COMMON SENSE

MARINE SENSORS - MARINE MONITORING

Professor Dermot Diamond, Dublin City University

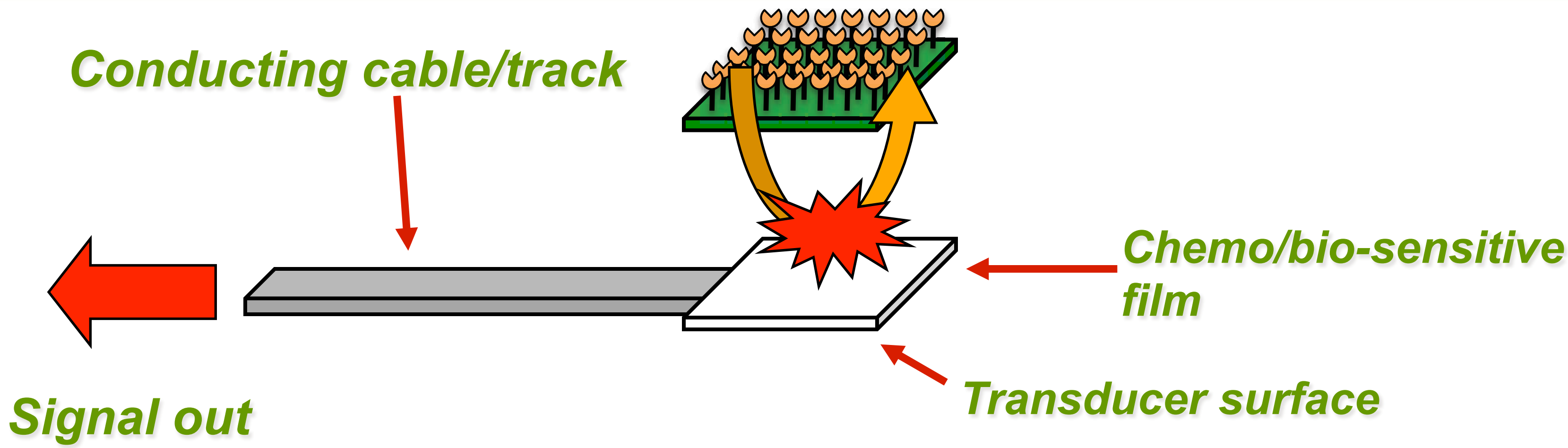
‘Sensor Roadmap: Future Trends on (Marine) Chemical Sensor Development’

COMMON SENSE 40 month meeting

Barcelona, Spain, 26 January 2017

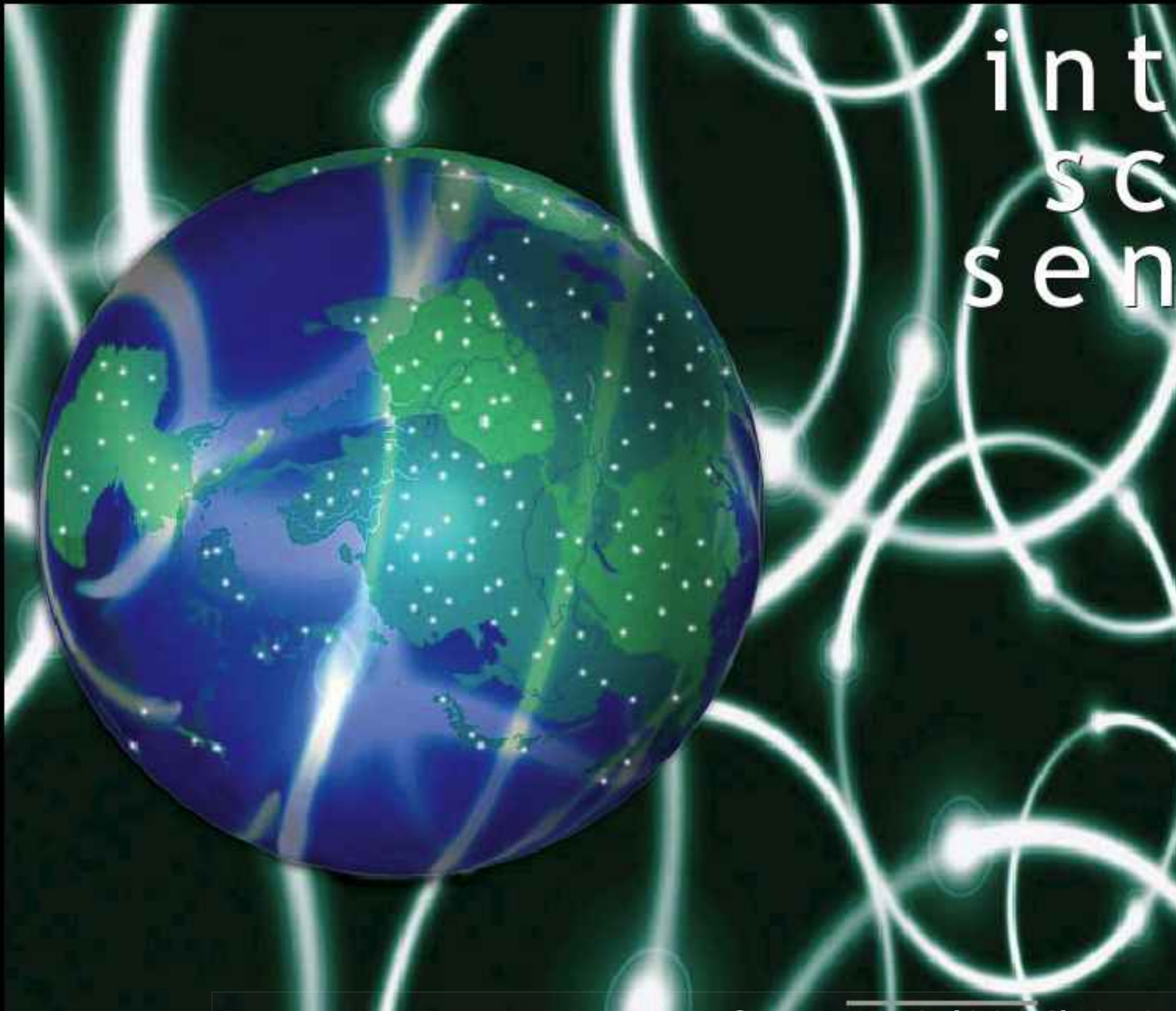
What is a Chemo/Bio-Sensor?

'a device, consisting of a transducer and a chemo/bio-sensitive film/membrane, that generates a signal related to the concentration of particular target analyte in a given sample'



Chemo/Bio-sensing involves selective **BINDING** & **TRANSDUCTION** on the device surface; this also implies the target analyte MUST meet the device surface (**LOCATION** & **MOVEMENT**). It provides a signal observable in the macroscopic world (**COMMUNICATION**)

Keynote Article: August 2004, Analytical Chemistry (ACS)



internet scale sensing

Dermot Diamond
Dublin City University
(Ireland)

Incredible advances in digital communications and computer power have profoundly changed our lives. One chemist shares his vision of the role of analytical science in the next communications revolution.

Digital communications networks are at the heart of modern society. The digitization of communications, the development of the Internet, and the availability of relatively inexpensive but powerful mobile computing technologies have established a global communications network capable of linking billions of people, places, and objects. Email can instantly transmit complex documents to multiple remote locations, and websites provide a platform for instantaneous notification, dissemination, and exchange of information globally. This technology is now pervasive, and those in research and business have multiple interactions with this digital world every day. However, this technology might simply be the foundation for the next wave of development that will provide a seamless interface between the real and digital worlds.

