FFI Forsvarets forskningsinstitutt

Why fuel cells for HUGIN Autonomous Underwater Vehicles

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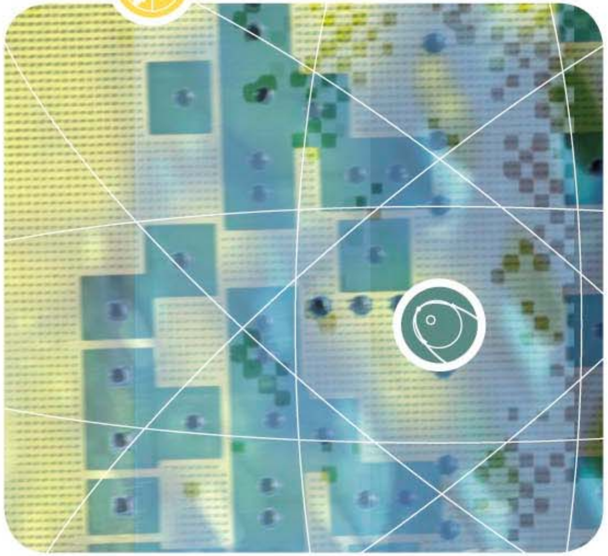


Power Sources at FFI

1973: Battery performance at winter temperatures

1978: Performance of primary litium batteries (Li/SO_2)

1980 - 85: Safety of primary Li batteries (Army)

1980-1990: Development of Al-air semi fuel cells (Army applications)

1983-1995+: Stationary sea water batteries (underwater applications)

1991-1993: Sea water batteries for AUVs (AUV-DEMO)

1995 -1998: Al-HP semi fuel cell for AUVs (HUGIN I/II)

2000 - 2002: Al-HP semi fuel cell for HUGIN 3000

1997- 2003: Forced flow sea water battery (CLIPPER)

2003 - 2004: Li-polymer rechargeable battery (HUGIN 1000)

2003 - Safety aspects of various Li battery technologies

2006 - Hydrogen-oxygen fuel cells for AUVs

What is HUGIN

- A family of unmanned underwater vehicles (UUV)
- Developed by FFI and Kongsberg Maritime
- #1 was technology demonstrator (1993)
- Today a product from Kongsberg Maritime
- Used for survey
  - Seabed mapping
  - Oceanography
  - Marine biology
  - Marine archeology
  - Mine countermeasure (MCM)
  - Intelligence, Surveillance, Target Aquisition and Reconnaissance (ISTAR)
  - Rapid Environmental Assessment (REA)

Unmanned Underwater Vehicles for Deep Sea Survey Operations:

- Constant speed
- Continuous use of sensors
- Long duration of mission (> 6 hours, typically 48 hours)
- Ambient temperature –2 to +25°C, typically +5°C.

$\Rightarrow$

- Low rate, high energy density power source
- Load nearly constant power
- Easy control of temperature

Slow UUVs must be neutrally buoyant:

$$WetWeight = Weight - \Sigma volume \bullet \rho = 0$$

$$Weight = \Sigma(density \bullet volume)$$

Figure of merit for a pressure resistant container (pressure hull):

mean density = (weight of empty container)/(volume of container)

mean density = f(design depth, shape, material)

Spherical containers: Lowest mean density
Cylinder with semi spherical end caps: More convenient shape

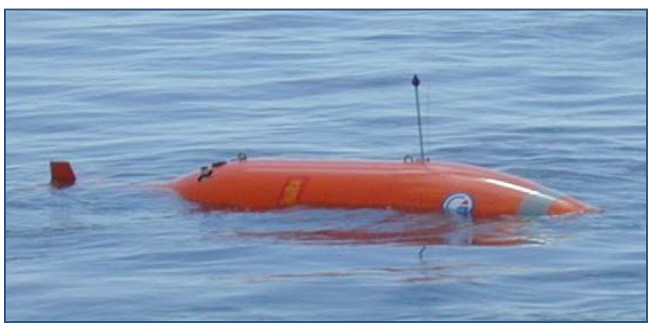
Scale Model Tests (1991)

AUV-DEMO (1993)

Electrochemical power sources for AUV applications, the alternatives:

