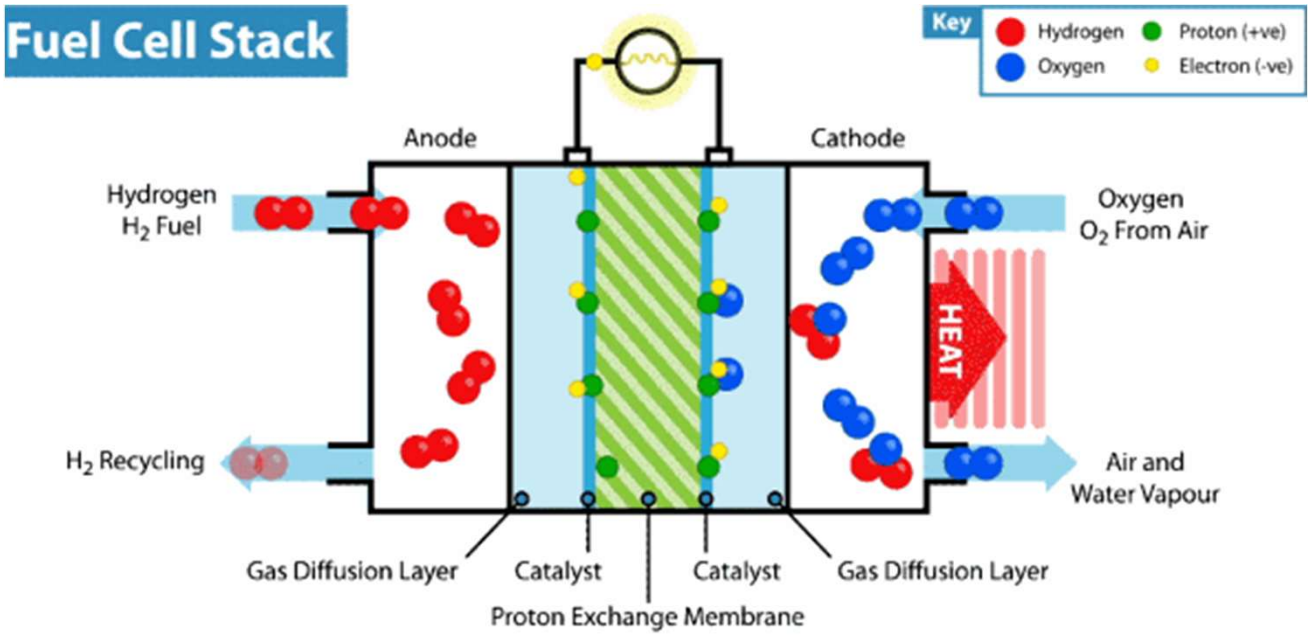
Seung-Gon Kim



# 1 Fuel Cells

**Fuel Cell :** An electrochemical cell that converts the chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent





Ground Vehicle

Aerial Vehicle


Residential Platform

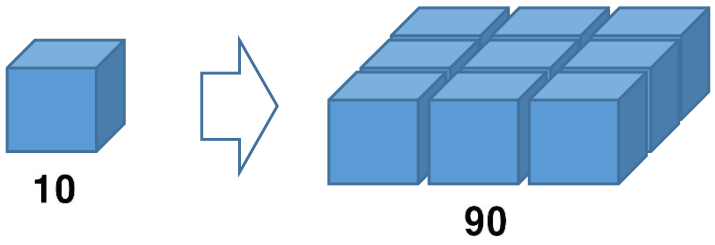
**Pros. :** Higher Energy Density(vs. battery), Low Operating Temperature, No exhaust except pure $H_2O$, Low Noise, Fast Recharge, Human Friendly

# 2 Energy Density

**Energy Density :** the amount of energy stored in a given system or region of space per unit volume
➔ J/m$^3$, Whr/L (Volumetric Energy Density)

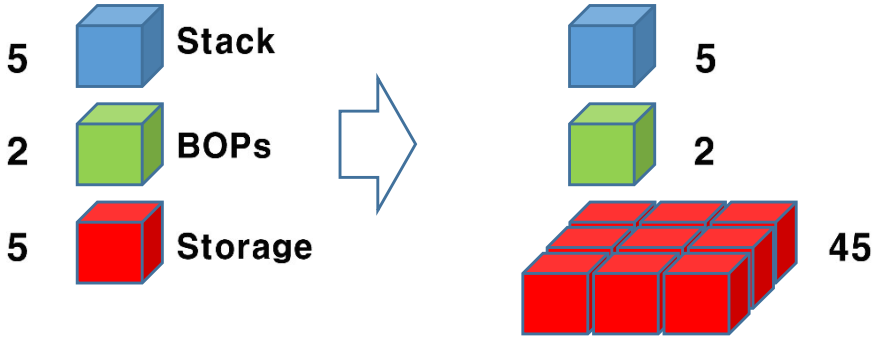
**cf.) Specific Energy :** the amount of energy stored in a given system or region of space per unit mass
➔ J/kg, Whr/kg (Gravimetric Energy Density)

## Battery Systems

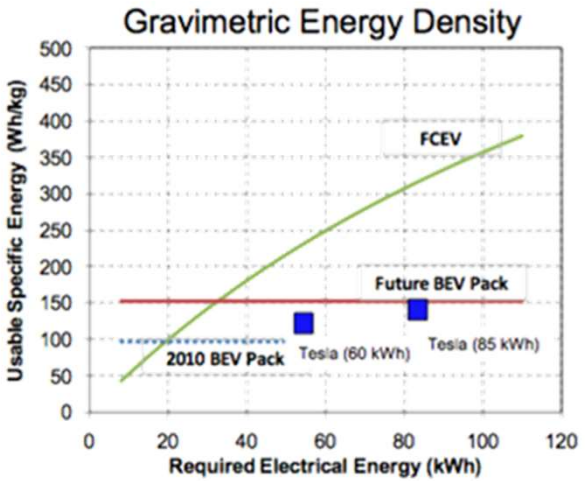


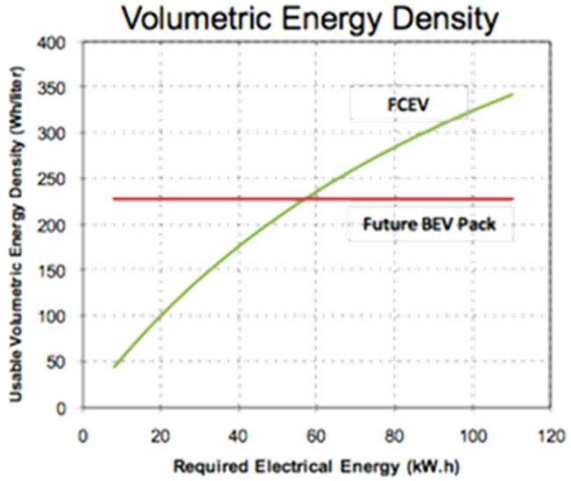

➔ **Energy Density maintained**

## Fuel Cell Systems




➔ **Energy Density increased**



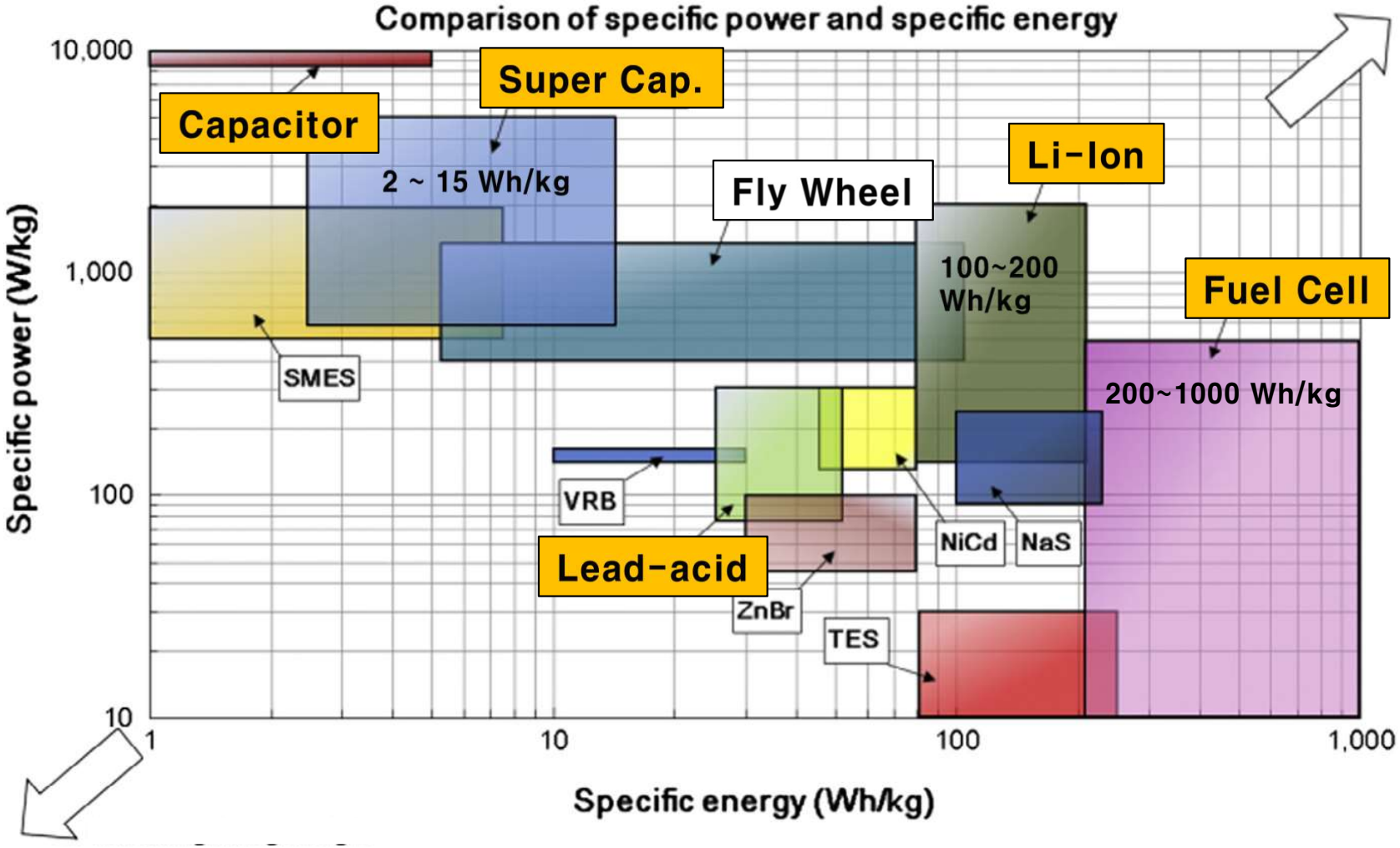




*Mathias, SAE HEVT 2014, Wagner et al. (2010)*

*Tesla Model S : 157Whr/kg*

*Chevrolet Bolt : 136Whr/kg*

# 3 Energy Solutions




**Super Cap.(High Power) – Li-Ion – FC(High Energy)**

*Ref.) Overview of current development in electrical energy storage technologies and the application potential in power system operation, 2015, Applied Energy*

# 4 Fuel Cell, Why?

Li-Ion Drone (DJI Mavic 3 pro)

Flight time(Hovering): 45min Max

Fuel Cell Drone(with LH2, MetaVista)