The crucial missing part in this scenario is the gateway through which these worlds will communicate: How can the digital world sense and respond to changes in the real world? Analytical scientists—particularly those working on chemical sensors, biosensors, and compact, autonomous instruments—are

Dermot Diamond, Anal. Chem., 76 (2004) 278A-286A
(Ron Ambrosio & Alex Morrow, IBM TJ Watson)

Remote (Continuous) Sensing Challenges: Platform and Deployment Hierarchies

Physical Transducers –low cost, reliable, low power demand, long life-time

Thermistors (temperature), movement, location, power,, light level, conductivity, flow, sound/audio, ……

Chemical Sensors – more complicated, need regular calibration, more costly to implement

Electrochemical, Optical, .. For metal ions, pH, organics…

Biosensors – the most challenging, very difficult to work with, die quickly, single shot (disposable) mode dominant use model

Due to the delicate nature of biomaterials enzymes, antibodies….

Increasing difficulty & cost

Increasing scalability

Gas/Air Sensing – easiest to realise

Reliable sensors available, relatively low cost

Integrate into platforms, develop IT infrastructure, GIS tools, Cloud Computing

On-land Water/ Monitoring

More accessible locations

Target concentrations tend to be higher

Infrastructure available

Marine Water

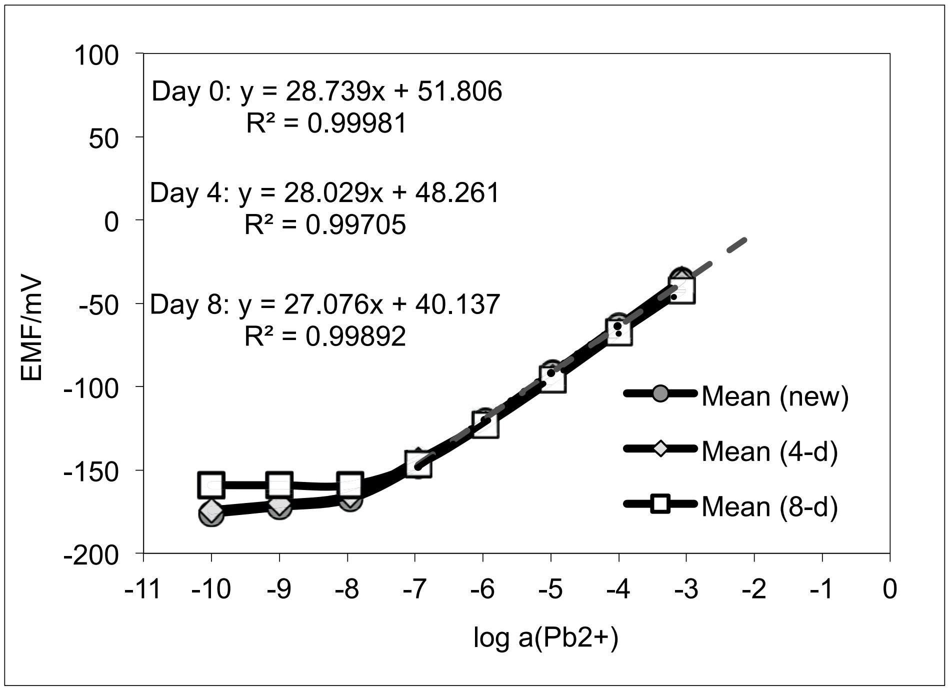
Challenging conditions

Remote locations & Limited infrastructure

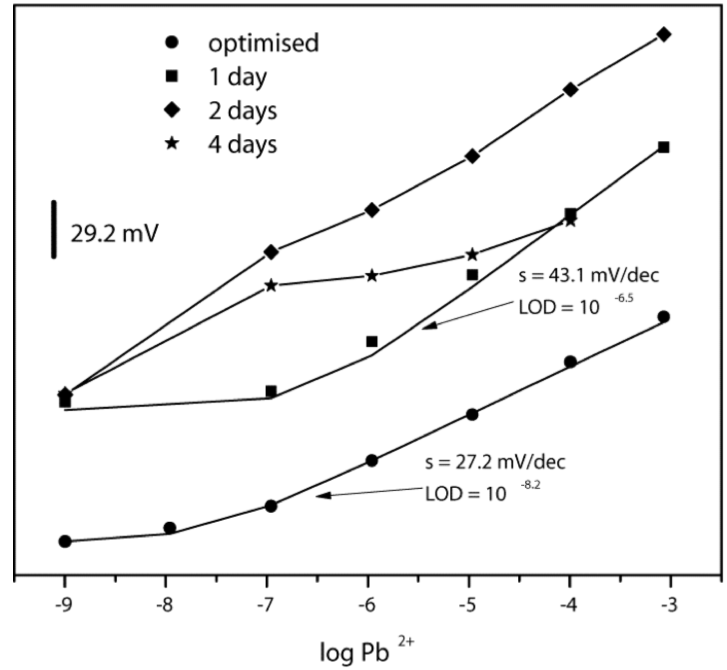
Concentrations tend to be lower and tighter in range