1. Standard batteries inside a pressure hull and working at atmospheric pressure
2. Pressure compensated batteries or semi-fuel cells working at ambient pressure, but electrically insulated from the seawater
3. Seawater batteries
4. Fuel cells

The HUGIN family



- More than 55 000 line km billed (1997-2005)
- Operations all over the oceans – from the Barents Sea to Brazil and Australia

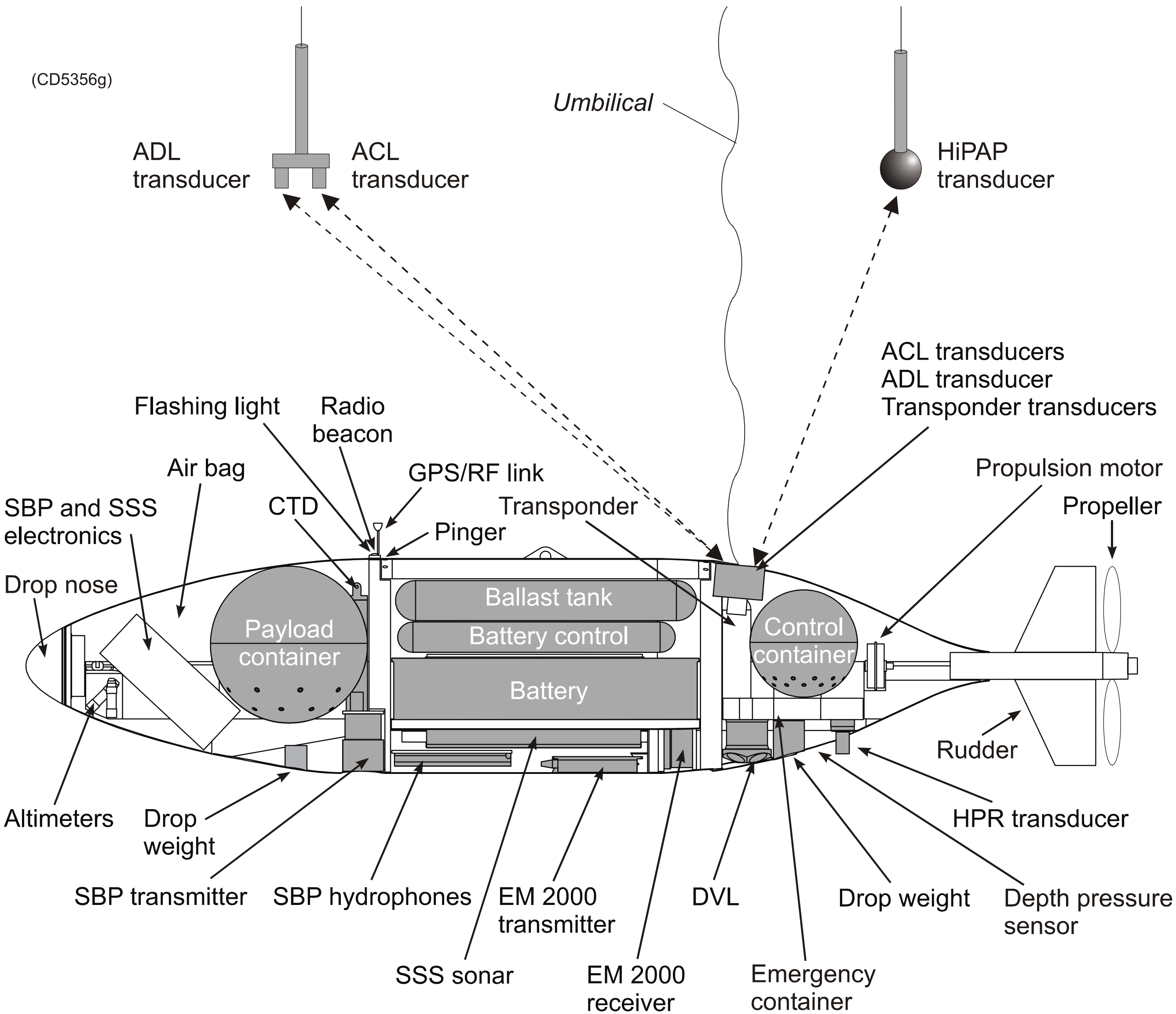
HUGIN 1 during recovery on board SCS Seaway Commander