Flight time(Hovering): over 12hours

# 5 Special-Purpose FC

**Uncommon purpose, Power pack with special purpose → Very Unique Requirement needed**

## For Remote Area

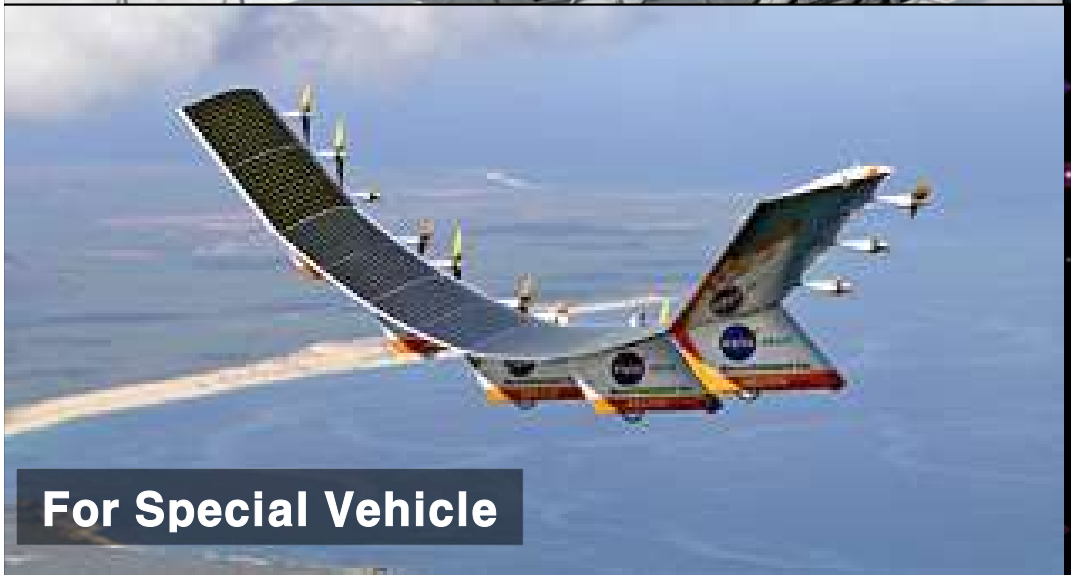
## For Disaster



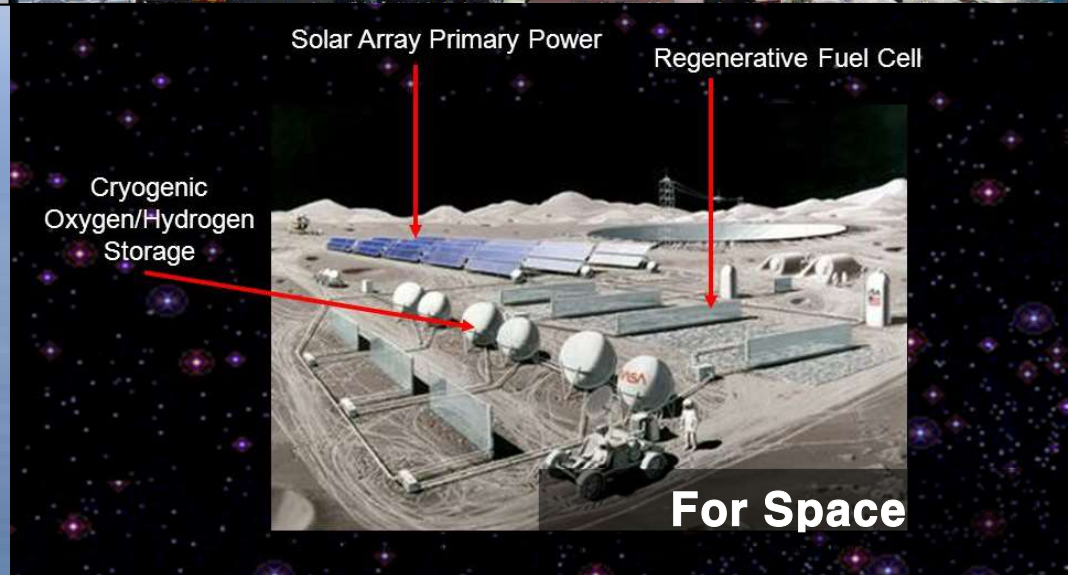





## For Special Vehicle



## For Space

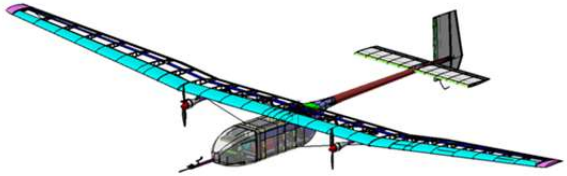


# 6 Aerial Platform

**High Specific Energy[Whr/kg], High Specific Power [Rotary wing], Regenerative[LE-UAV]**


UAM

Multi-Rotor UAV



Fixed-Wing UAV

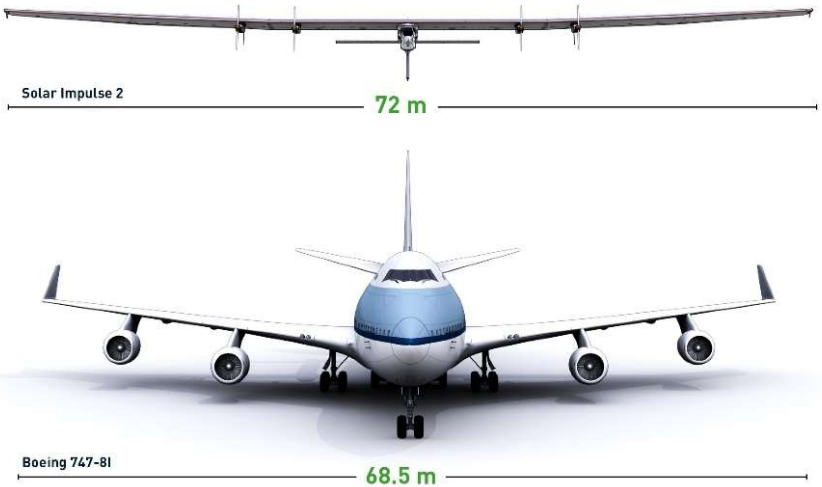
*Interstellar, 2014, Paramount Pictures*


*Helios Prototype, 2003, NASA/AeroVironment*

# 7 HALE Development

**High-Altitude Long Endurance Unmanned Aerial Vehicle**

**Helios, (NASA/AeroVironment)**
**WSP: 75.3m**
**Weight: 600kg**




**Solara 50 (Google/Titan Aerospace)**
**WSP: 50m**
**Weight: 90kg**

**SolarEagle (Boeing/DARPA)**
**WSP: 120m**
**Weight: 900kg**

**Odysseus (Aurora Flight Science)**
**WSP: 74m**
**Weight: 1133kg**

**PHASA-35 (BAE Systems)**
**WSP: 35m**
**Weight: 149kg**

**Caihong T-4 (CAAA)**
**WSP: 39m**
**Weight: 400kg**

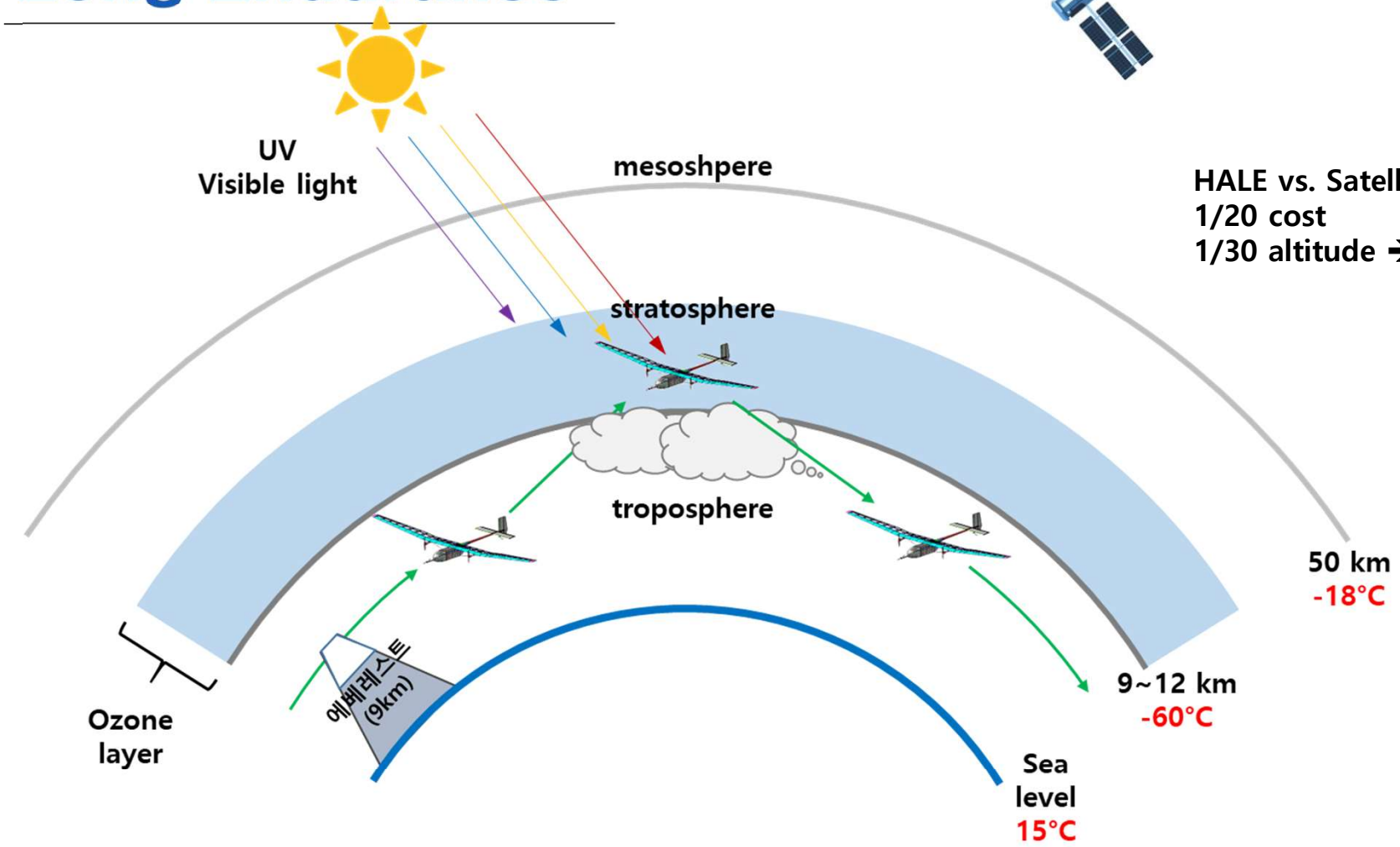
**HAWK30 (AeroVironment)**
**WSP: 79m**
**Weight: ND**

**Aquila (Facebook/Ascenta)**
**WSP: 42.7m**
**Weight: 400kg**

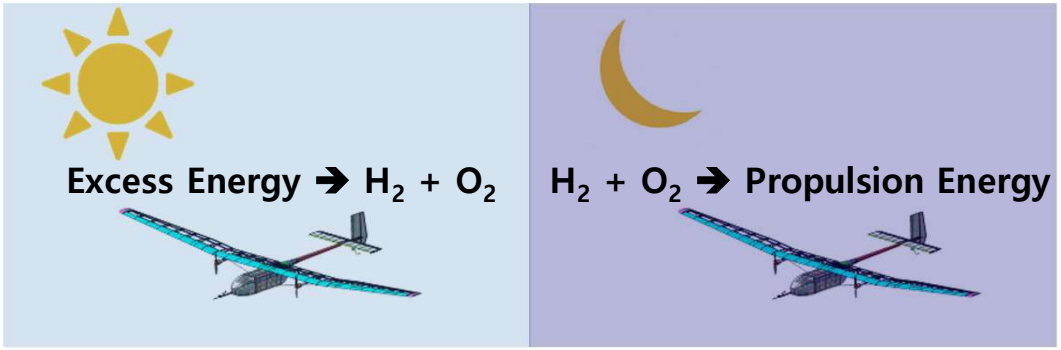
**Zephyr-S (Airbus)**
**WSP: 24m**
**Weight: 72kg**