Change in Electrode Function over Time

See Electrochimica Acta 73 (2012) 93–97



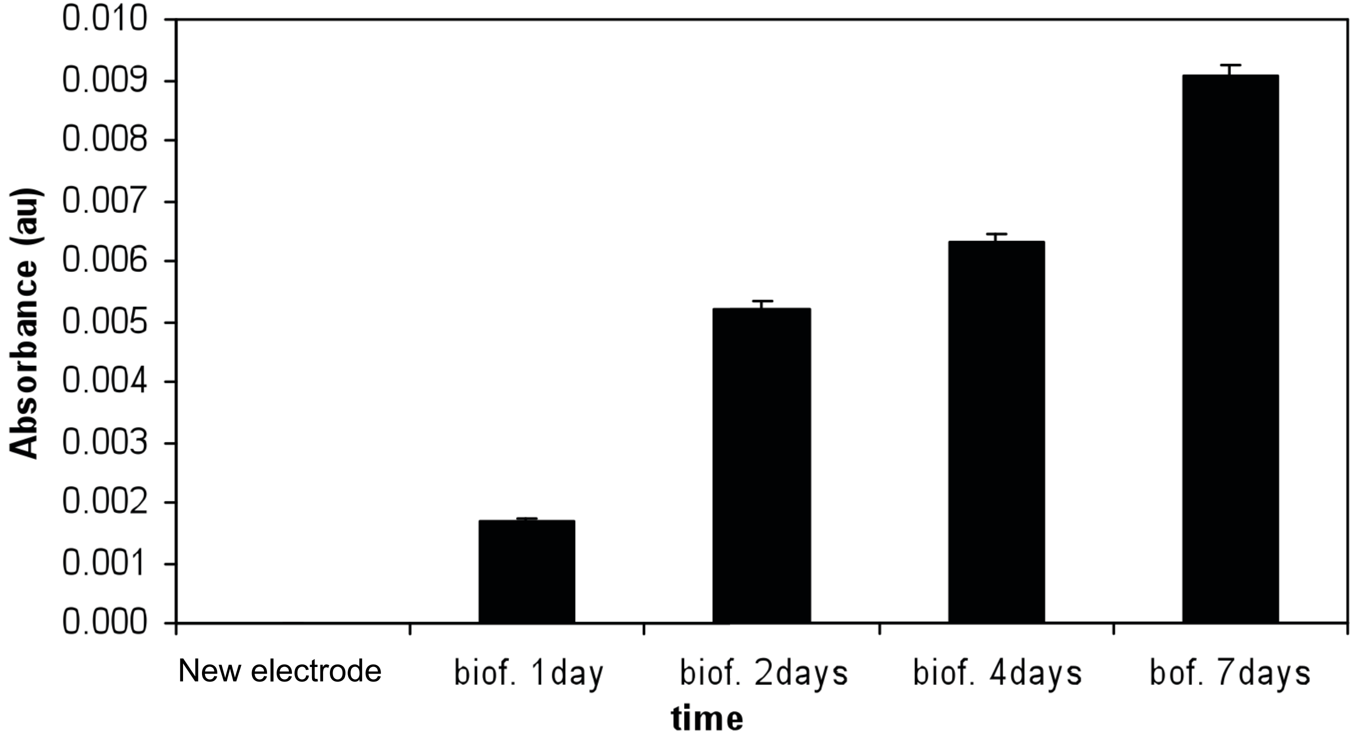
stored in 10^{-9}M Pb^{2+}, pH=4



Continuous contact with river water

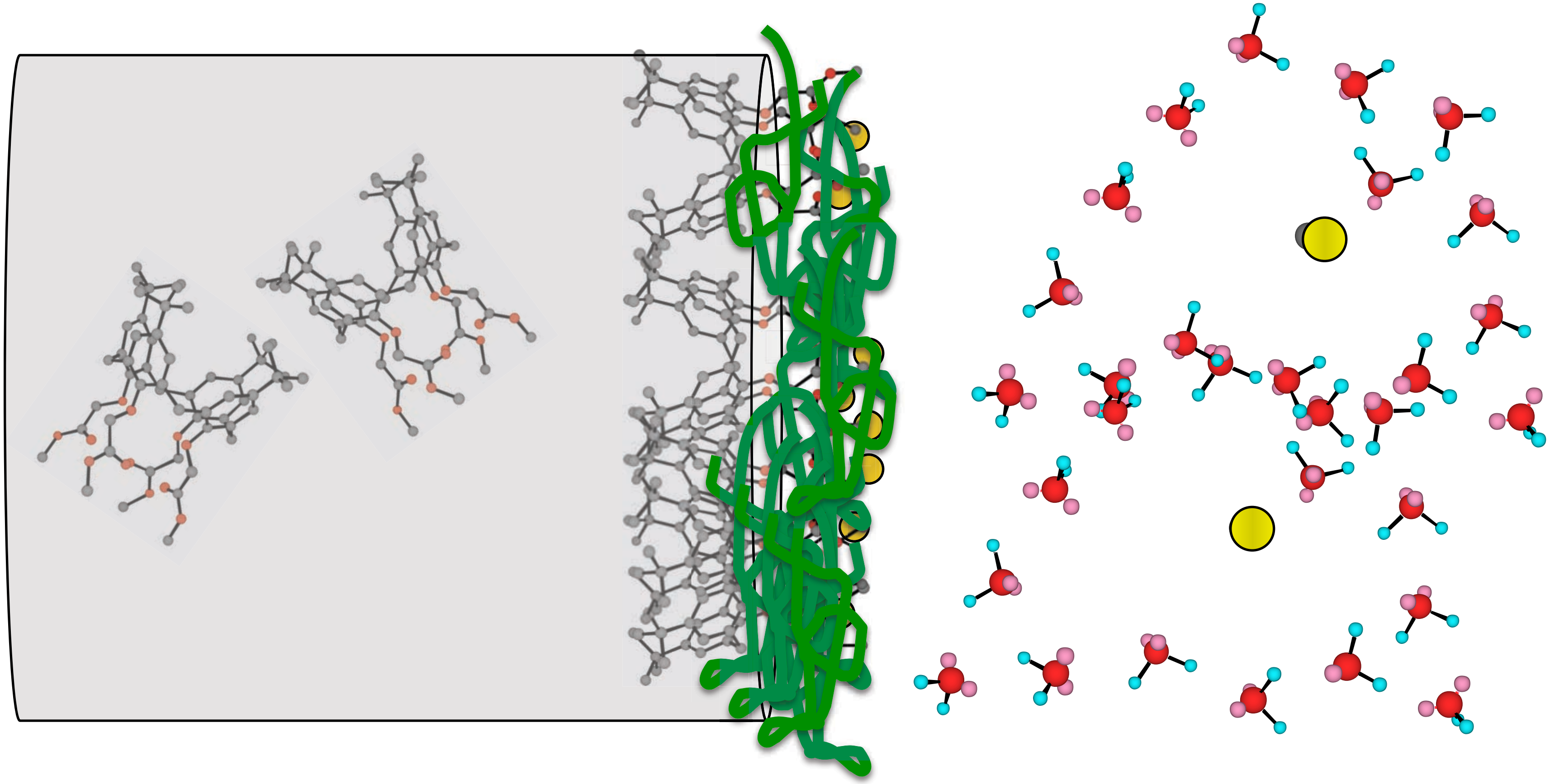
Conventional PVC-membrane based ISEs

Biofilm Formation on Sensors



- **Electrodes exposed to local river water (Tolka)**
- **‘Slime test’ shows biofilm formation happens almost immediately and grows rapidly**

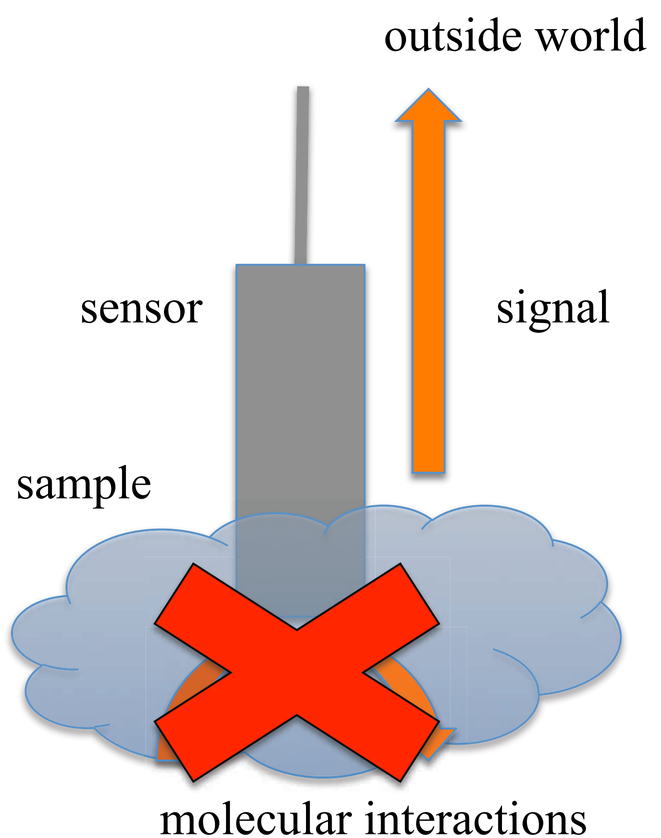
Control of membrane interfacial exchange & binding processes