HUGIN 3000 AUV

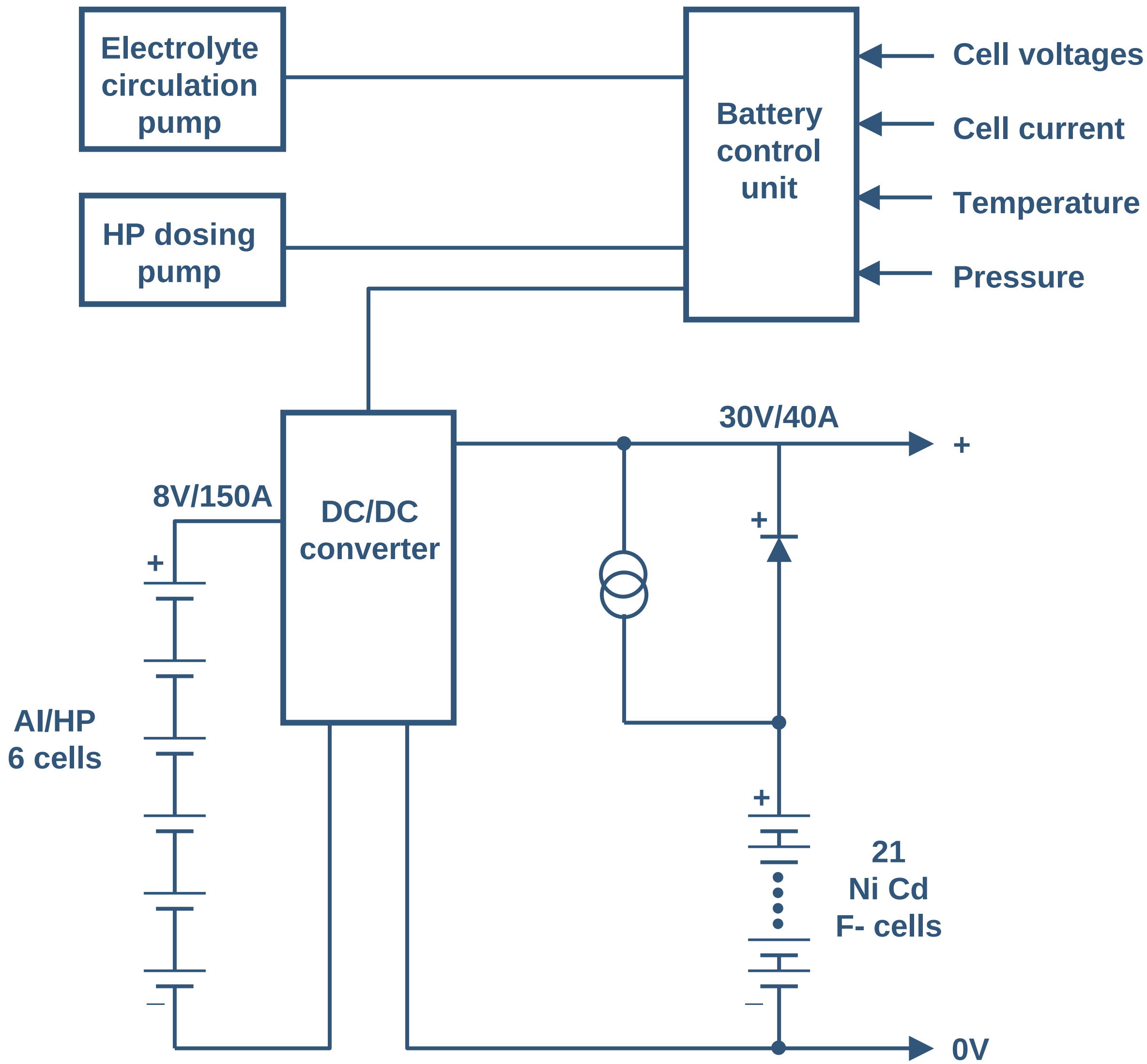
Operated by **C&C Technology (3)**, **Geoconsult** and **Fugro**