# 8 Long Endurance

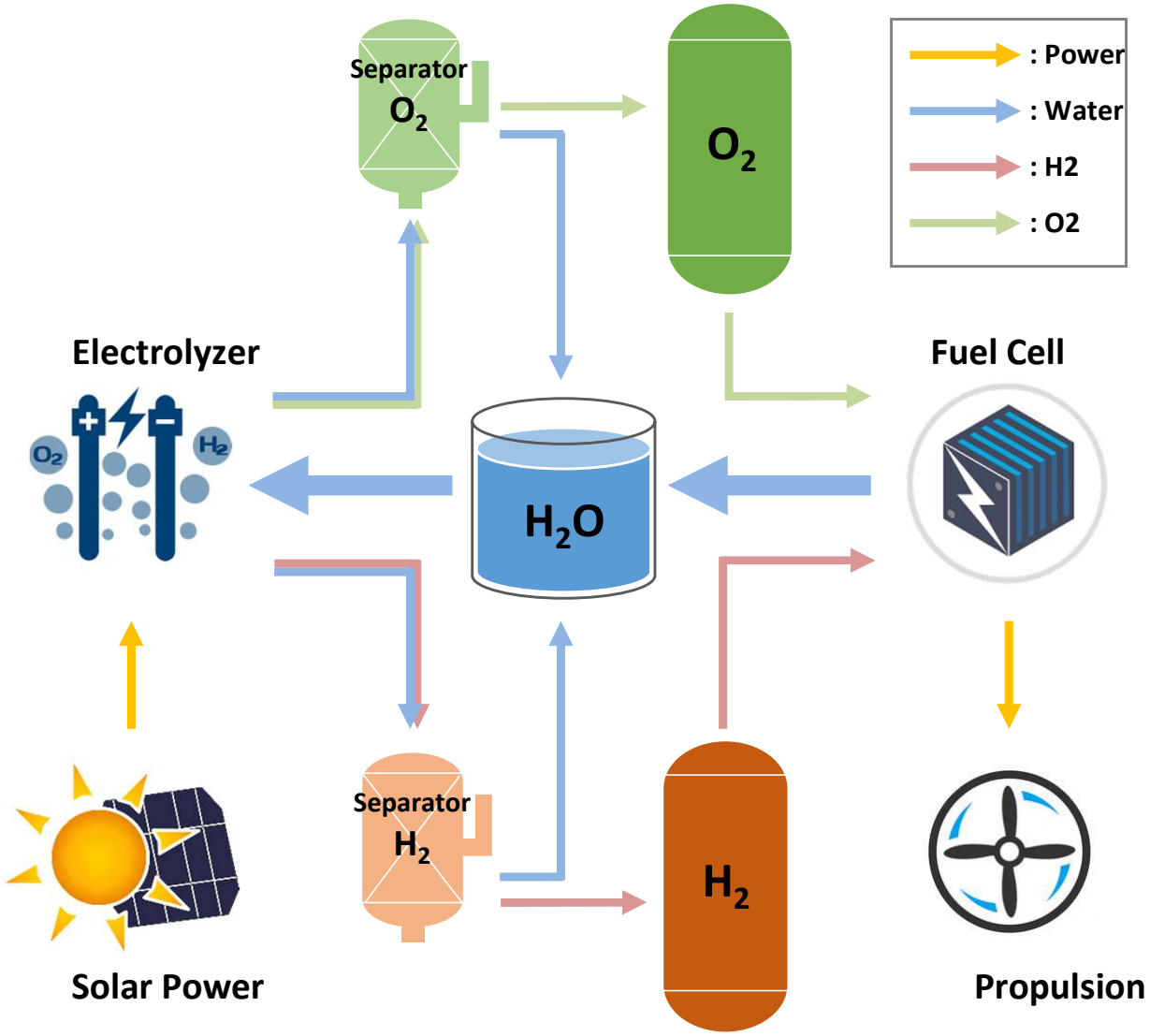
Altitude 500km ~ 36000km




HALE vs. Satellite
1/20 cost
1/30 altitude ➔ powerful

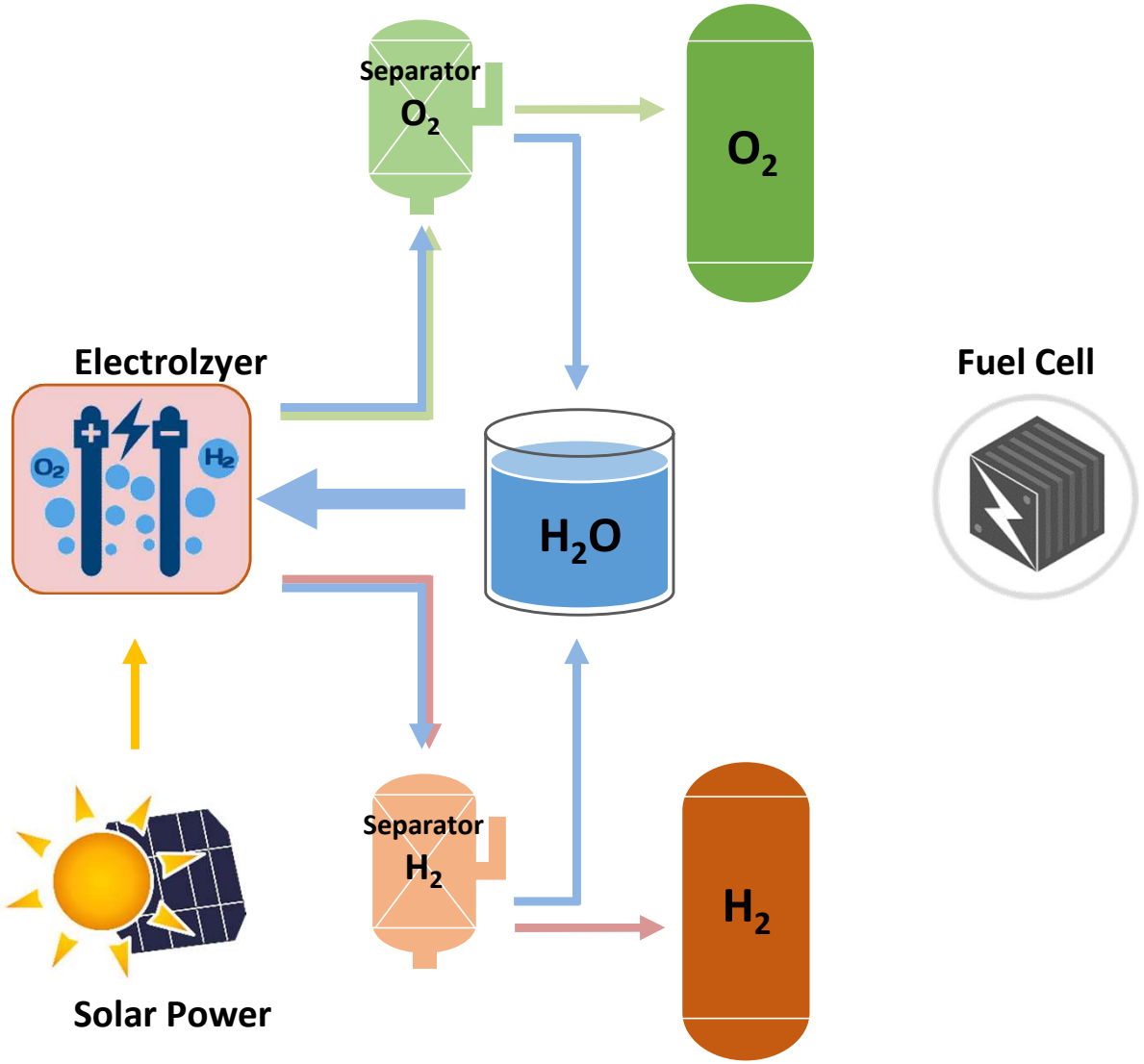


# 9 How RFC works?



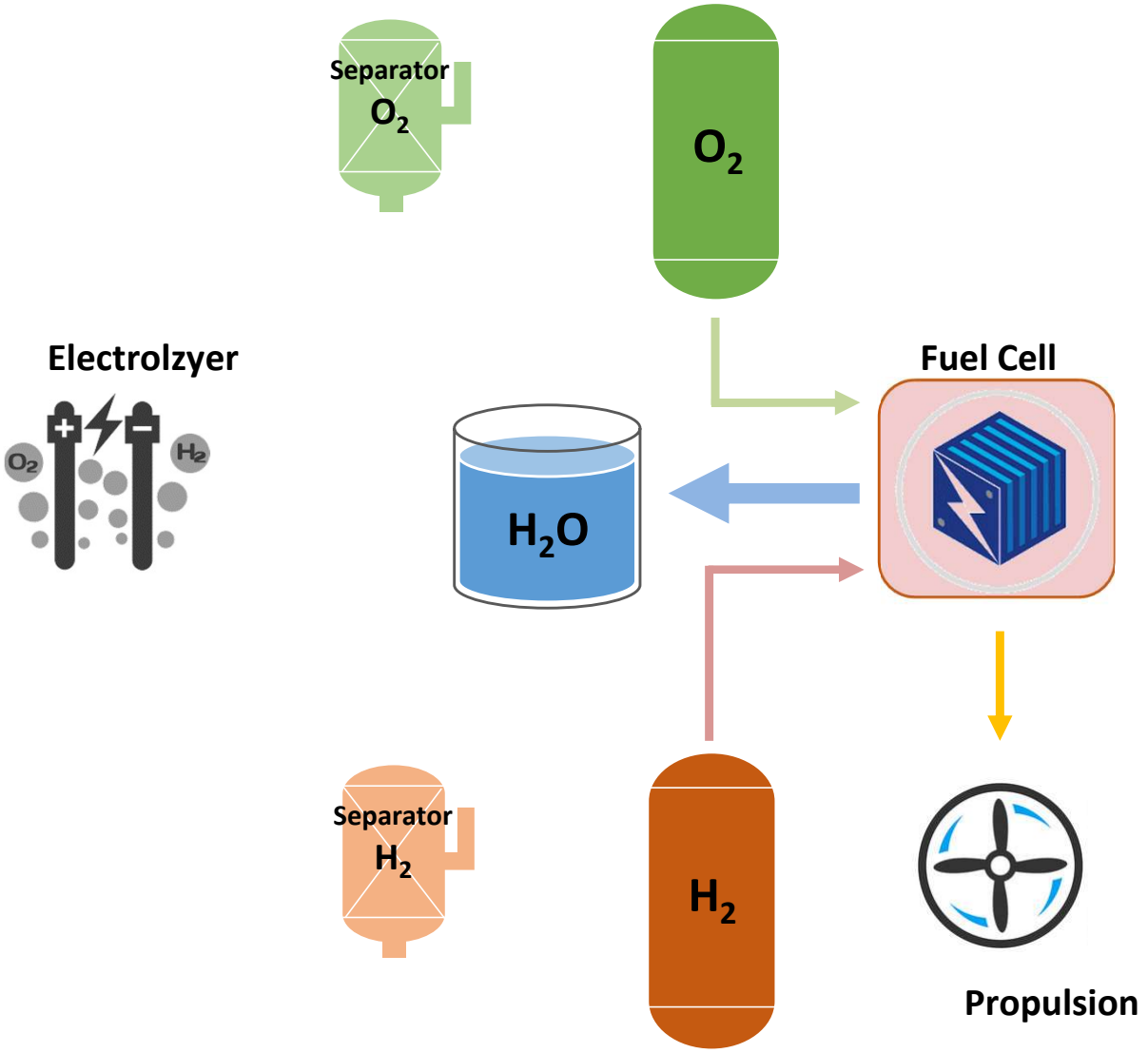

[RFC working mechanism]

# 9 How RFC works?




[RFC working mechanism - Day]

# 9 How RFC works?



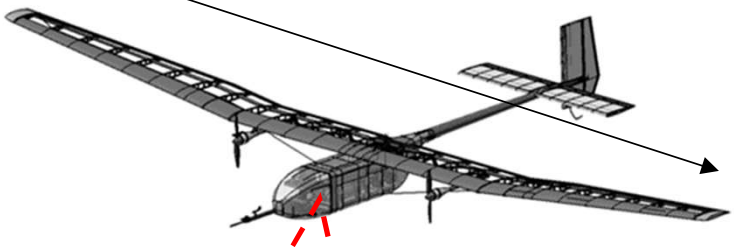

[RFC working mechanism - Night]