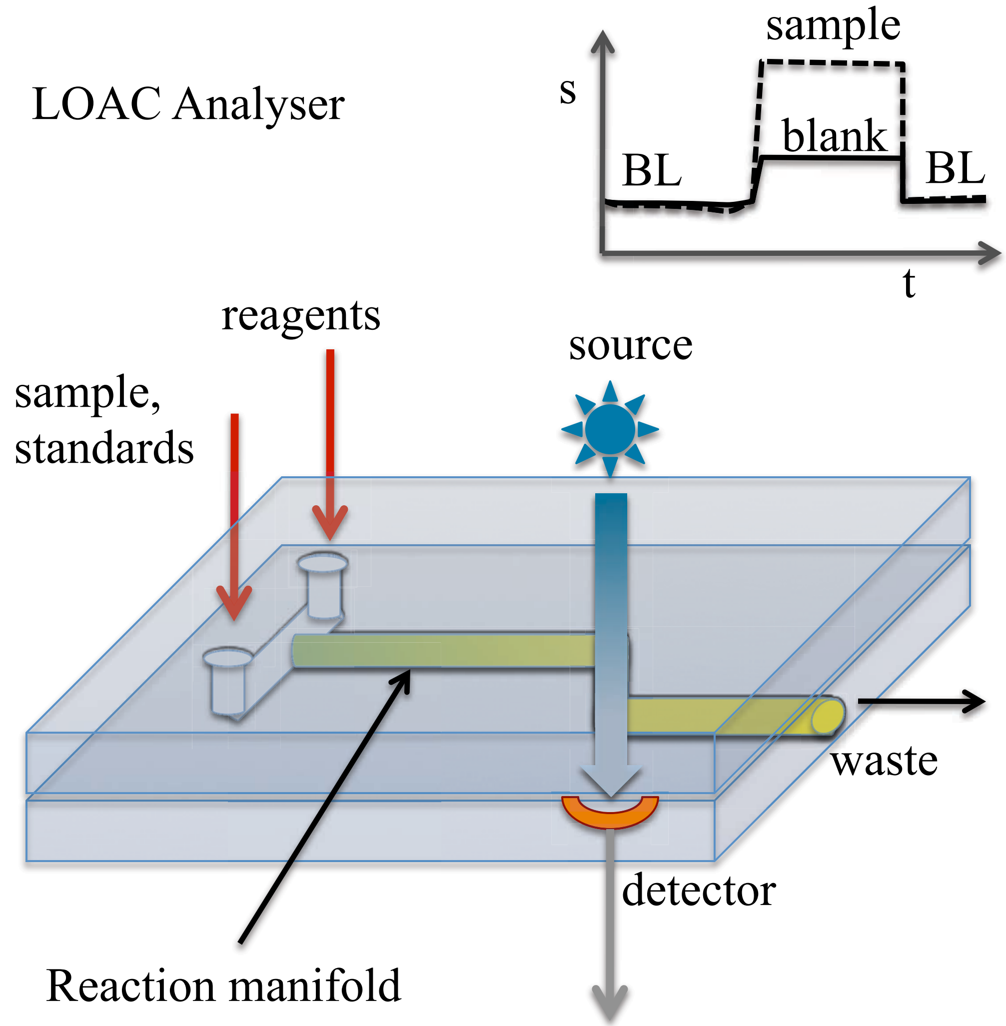
Remote, autonomous chemical sensing is a tricky business!

Direct Sensing vs. Reagent Based LOAC/ufluidics

Direct Sensing



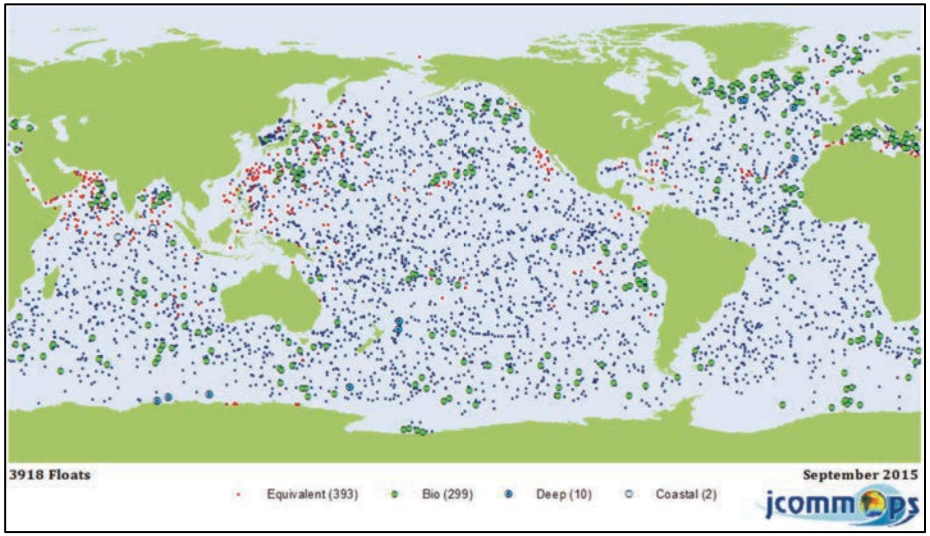
LOAC Analyser

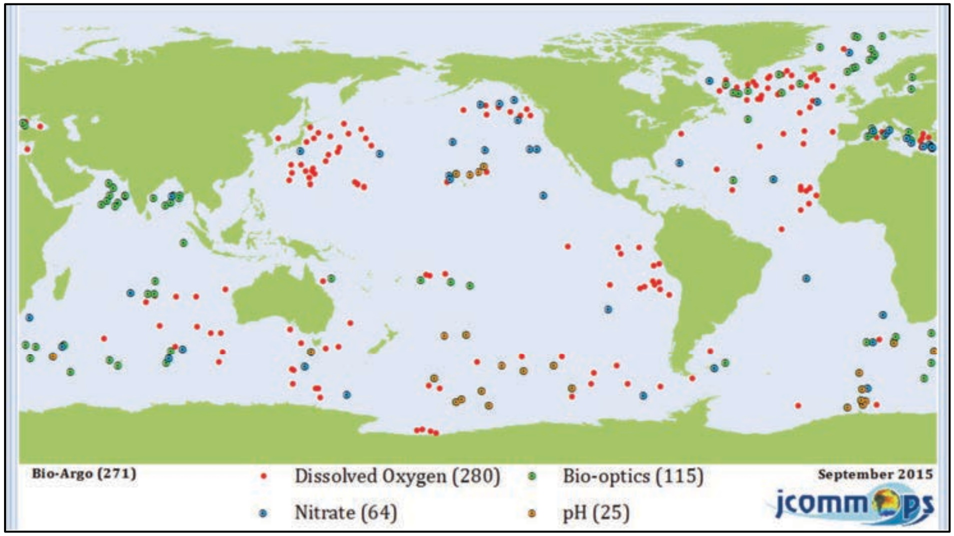


Osberstown – 3 week deployment

Biofouling of sensor surfaces is a major challenge for remote chemical sensing – both for the environment and for implantable sensors

Argo Project (accessed March 20 2016)





- **Ca. 4,000 (3918) floats: temperature and salinity**
- **Bio/Chem: Nitrate (64), DO (280), Bio-optics (115), pH (25)**

DO is by Clark Cell (Sea Bird Electronics) or Dynamic fluorescence quenching (Aanderaa)

@€60K ea!

See https://picasaweb.google.com/JCOMMOPS/ArgoMaps?authuser=0&feat=embedwebsite

'calibration of the DO measurements by the SBE sensor remains an important issue for the future', Argo report 'Processing Argo OXYGEN data at the DAC level', September 6, 2009, V. Thierry, D. Gilbert, T. Kobayashi

pH sensing – wasn't that solved by Nikolskii in the 1930's?

EVENT	DATE
Launch (San Francisco)	September 2013
PHASE 1: Innovation Phase	
Registration opens	January 1, 2014
Early-bird Registration deadline	March 2014
OA Solutions Fair and Kick-Off Event	March 2014

Overview

Competition Guidelines

Competition Schedule

Registration Process

OVERVIEW

The Challenge: Improve Our Understanding of Ocean Acidification

The Wendy Schmidt Ocean Health XPRIZE is a $2 million global competition that challenges teams of engineers, scientists and innovators from all over the world to create pH sensor technology that will affordably, accurately and efficiently measure ocean chemistry from its shallowest waters… to its deepest depths.