1.2 kW / 50kWh alkaline aluminium / hydrogen peroxide semi-fuel cell

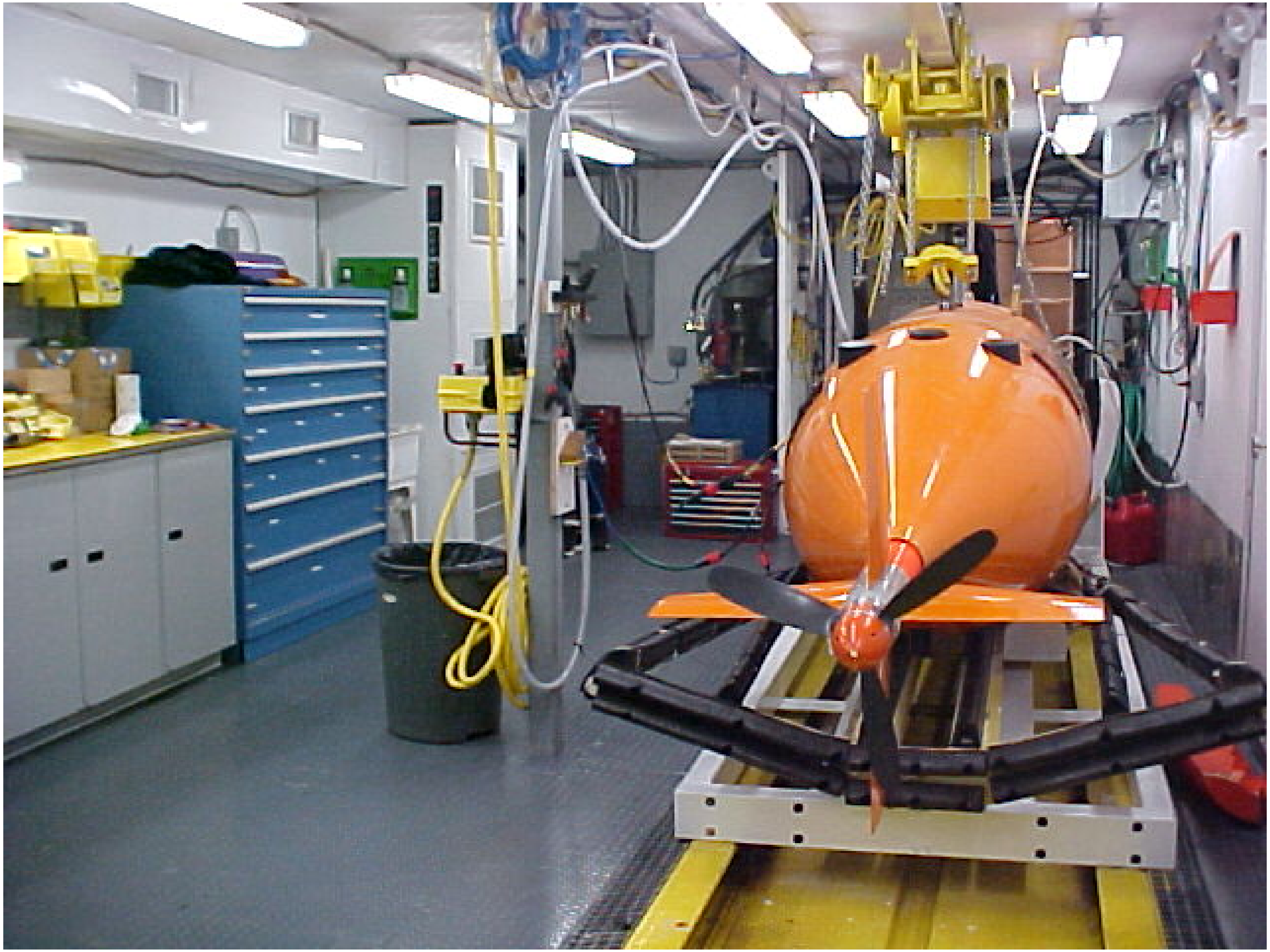
(CD5356g)



ADL transducer
ACL transducer
Umbilical
HiPAP transducer
ACL transducers
ADL transducer
Transponder transducers
Flashing light
Radio beacon
Air bag
GPS/RF link
SBP and SSS electronics
CTD
Transponder
Pinger
Propulsion motor
Propeller
Drop nose
Ballast tank
Battery control
Battery
Payload container
Control container
Rudder
Altimeters
Drop weight
HPR transducer
SBP transmitter
SBP hydrophones
EM 2000 transmitter
DVL
Drop weight
Depth pressure sensor
SSS sonar
EM 2000 receiver
Emergency container


Electrolyte circulation pump
HP dosing pump
Battery control unit
Cell voltages
Cell current
Temperature
Pressure
DC/DC converter
8V/150A
30V/40A
+
Al/HP
6 cells
21
Ni Cd
F- cells
0V

HUGIN 3000 service station. Note hoses for H_2O_2 and KOH.