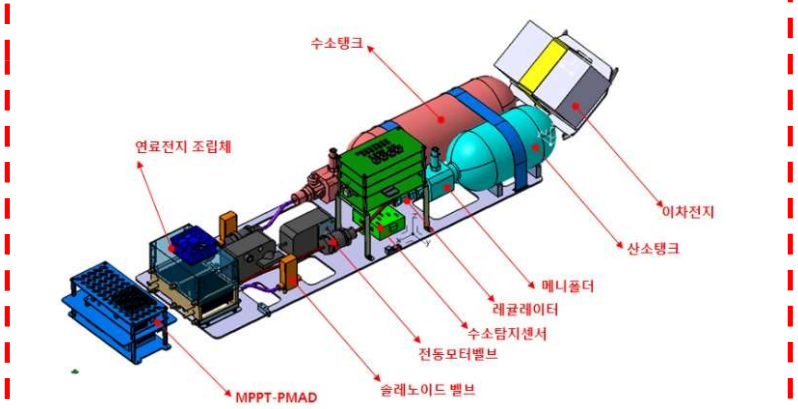
# 10 Project Summary

**Project name : Development of RFC system for HALE**
**2013.12 ~ 2017.12**
**10,623,000,000 KRW**

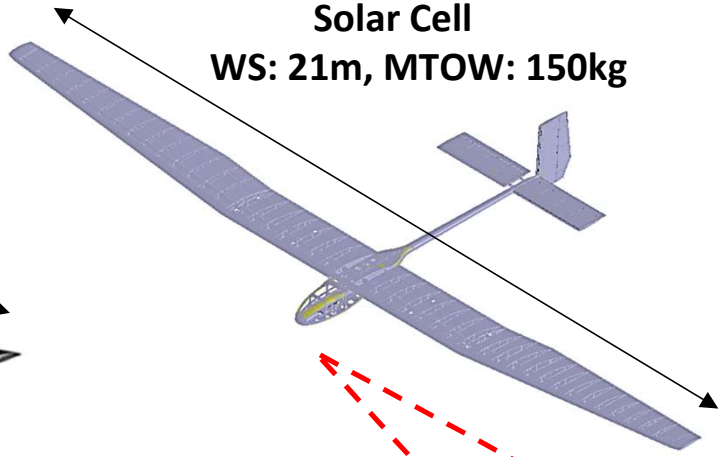
## 축소기
**Fuel Cell + Solar Cell**

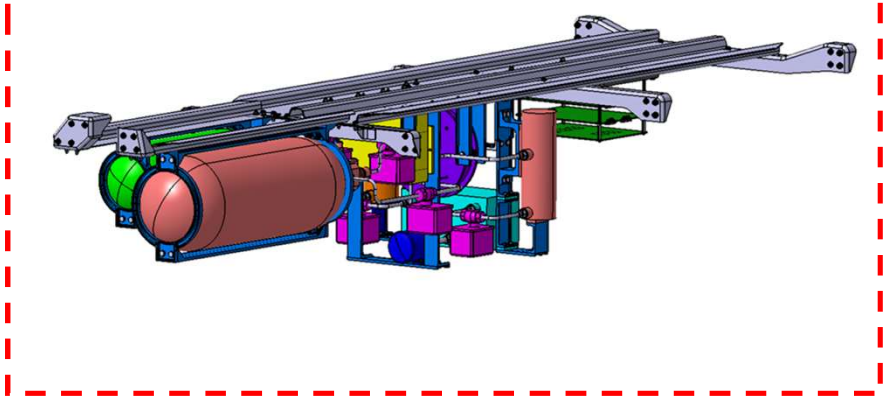
**WS: 7m, MTOW: 20kg**



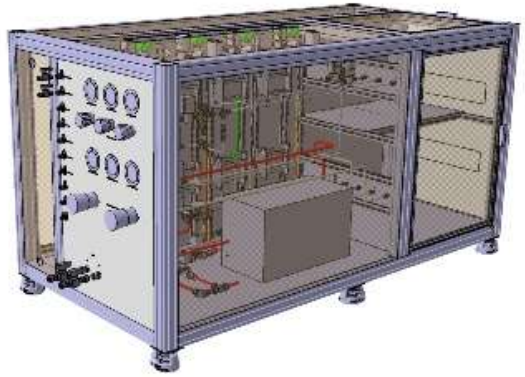



## 기술 시범기
**Fuel Cell + Electrolyzer + Solar Cell**
**WS: 21m, MTOW: 150kg**



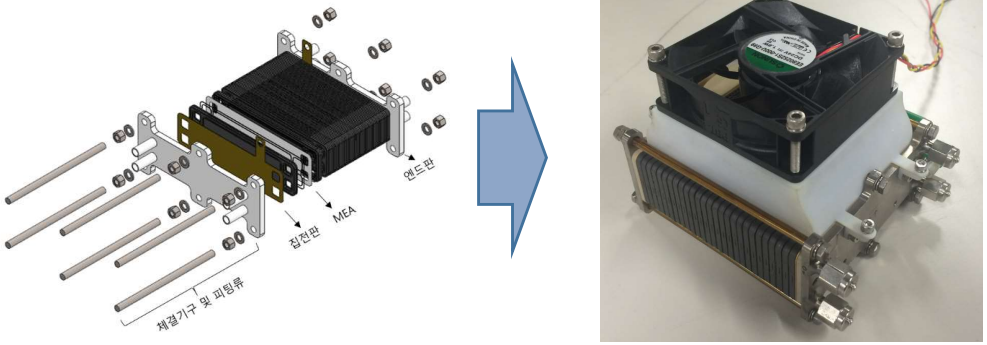


## 지상 시험기
**Fuel Cell + Electrolyzer + EC pump**
**MTOW: 500kg**

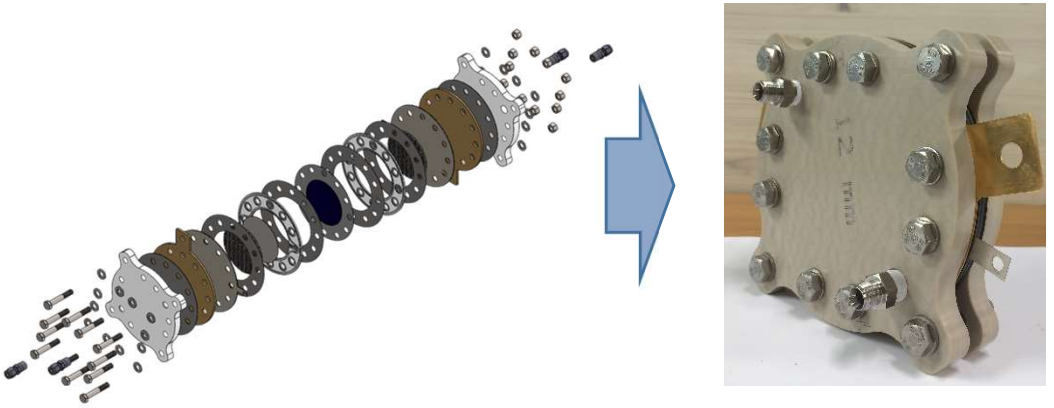


# 11 Project Summary

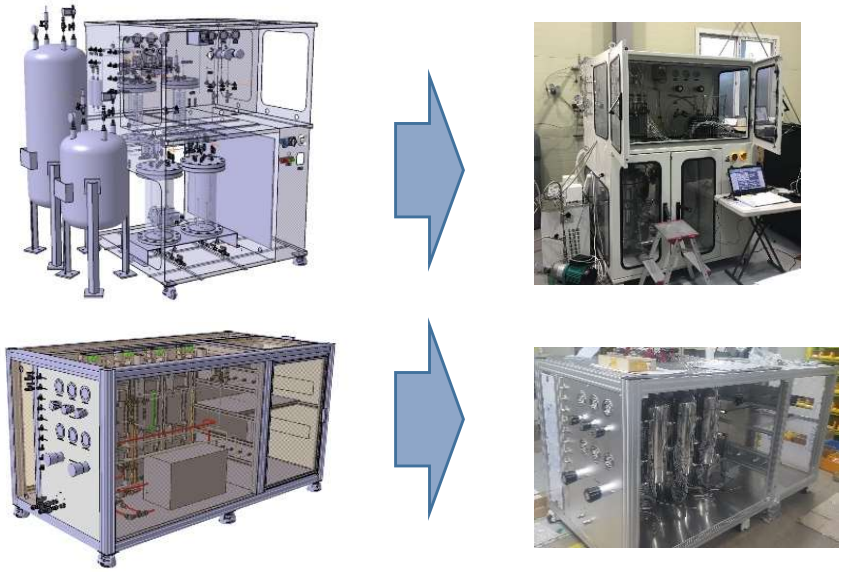
## FC stack design and Production



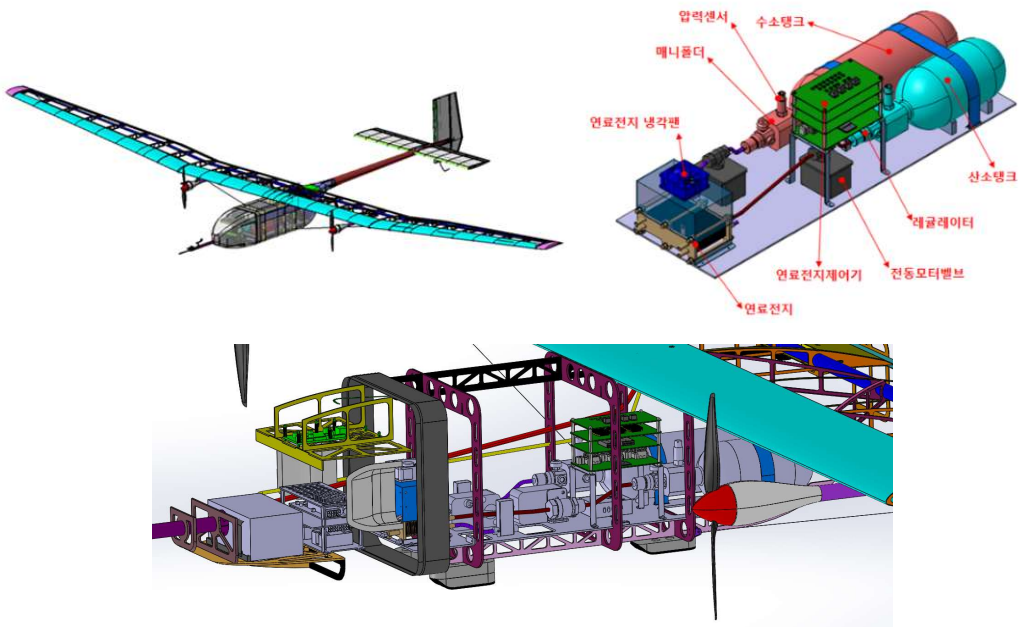

## ELZ stack design and Production



## Ground system for 500kg plane

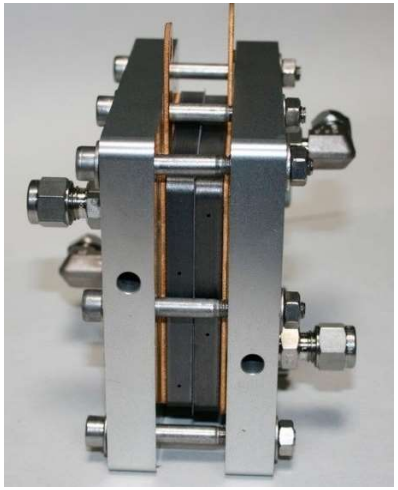


## System design and test

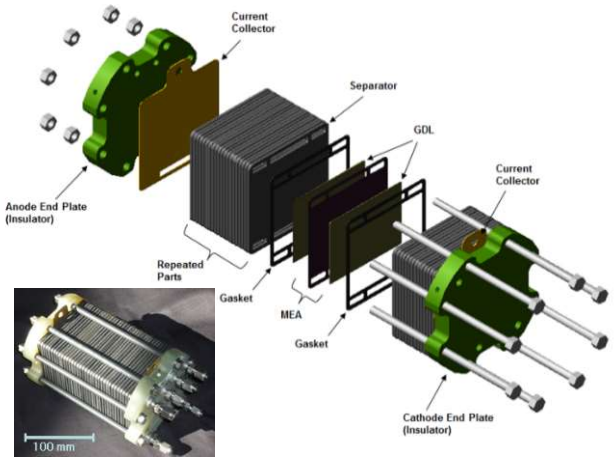


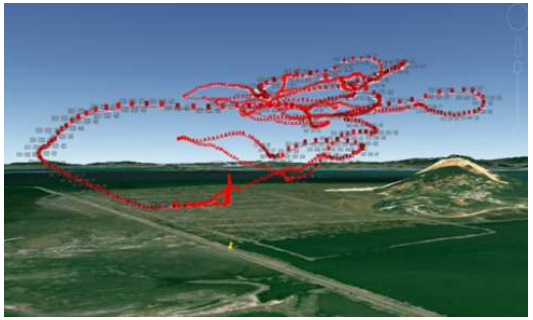
# 12 Stack Design

**Stack design for Experiments:**
**Below 200 W/kg**



**Stack design for Aircrafts:**
**Over 1kW/kg**

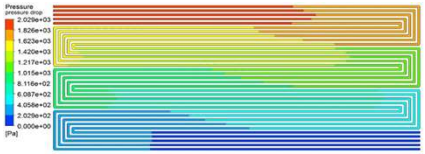


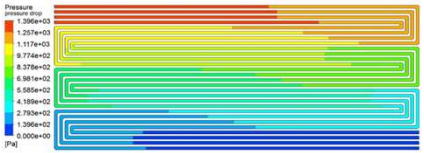
**40min flight test**

## Stack Design issues

### Flow Field Design

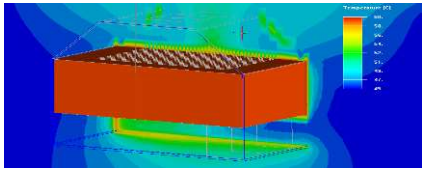