There are two prize purses available (teams may compete for, and win, both purses):

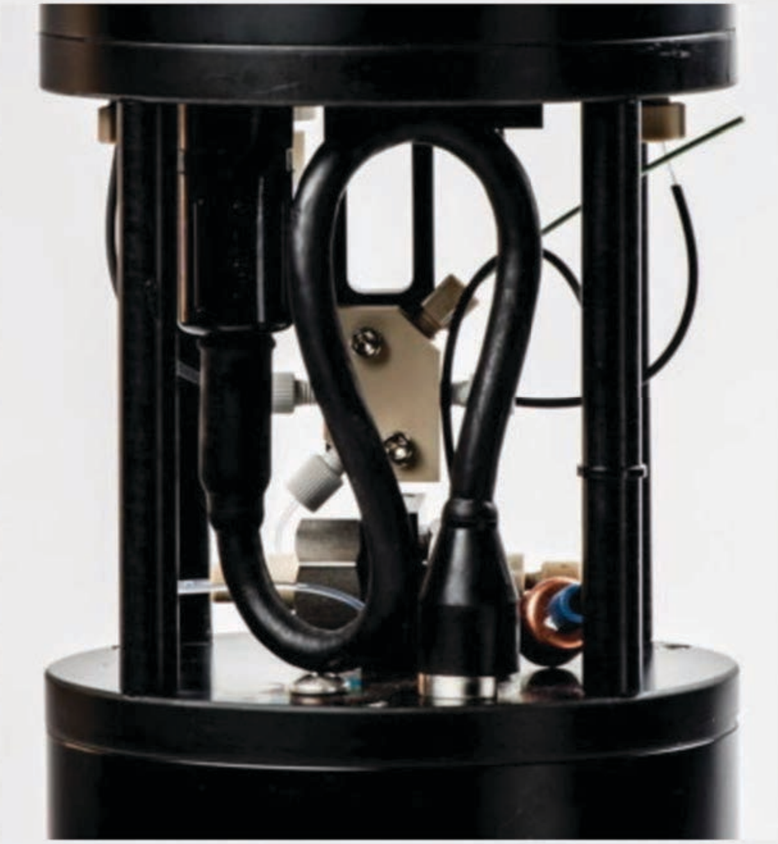
A. $1,000,000 Accuracy award – Performance focused ($750,000 First Place, $250,000 Second Place): To the teams that navigate the entire competition to produce the most accurate, stable and precise pH sensors under a variety of tests.

Wendy Schmidt Ocean Health XPRIZE

$2,000,000 up for grabs!
Task is to provide a way to do reliable measurements of pH in the ocean environment

The winner will almost certainly be a reagent based platform, not a conventional chemical sensor

SAMI-pH - Ocean pH Sensor



- Measures pH_T (total hydrogen scale) in the marine pH range of 7-9
- Uses a highly accurate colorimetric reagent method
- System does not suffer from the drift that plagues most electrode based pH probes
- Designed to provide researchers with valuable *in-situ* time series data at depths up to 600 meters
- 234-day deployment capability (hourly measurements, 25C)
- Extra battery package allows the SAMI-pH to run for more than a year
- Can support up to 3 external instruments (e.g., PAR, dissolved oxygen, chlorophyll fluorometer, CTD)
- Supports Seabird underwater inductive modems or external loggers via RS-232

HEAL OUR OCEANS

The Wendy Schmidt Ocean Health XPRIZE promises to improve our understanding of how CO2

And for nutrients….

From 29 to 6 participants…

The Challenge

- Application
- The Problem
- Timeline
- Awards
- Market Information
- Reports
- Provide Your Input
- Participants
- Frequent Questions

The Coalition

- Office of Science and Technology Policy
- US Department of Agriculture
- US Environmental Protection Agency
- US Geological Survey
- National Oceanic and Atmospheric Admin
- National Institute of Science and Technology
- Everglades Foundation
- US Integrated Ocean Observing System

Nutrient Sensor Challenge

Participants Selected for Final Verification Testing in 2016		
Decagon Devices, Inc.	Real Tech	SYSTEA S.p.A.
National Oceanography Centre	Sea-Bird Coastal	T.E. Laboratories & Dublin City University
Detailed Protocols used for ACT Verification Testing of Next-Generation Nutrient Sensors are available for download here		

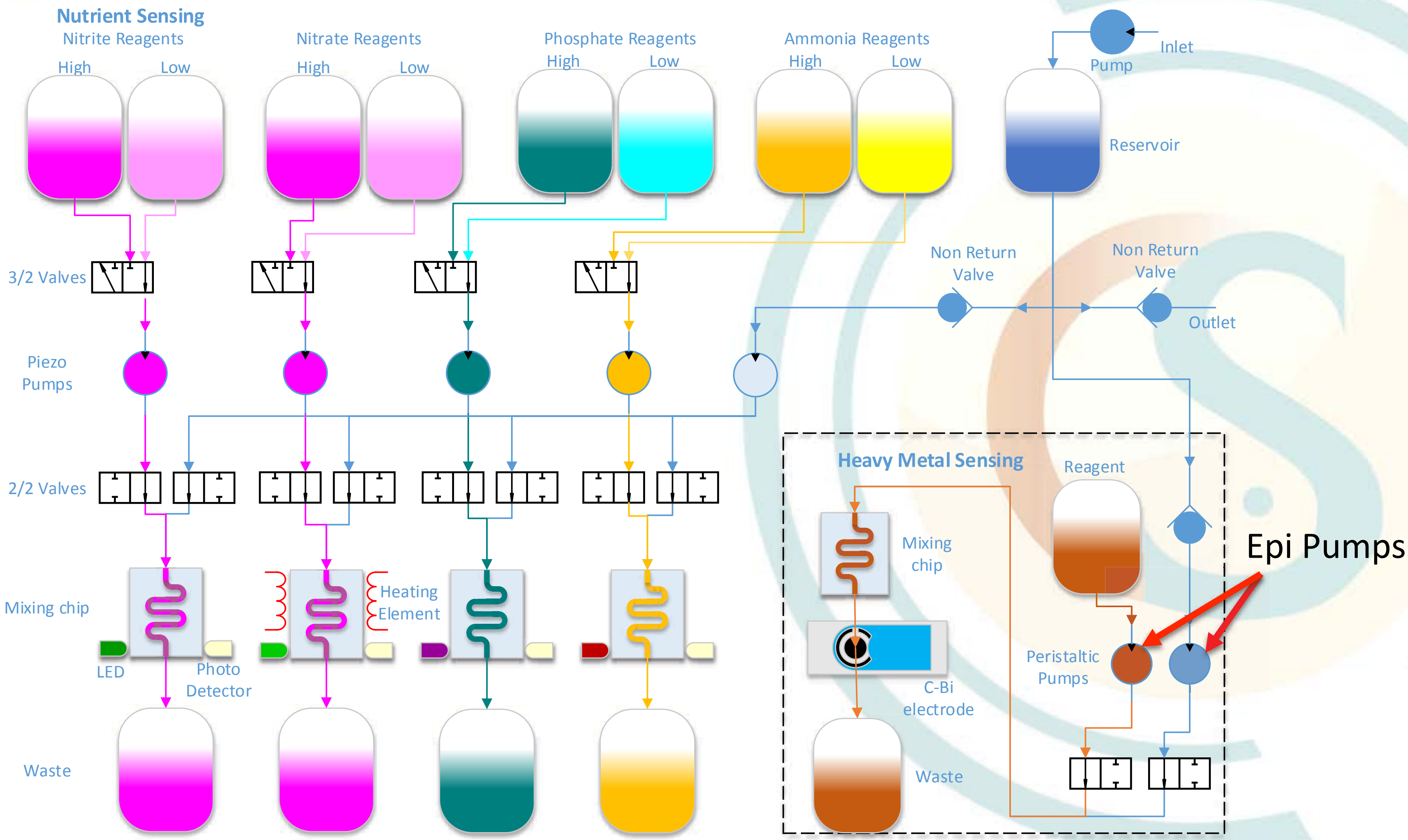
Registered Participants as of March 2015	
USDA Ag Research Service	Sea-Bird Coastal
Turner Designs	Open Photonics Inc.
ASA Analytics	Translume, Inc.
RATES	JAL Engineering
YSI, Inc.	Aquisure
Decagon Devices, Inc.	University of Illinois / MoboSense, LLC.
SYSTEA S.p.A.	Lumense, Inc.
Franklin Thompson	National Oceanography Centre
SUNY Binghampton	Environmental Monitoring Solutions, Ltd.
SubChem Sensor Systems, Inc.	Geekchitecture
T.E. Laboratories & Dublin City University	Katsujinken Foundation
CleanGrow, Ltd.	Water Canary
Blue Legacy International	Ayyeka
UCSD Biodynamics Lab	Real Tech
SRI International, Marine & Space Sensing Laboratory	

Winners will be announced March 2nd 2017 in Hawaii

sfi DCU UCC OÉ Gaillimh NUI Galway UCD Dublin

COMMON SENSE
MARINE SENSORS - MARINE MONITORING

Hydraulic schematic



This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 614155.