ADVANTAGES OF AUVs

•HIGHER RESOLUTION BATHYMETRY

Example - 2000m water depth:

Surface deployment: 7.0m depth resolution

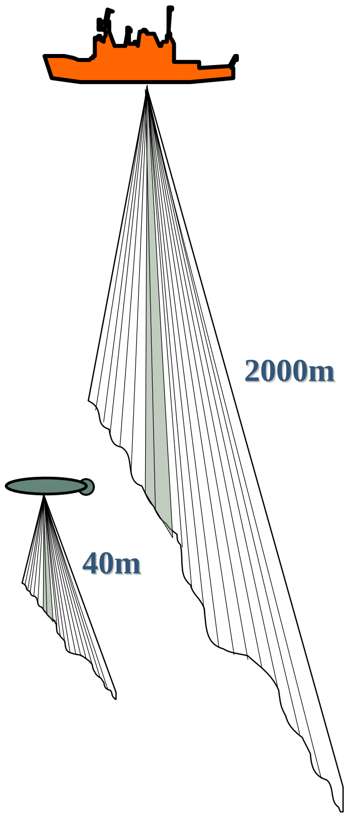
AUV deployment: 0.2m depth resolution

•HIGH RESOLUTION CO-LOCATED IMAGERY

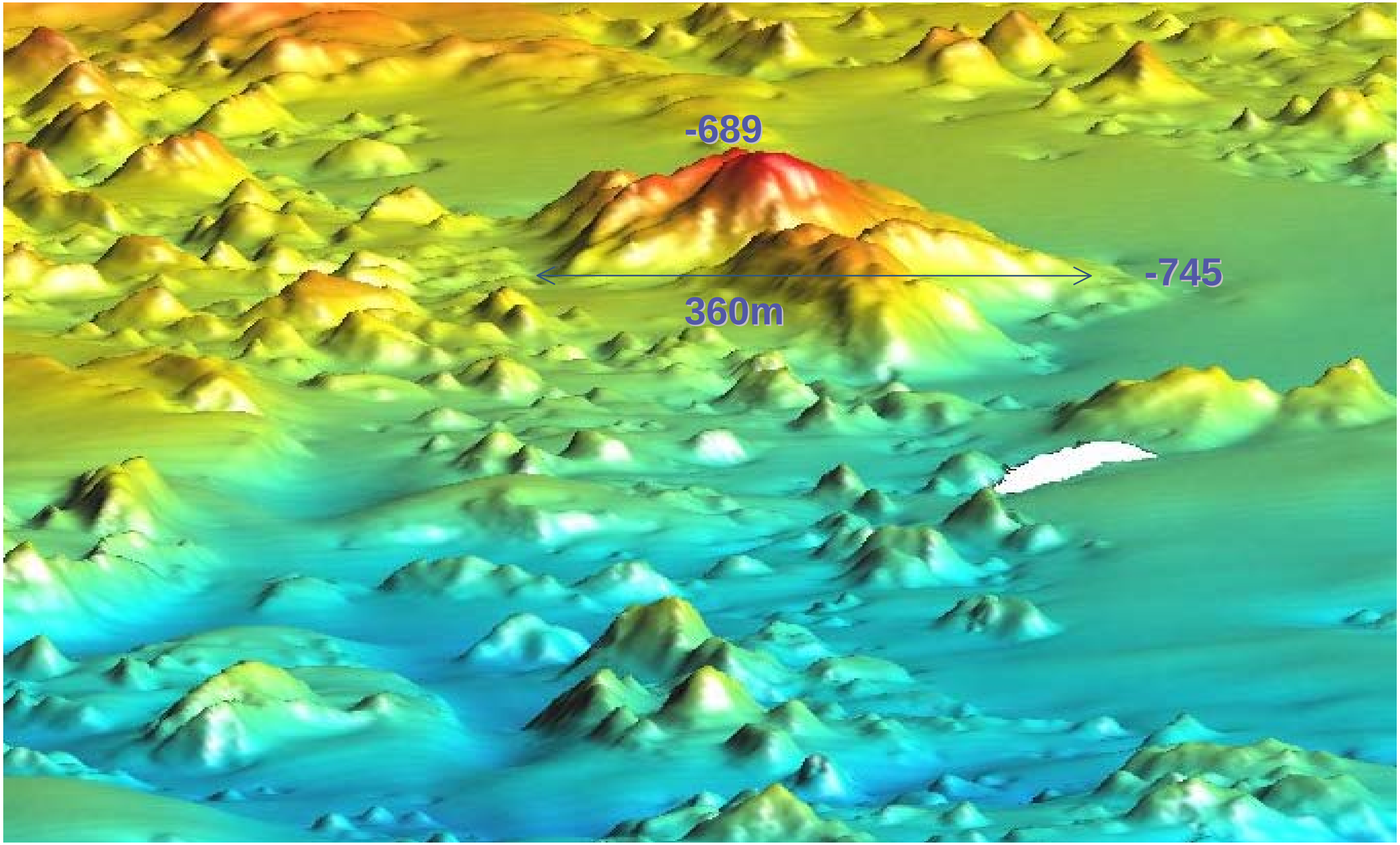
Example - 2000m water depth:

Surface deployment: 40.0m pixel

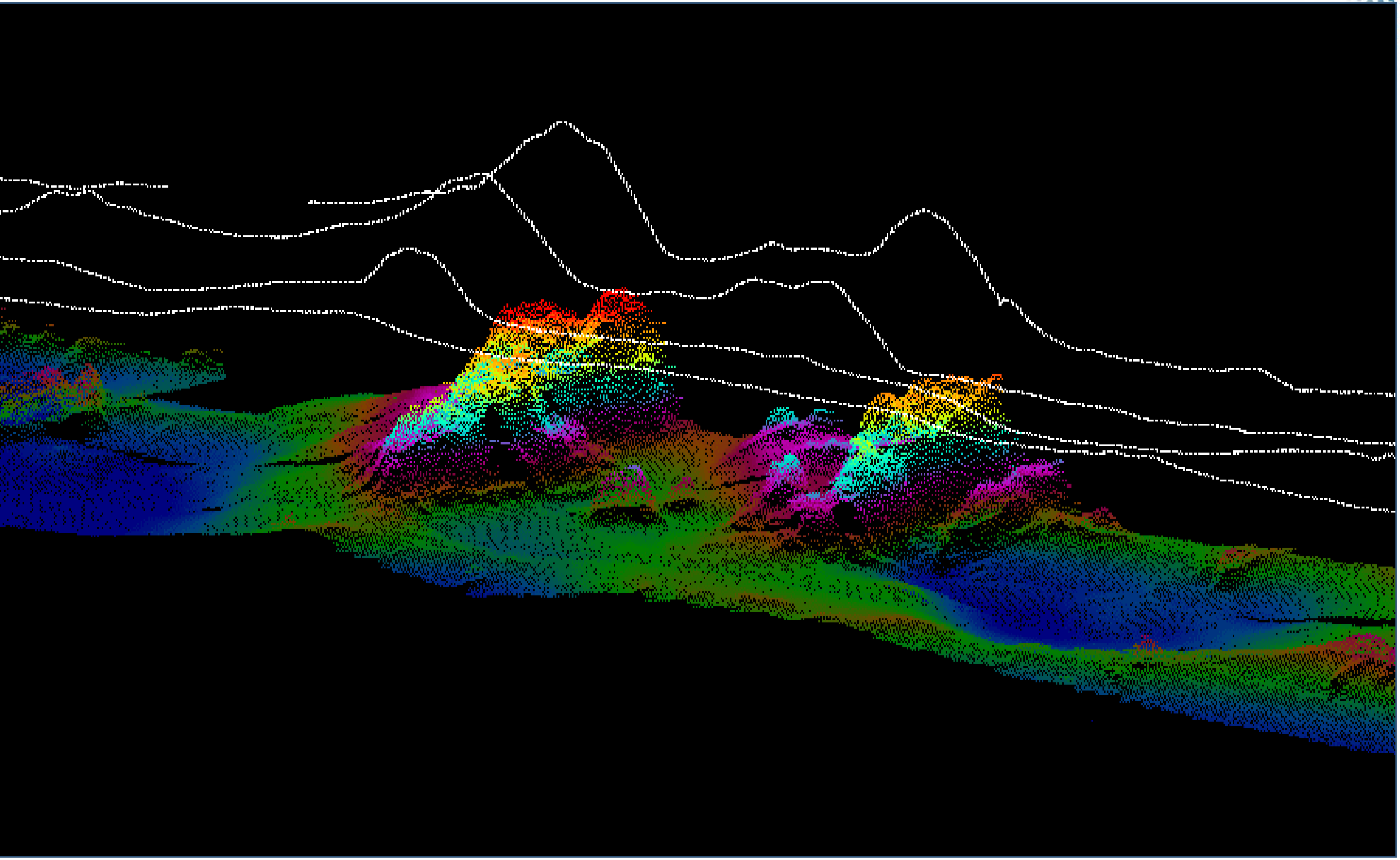
AUV deployment: 0.5m pixel