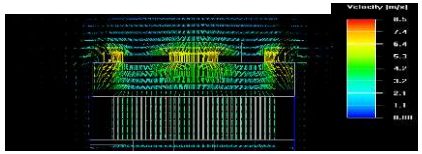
- Serpentine 0.75mm -



- Serpentine 1mm -

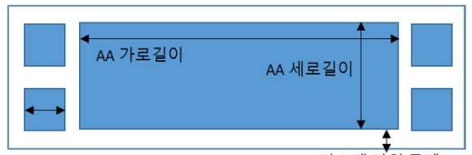
### Cooling method

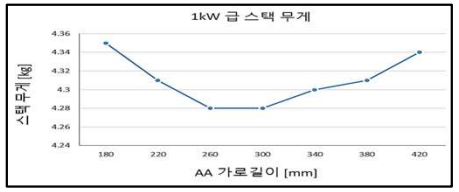




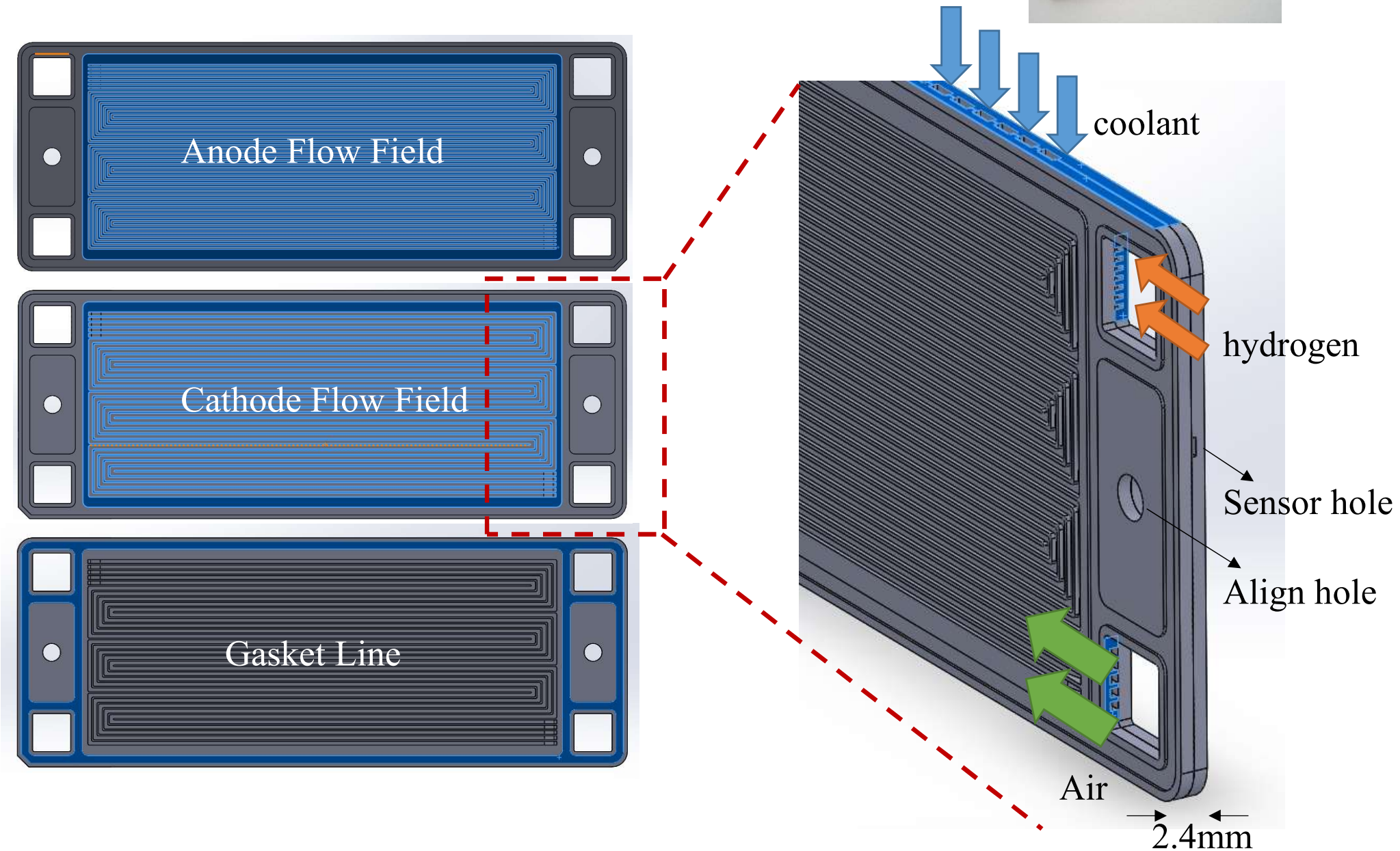
### Gasket line optimization


### Maximize Power density

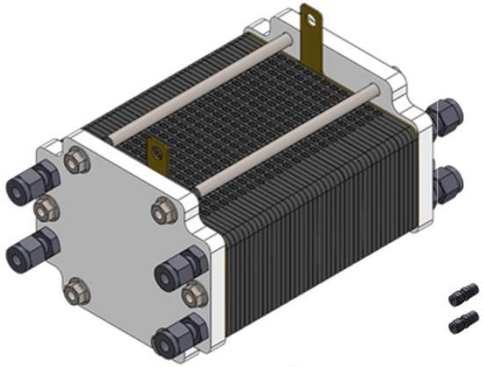


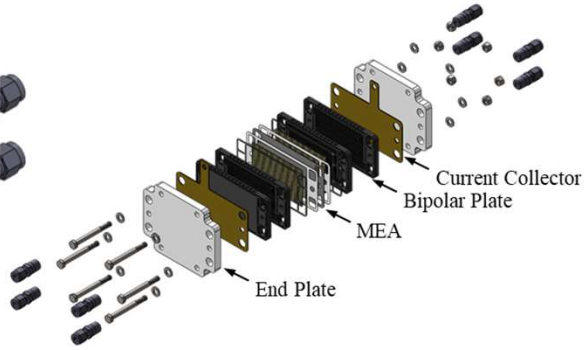



# 13 Stack Design – Bipolar Plate

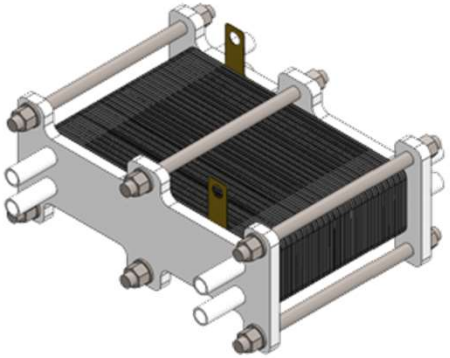


# 14 Stack Design – Results

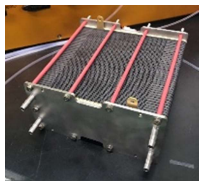


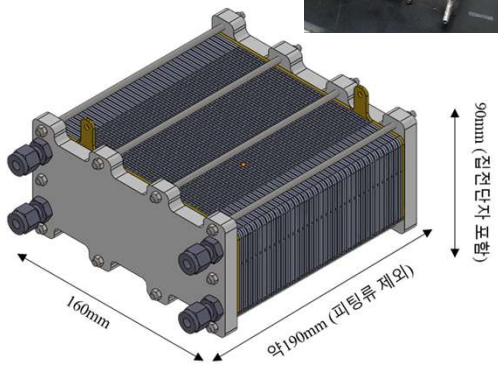



Active area : 45cm$^2$, 20 plates
600W PEMFC stack

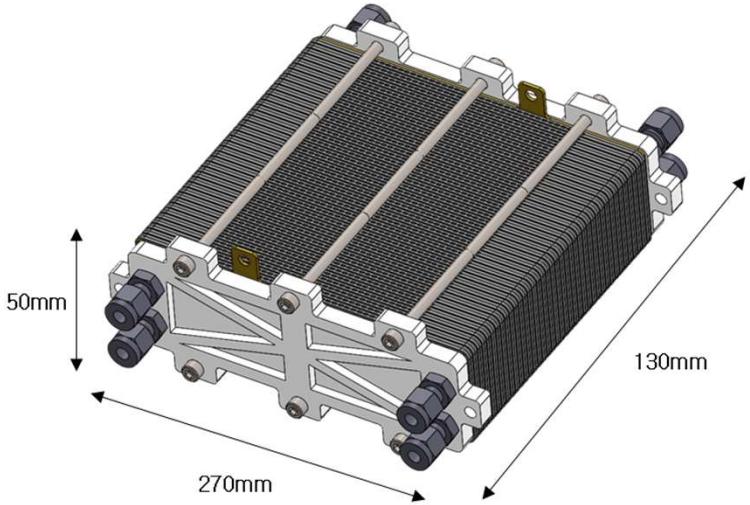


Active area: 20cm2, 26 plates
200W PEMFC stack

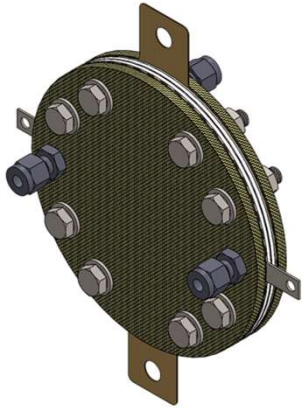


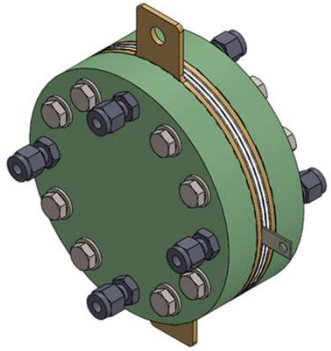


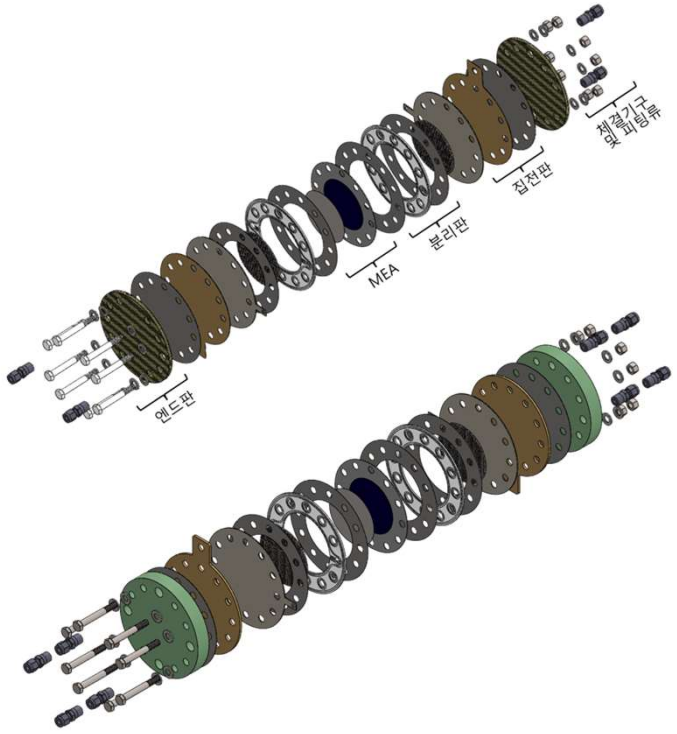

500W PEMFC stack




1kW PEMFC stack

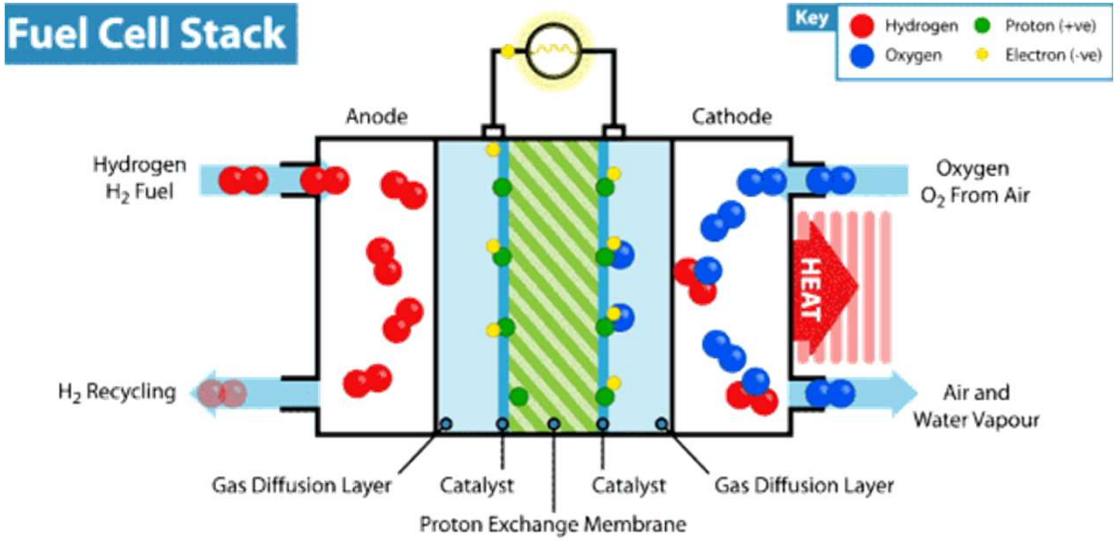


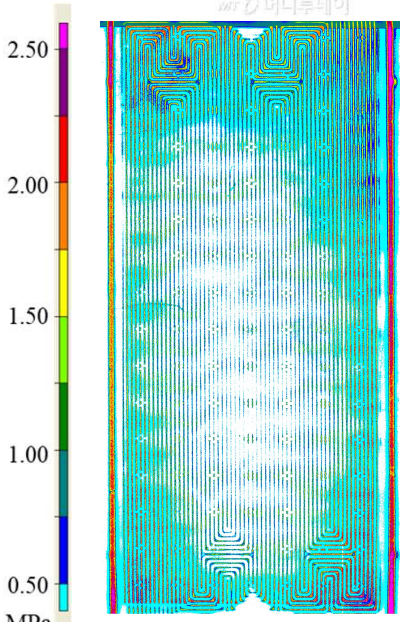




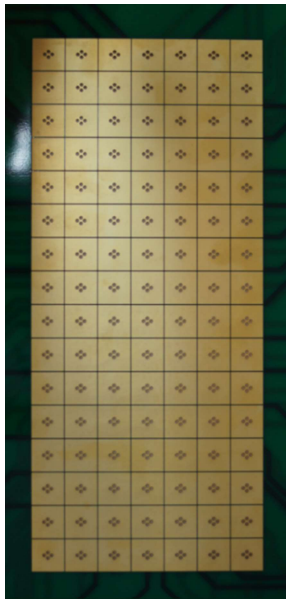

PEM Electrolyzer

# 15 In-situ current distribution measurement

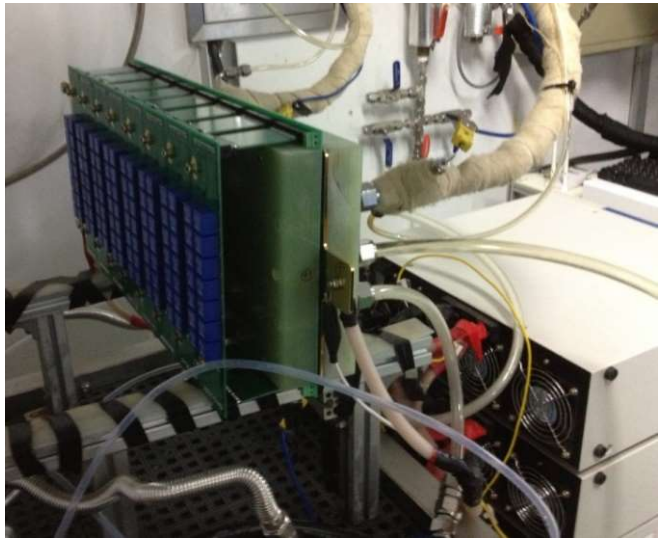



Pressed Area : 27761 ($mm^2$)
Ave. Pressure : 0.77 Mpa
Max. Pressure : 3.06 Mpa
Load : 21321 N