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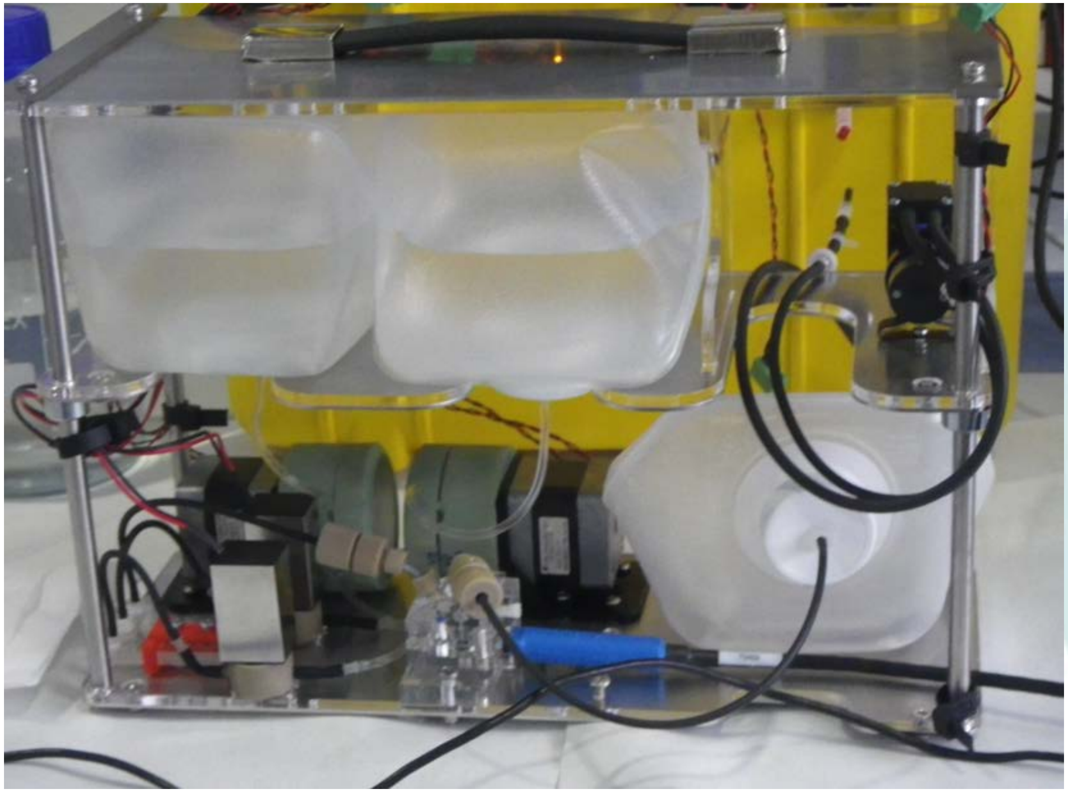
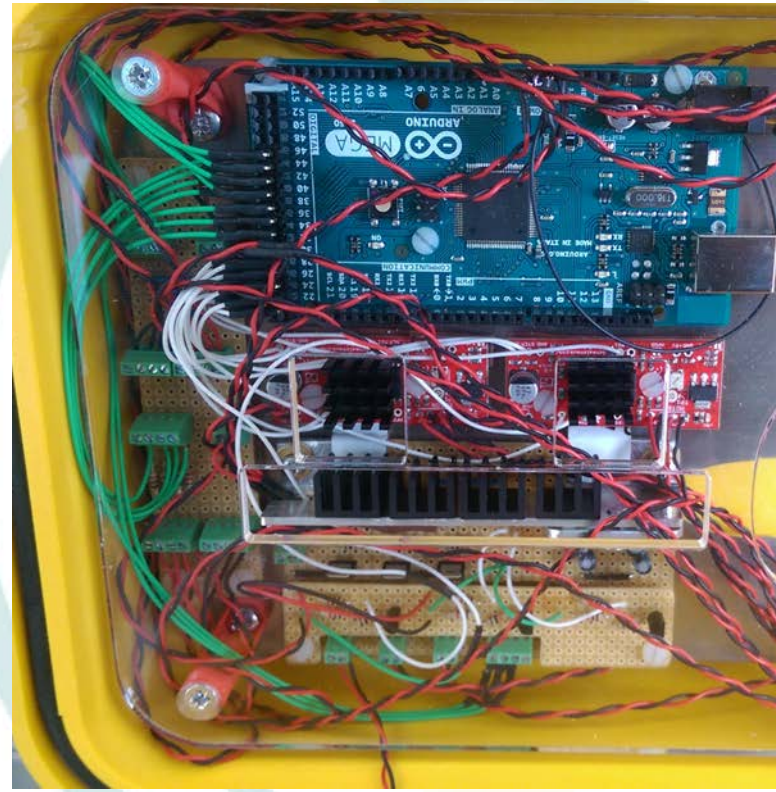
Heavy Metals Sensing System





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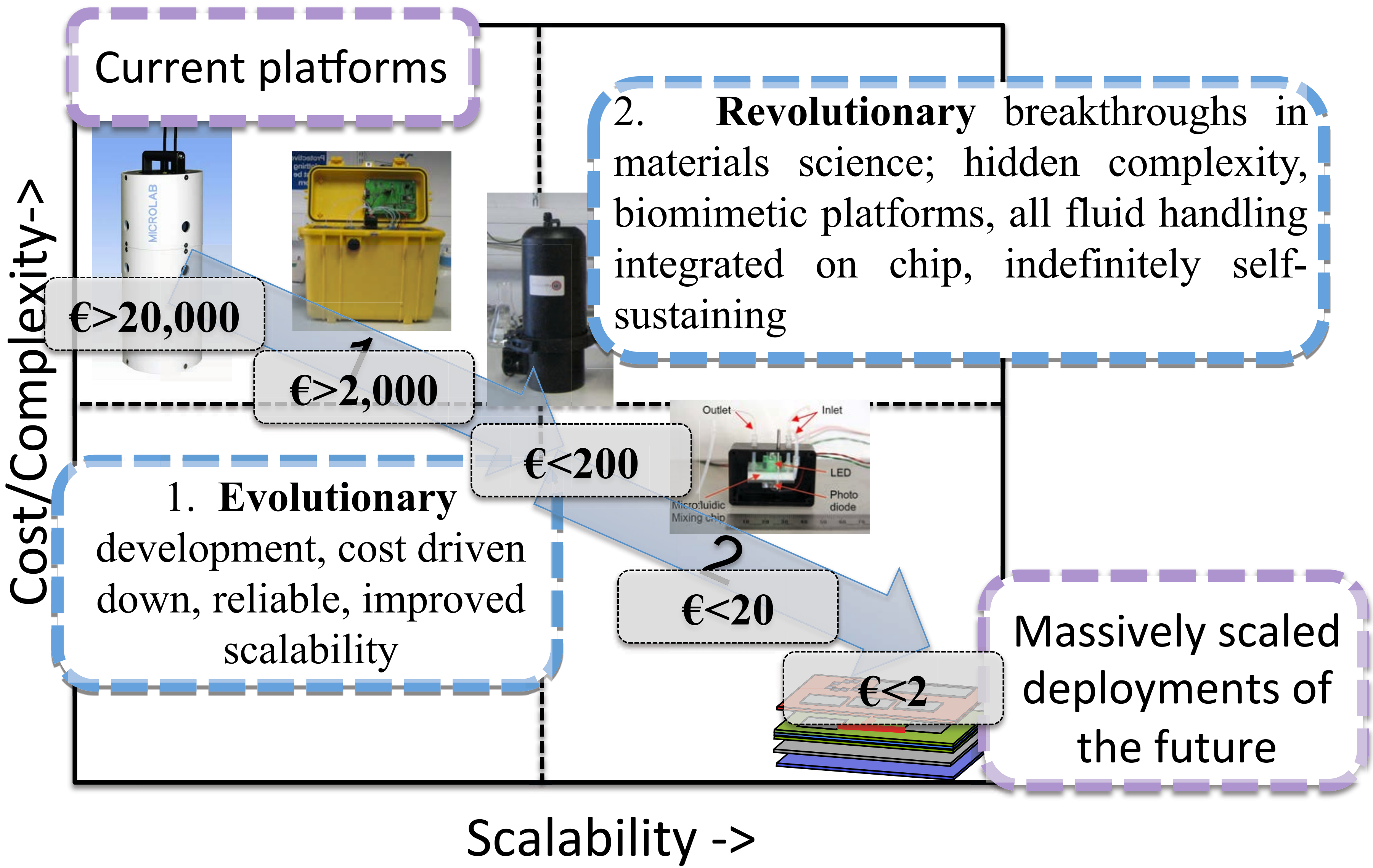
Current State of the Art