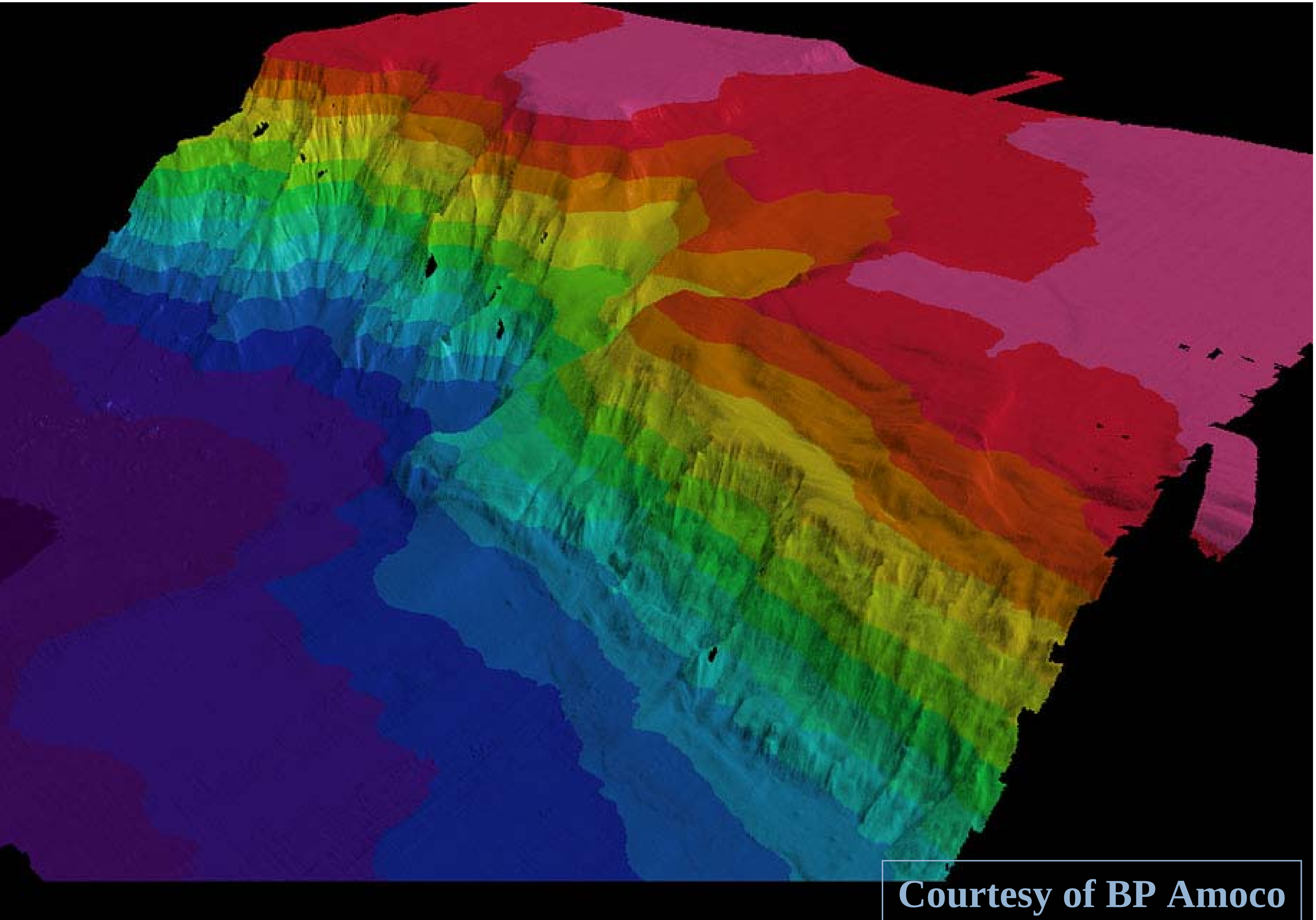
Example data:
North Sea, 500-900 m water depth