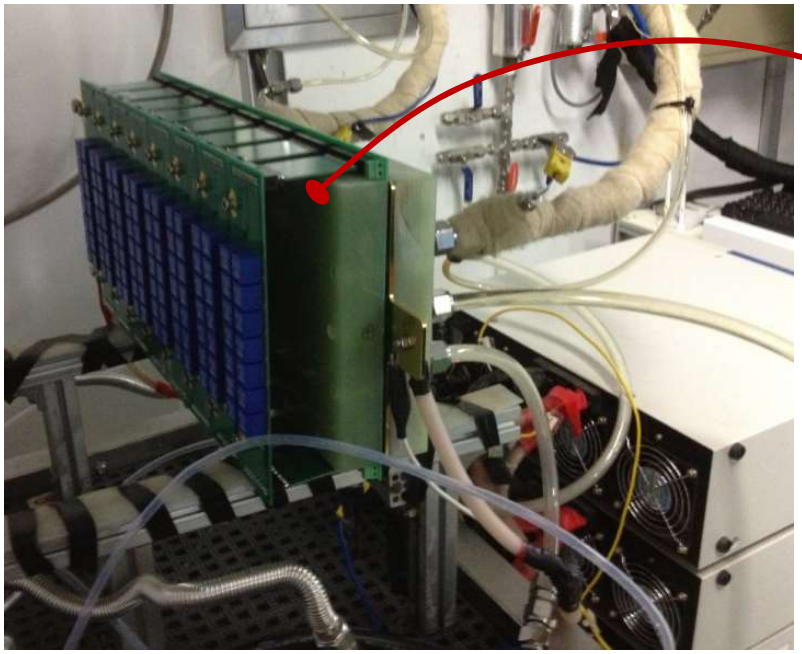
112 segmented cell

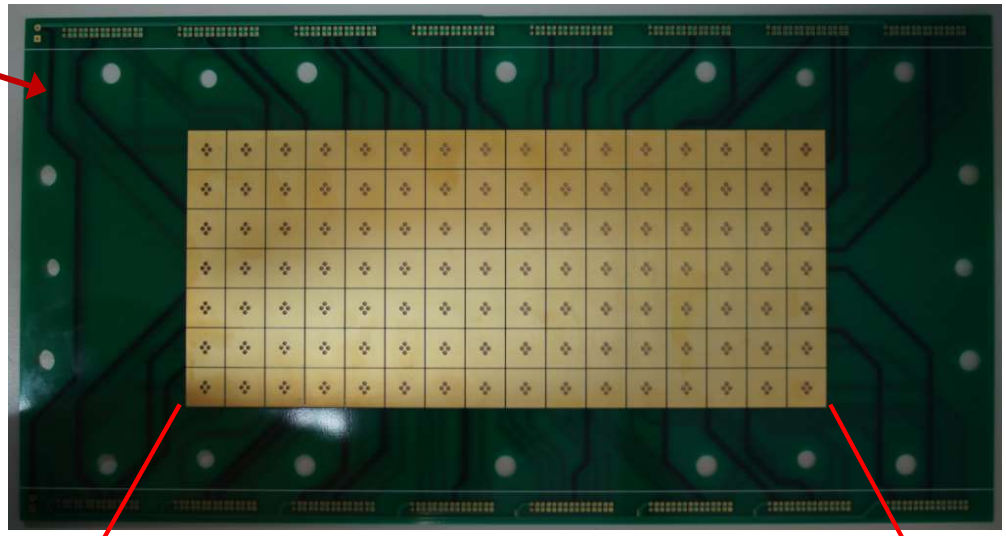


Current distribution test
of large scale single cell

# 16 In-situ current distribution measurement

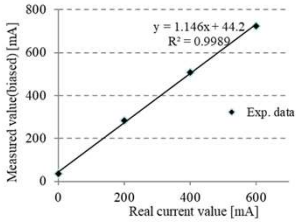
< Single cell test environment >

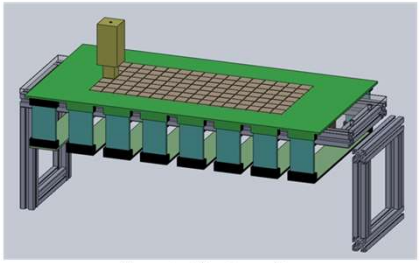




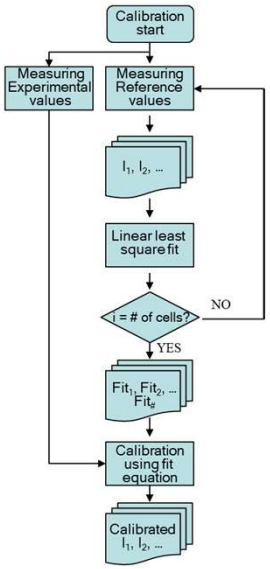
< Segmented cell current collector >

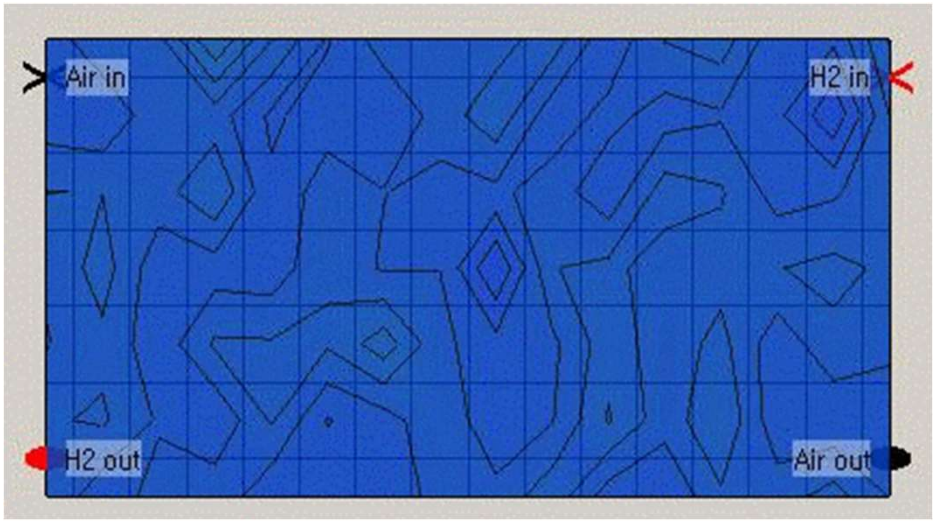
AMETES
CS2.5A-02



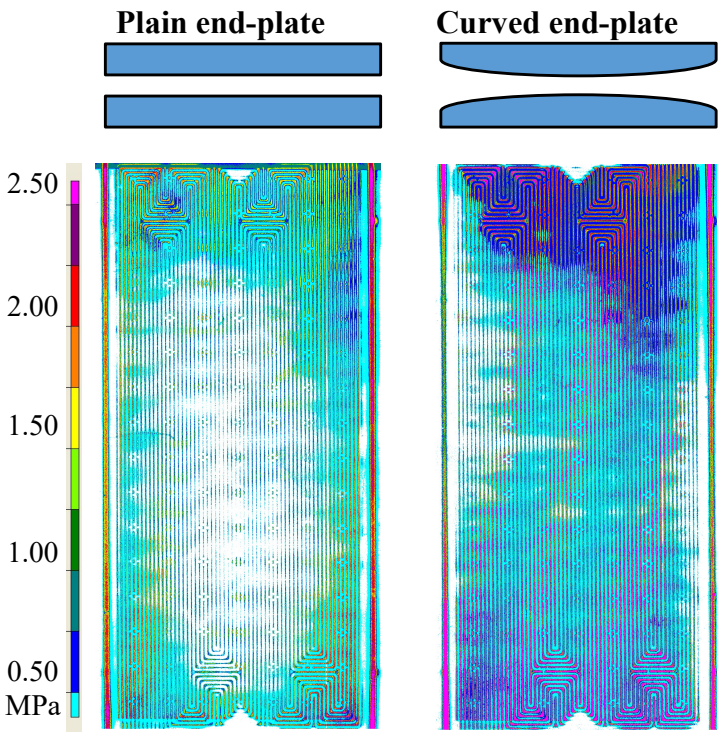
Current calibration unit

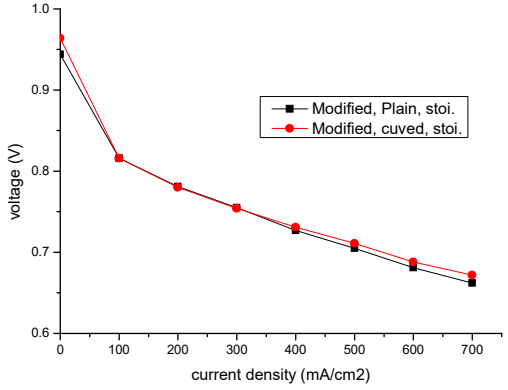


# 17 Current distribution studies

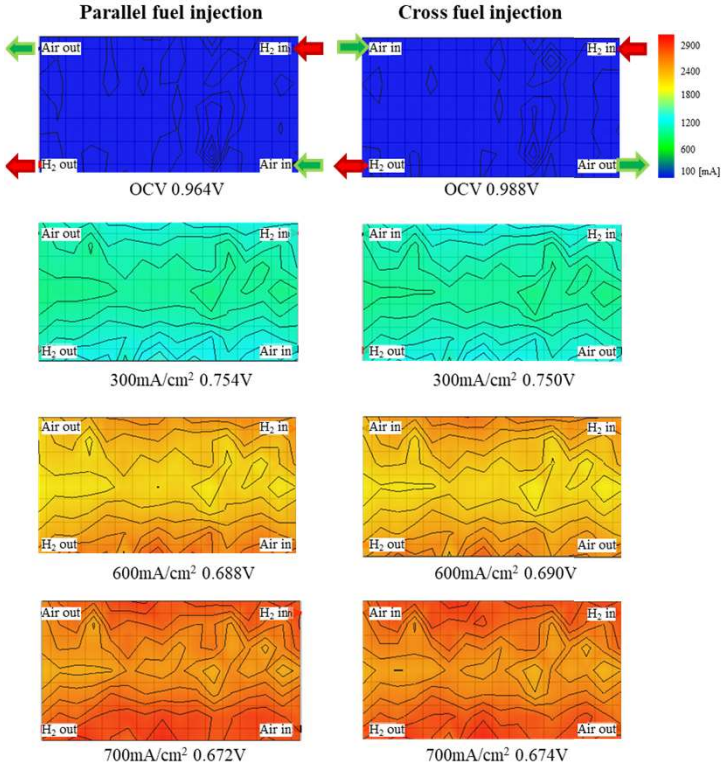
## 1. Contact resistance

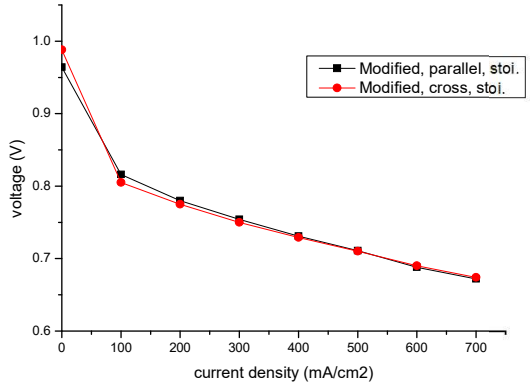



*Int. J. Hydro. Engr. (2015), SG Kim et. Al.*

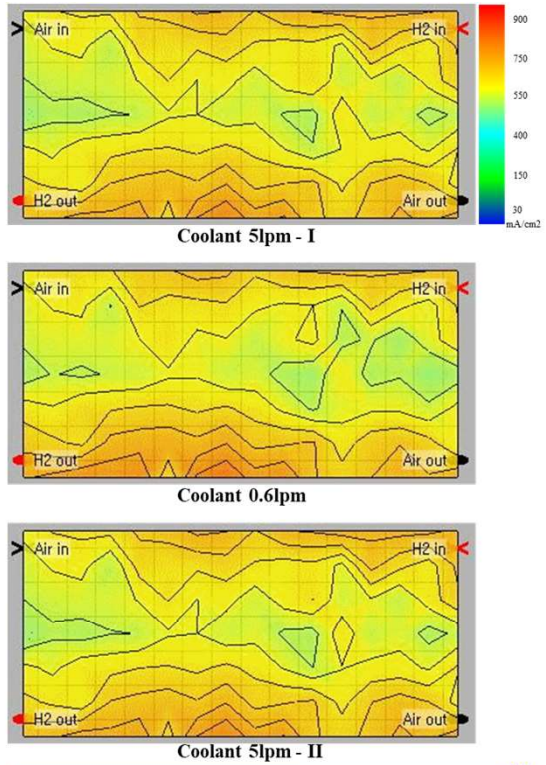
## 2. Fuel injection composition

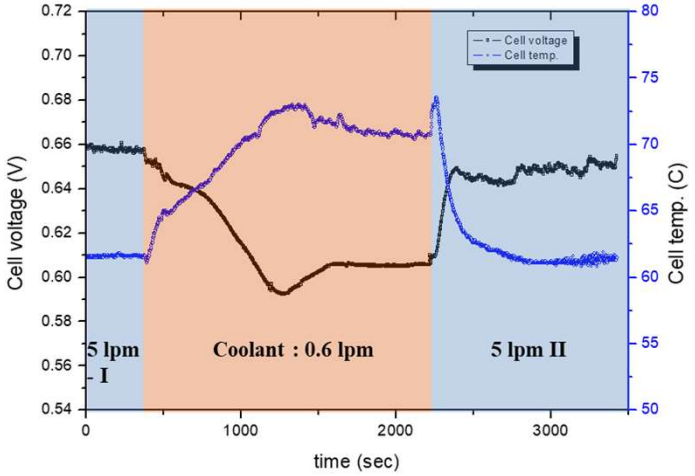



*국내특허: 10-1676752, 10-1639528*

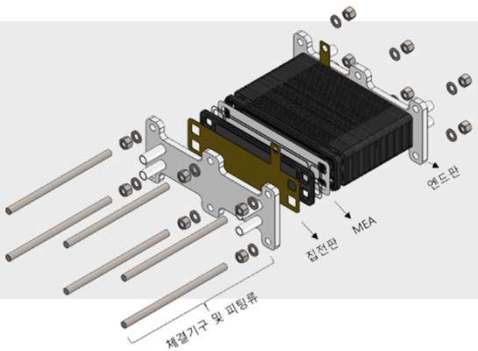
## 3. Temperature variation

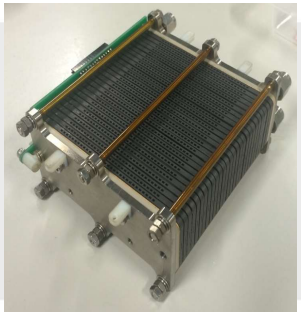


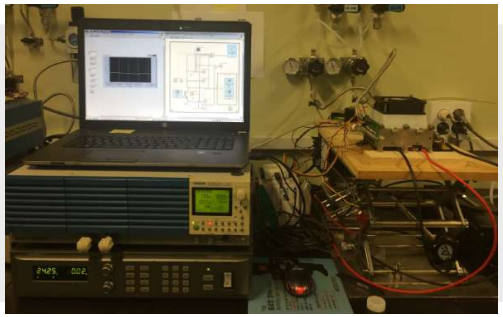



# 18 System Development

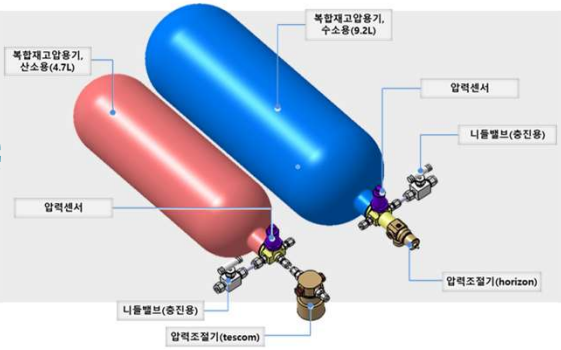
## 스택 설계/제작 평가

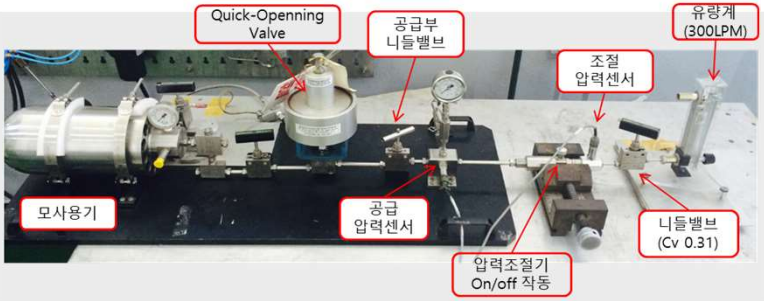