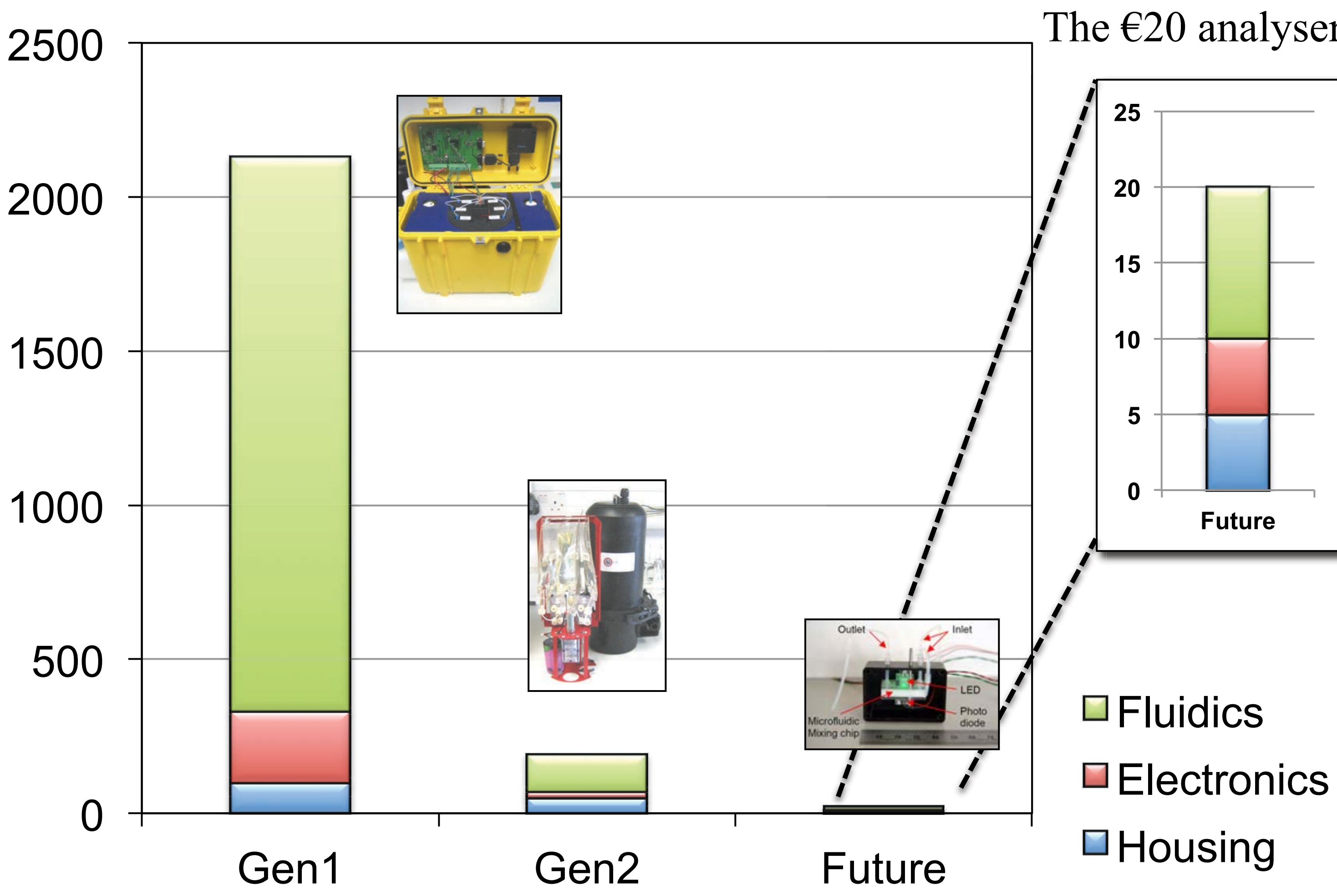
- **Units are big – basically lab units repackaged into boxes**
- **Expensive - >€20K per unit + recurrent costs is not unusual**

sfi DCU UCC OÉ Gaillimh NUI Galway UCD DUBLIN

Achieving Scale-up

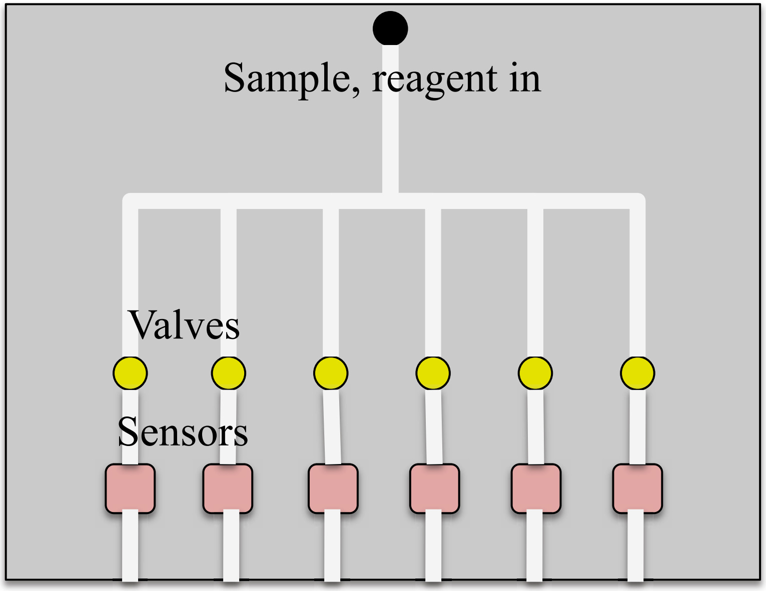


Cost Comparison Analysis (€)



Extend Period of Use via Arrays of Sensors….?

- If each sensor has an in-use lifetime of 1 week….
- And these sensors are very reproducible….
- And they are very stable in storage (up to several years)….