Deep water coral reef off western Norway



Seabed mapping, Sigsbee Escarpment, Gulf of Mexico



Courtesy of BP Amoco

HUGIN 1000 Mine reconnaissance AUV:

Design depth: 1000 m
Max speed: 6 knots
Endurance: 20 hours at 4 knots and all sensors working

Sensors:

- Side scan sonar
- Multibeam echo-sounder
- CTD
- Doppler velocity log
- Inertial navigation system

Energy requirement: Ca 15 kWh
Power requirement: 2kW peak

HUGIN 1000 version 0 on board RNoN KARMØY

Comparison of power sources - Assumptions

- Generic AUV:
  - Volume: 1,2 m^3 ,
  - Volume allocated to batteries: 25%
  - Design speed: 4 knots
  - Propulsion power: 250 W
  - Hotel load including sensors: 500 W
- Design water depth: 1000 or 3000 m
- Battery compartment neutrally buoyant
- Pressure hull from Al 6082 T6
- Syntactic foam with density 550 kg/m^3 for flotation

Resulting endurance:

Technology	Endurance (hours)	Comments
Lithium ion	16 - 28	Pressure hull
Lithium polymer	20 - 30	Ambient pressure
Aluminium / H_2O_2	33	Ambient pressure
Lithium primary	30 - 60	Pressure hull
H_2 / O_2 fuel cell	40+	Pressure hull

Batteries operating in a pressure resistant container:

- **good for shallow water,**
- **weight of battery container increases with design depth**
- **container technology dependent**

Batteries operating at ambient pressure:

- **advantage increases with design depth (50% gain at 3000m)**

Seawater batteries:

- **AgCl/Mg – compact, high energy, but expensive**
- **Dissolved oxygen / Mg – very high energy, but low power**

Fuel cells using compressed gas in low weight containers:

- **high energy density**
- **positively buoyant – even with 3000 m design depth**

Fuel cell example:

- Compressed gases at 300 atm (16 kg)
- Spherical aluminium containers (2 large, one small)
- Cell voltage 0.70 V
- Faradayic efficiency 0.95
- Weight of Fuel Cell 20 kg
- Power for and weight of auxiliary systems is neglected

System weight	System volume	System energy density	System energy
246 kg	300 litre	130 Wh/kg	32 kWh

- Net positive buoyancy of 55 kg!

Present Fuel Cell Program at FFI (until April 2009)

- Buy hardware and knowledge
- Operate PEM stack in a sealed, pressure resistant container
- Qualify carbon fibre composite gas cylinders for external pressure
- Mineaturisation of control system
- Get experience, make an operational and sealed system

Challenges

- Safety – low temperature catalytic combustion etc
- Fire avoidance (pure oxygen)
- Buildup of inerts
- Gas purity – cost and logistics aspects

Next phase

- Rapid refueling system
- In water testing

Why hydrogen / oxygen fuel cells in AUVs?

Generic deep diving AUVs contain up to 40% foam by volume, just to be able to float.

Average density of composite hydrogen storage cylinders with 450 Bar working pressure is 450 - 550 kg/m^3,
less than buoyancy foam.

Think system and you may get your fuel free of charge
(not quite – a few caveats, but....)

www.ffi.no/hugin