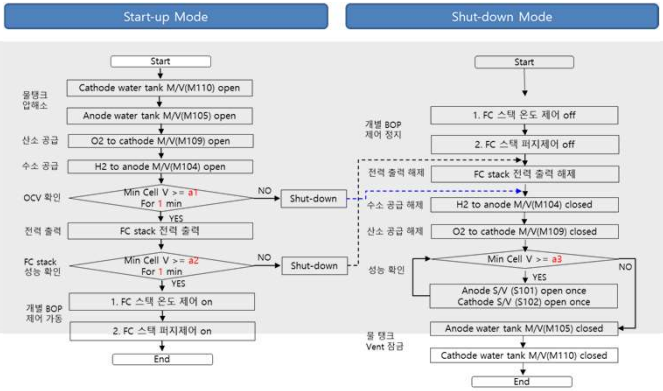


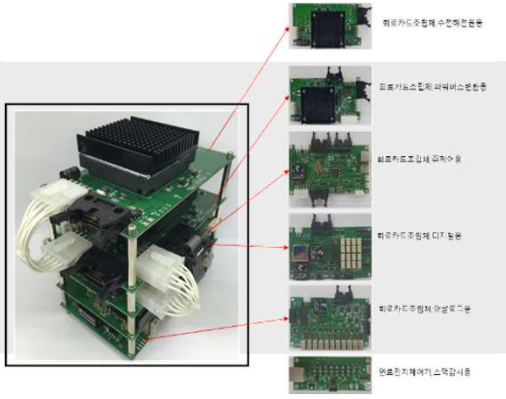
## 고압용기 조달 및 평가



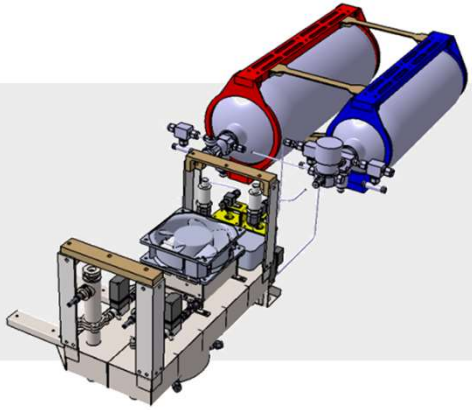

## 제어기 설계를 위한 운전제어 알고리즘 설계

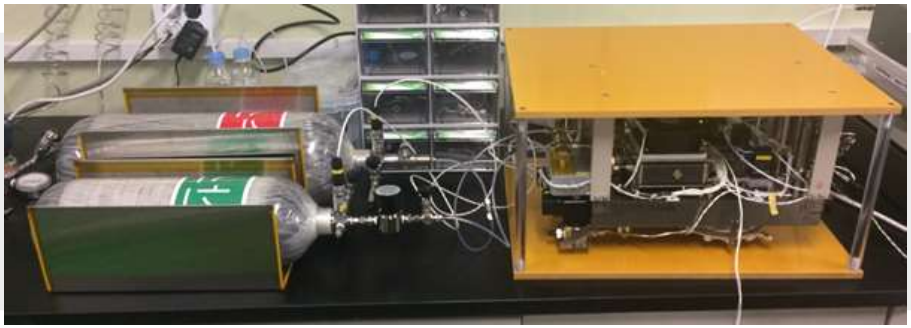


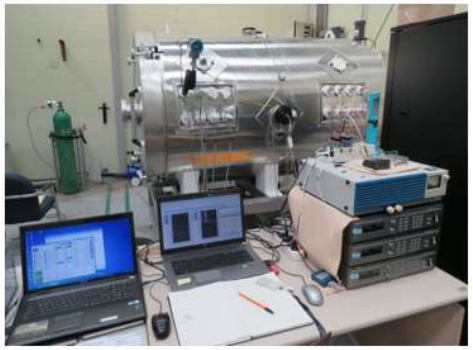
# 19 System Development

**핵심 시스템 상세설계 및 제작**

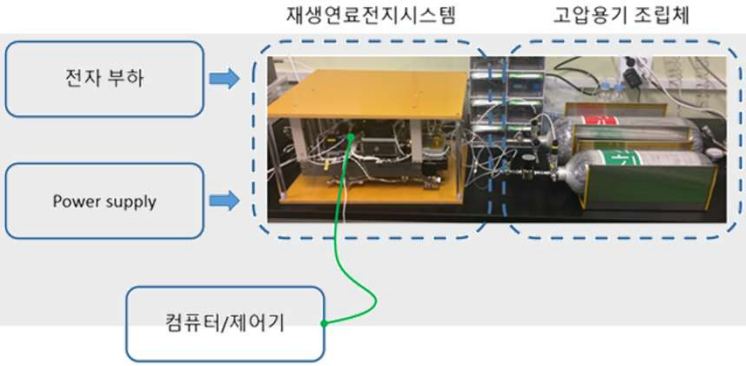




**환경 시험 챔버 개발 및 열환경 시험**

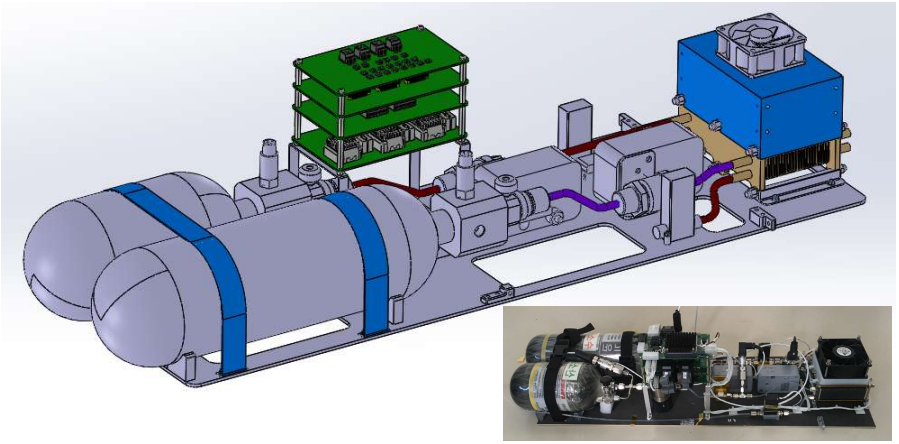


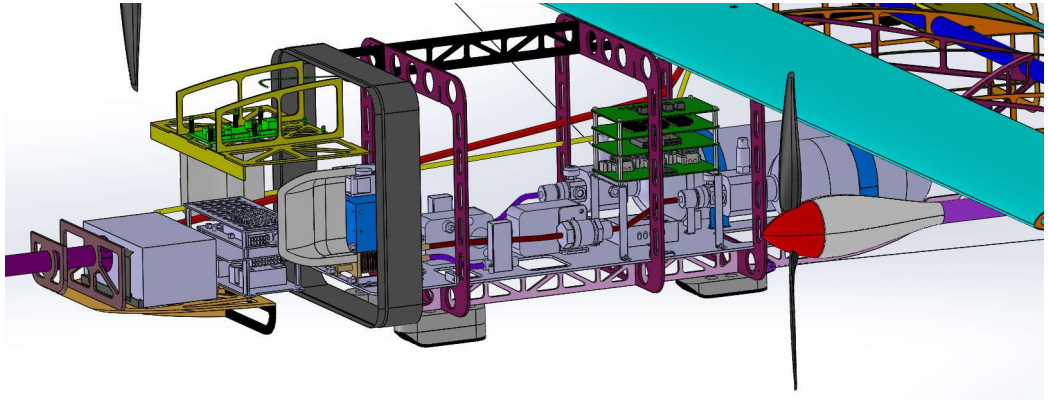
**부체계 연동 시험**

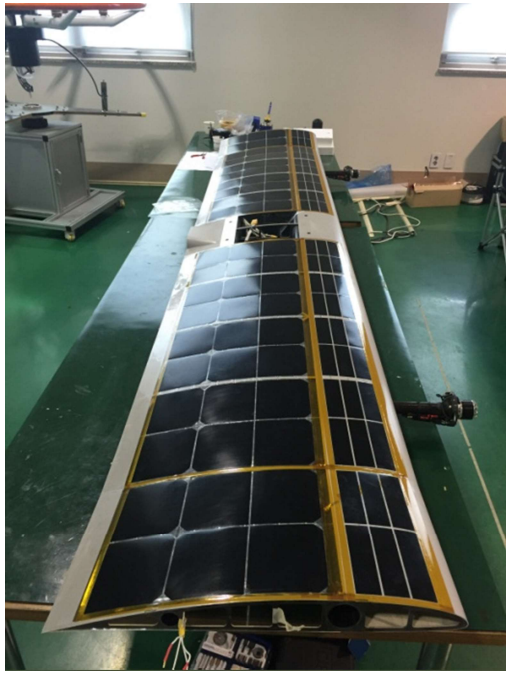



# 20 Test Flight – 축소기

**WS: 7m, MTOW: 20kg**

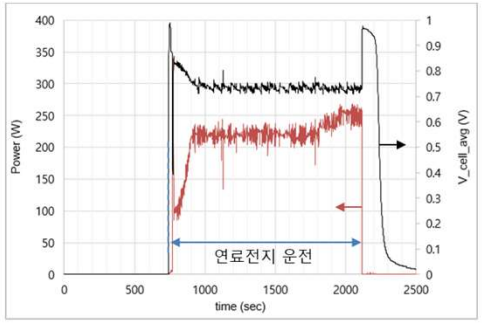


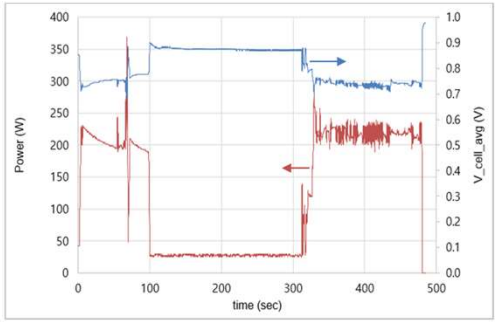




〈 Center wing 작업 완료 〉

〈 태양전지 출력시험 〉

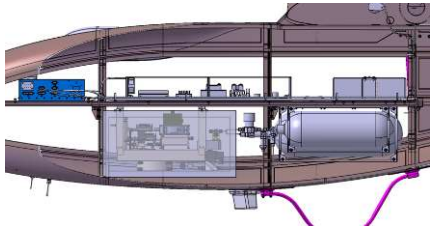


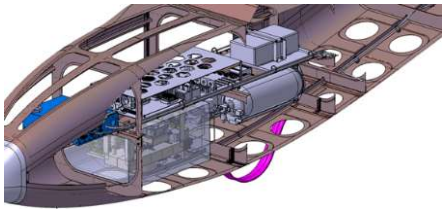




- 주요 구성품 비행 적합성 확인, 목표 성능 검증 (6월, 8월 2차례 시험 비행 실시)

# 21 Test Flight – 시범기

**WS: 21m, MTOW: 150kg**
**국내최초 RFC 비행체 시험**



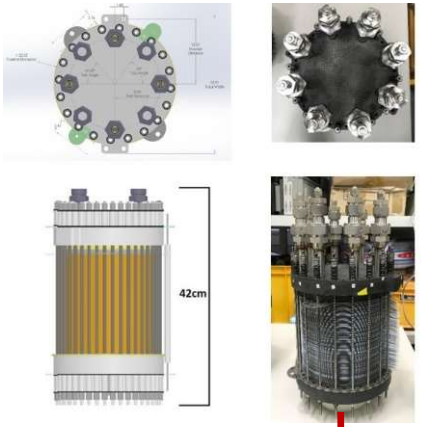


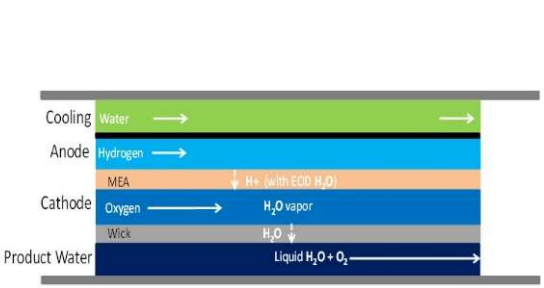
# 22 지상 시험

MTOW: 500kg

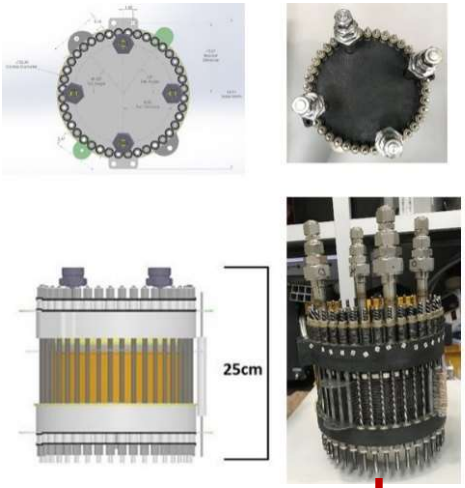
*JMST. (2016), Cha and Kim et al.*

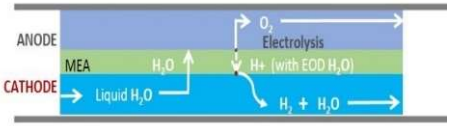
*미국특허: 10,209,686, 10,515,556*
*국내특허: 10-1752859, 1666373, 10-1752861*



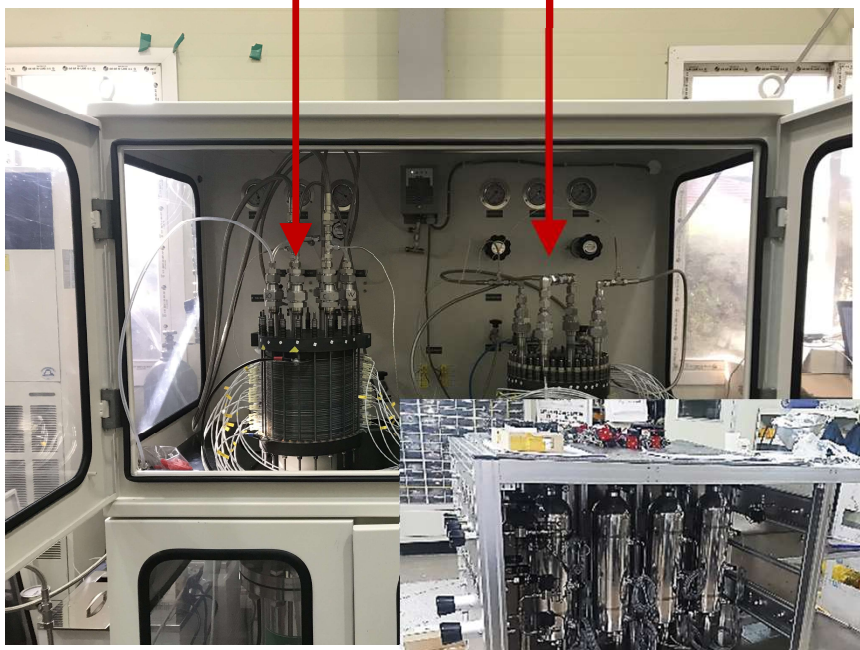

**Fuel Cell**
**Rated power: 1.5kW**
**Max power: 2.5kW**




**Electrolyzer**
**Rated power: 4.4kW**
**Max power: 7.7kW**

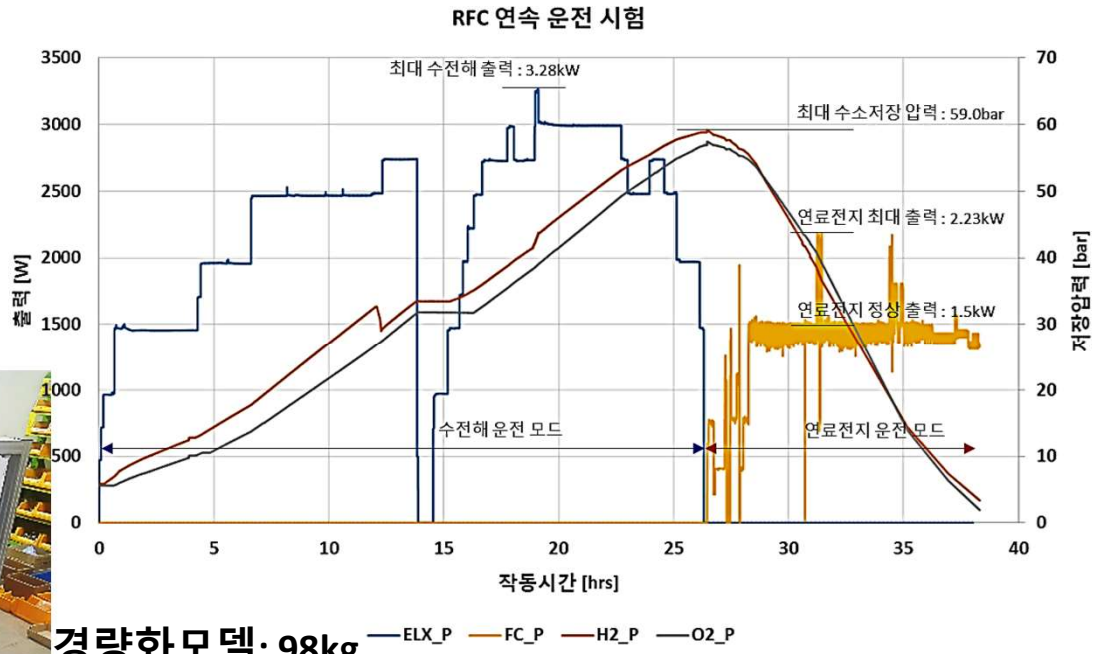
**국내최초 무 압축기 방식**
**수소/산소 직접 충전 (59bar)**



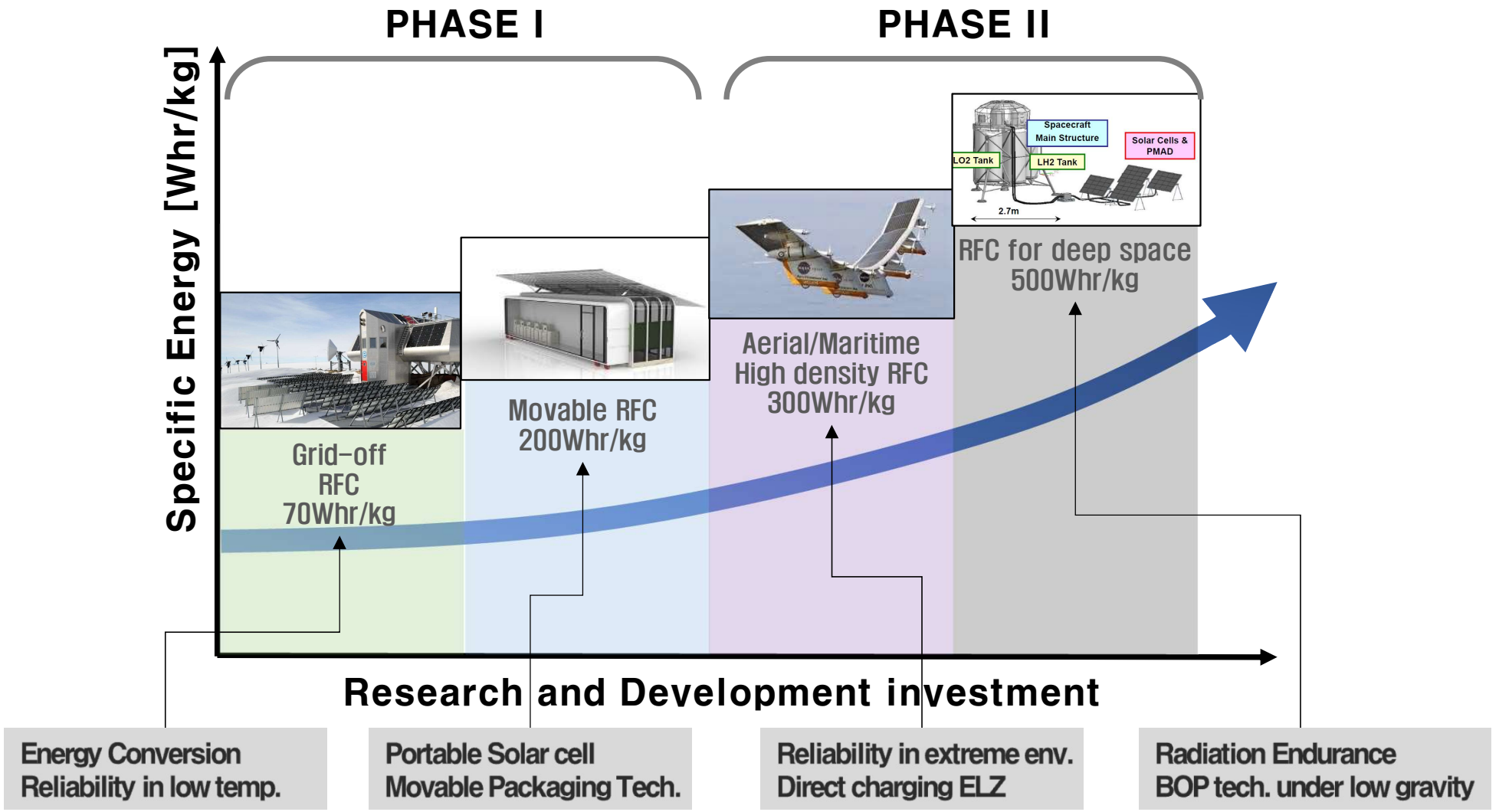
**기본모델: 393kg**



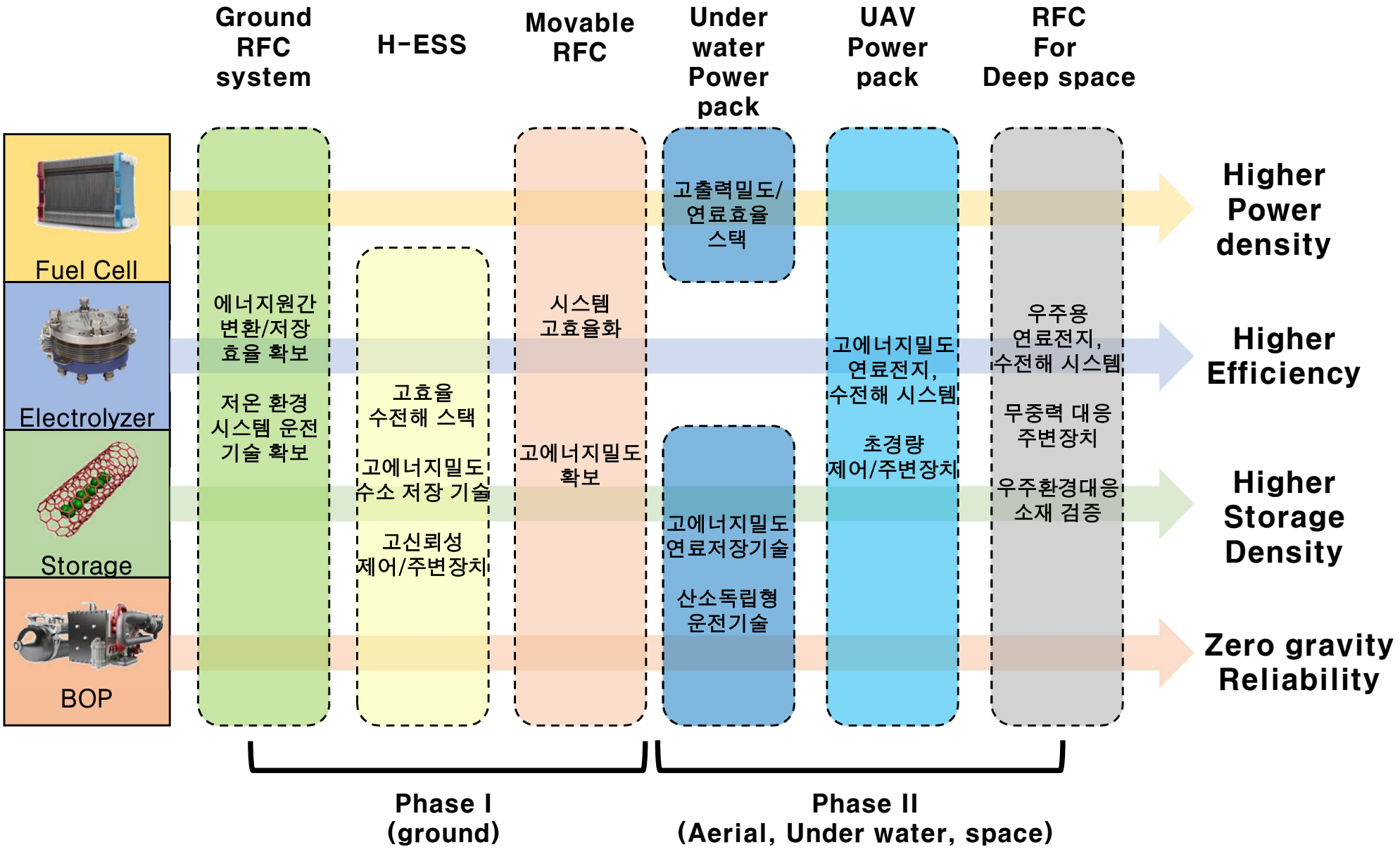
**경량화모델: 98kg**



# 23 기술개발 로드맵

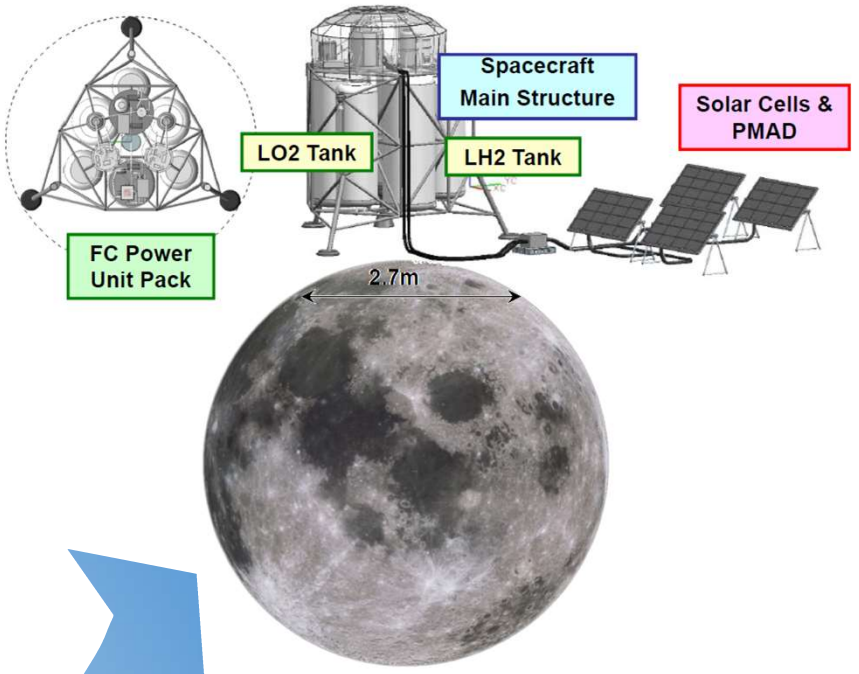

PHASE I
PHASE II
Specific Energy [Whr/kg]
Grid-off
RFC
70Whr/kg
Movable RFC
200Whr/kg
Aerial/Maritime
High density RFC
300Whr/kg
RFC for deep space
500Whr/kg
Spacecraft
Main Structure
Solar Cells &
PMAD
LO2 Tank
LH2 Tank
2.7m
Research and Development investment
Energy Conversion
Reliability in low temp.
Portable Solar cell
Movable Packaging Tech.
Reliability in extreme env.
Direct charging ELZ
Radiation Endurance
BOP tech. under low gravity

# 24 기술개발 로드맵에 따른 요소기술 분석



# Conclusion

## Regenerative Fuel Cell System for Deep Space


Environmental Independency

High Reliabilty

High Energy Density

**Thank you !**