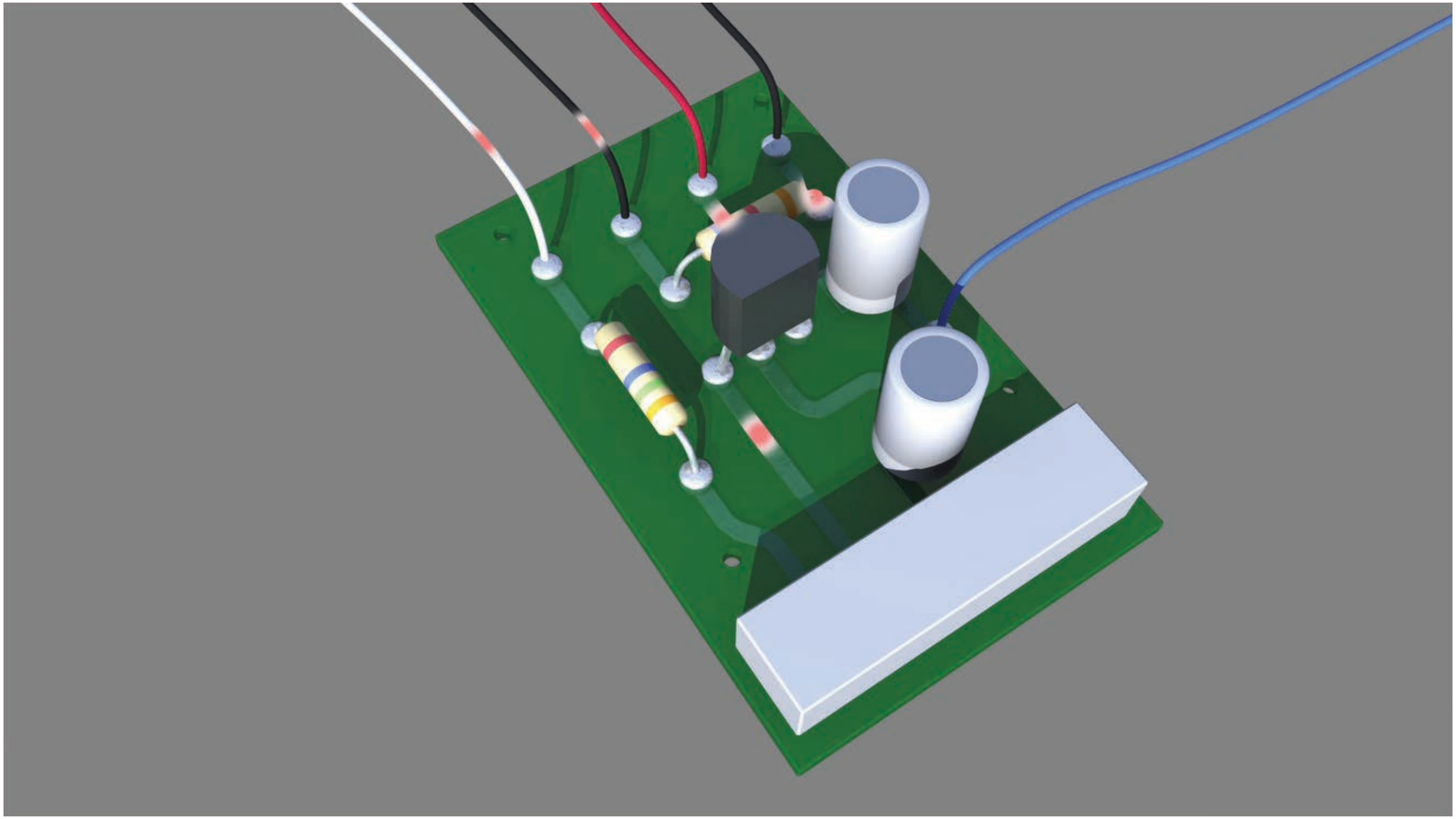


Then 50 sensors when used sequentially could provide an aggregated in-use lifetime of around 1 year

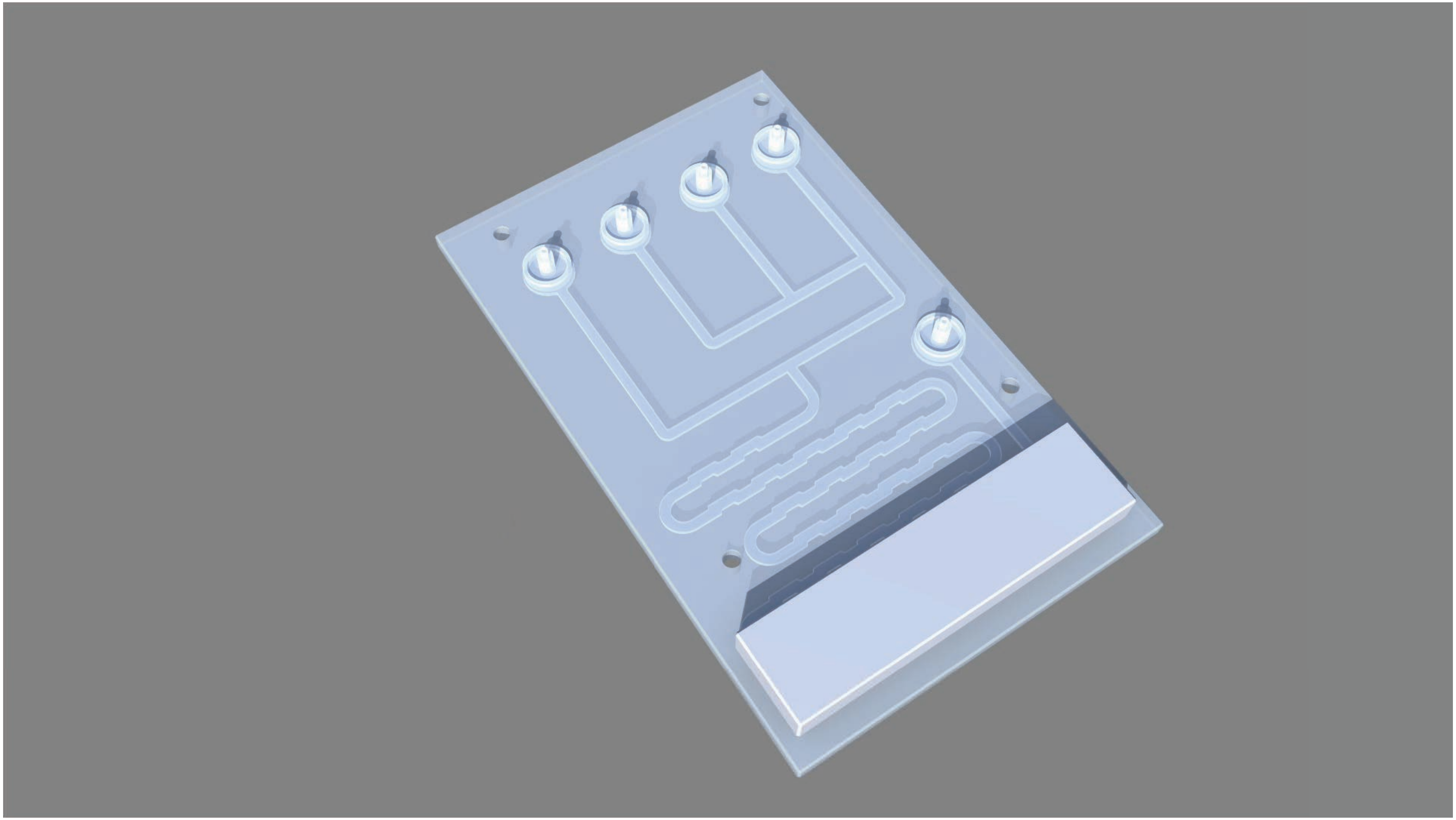
But now we need multiple valves integrated into a fluidic platform to select each sensor in turn

Microfluidics – Evolution….

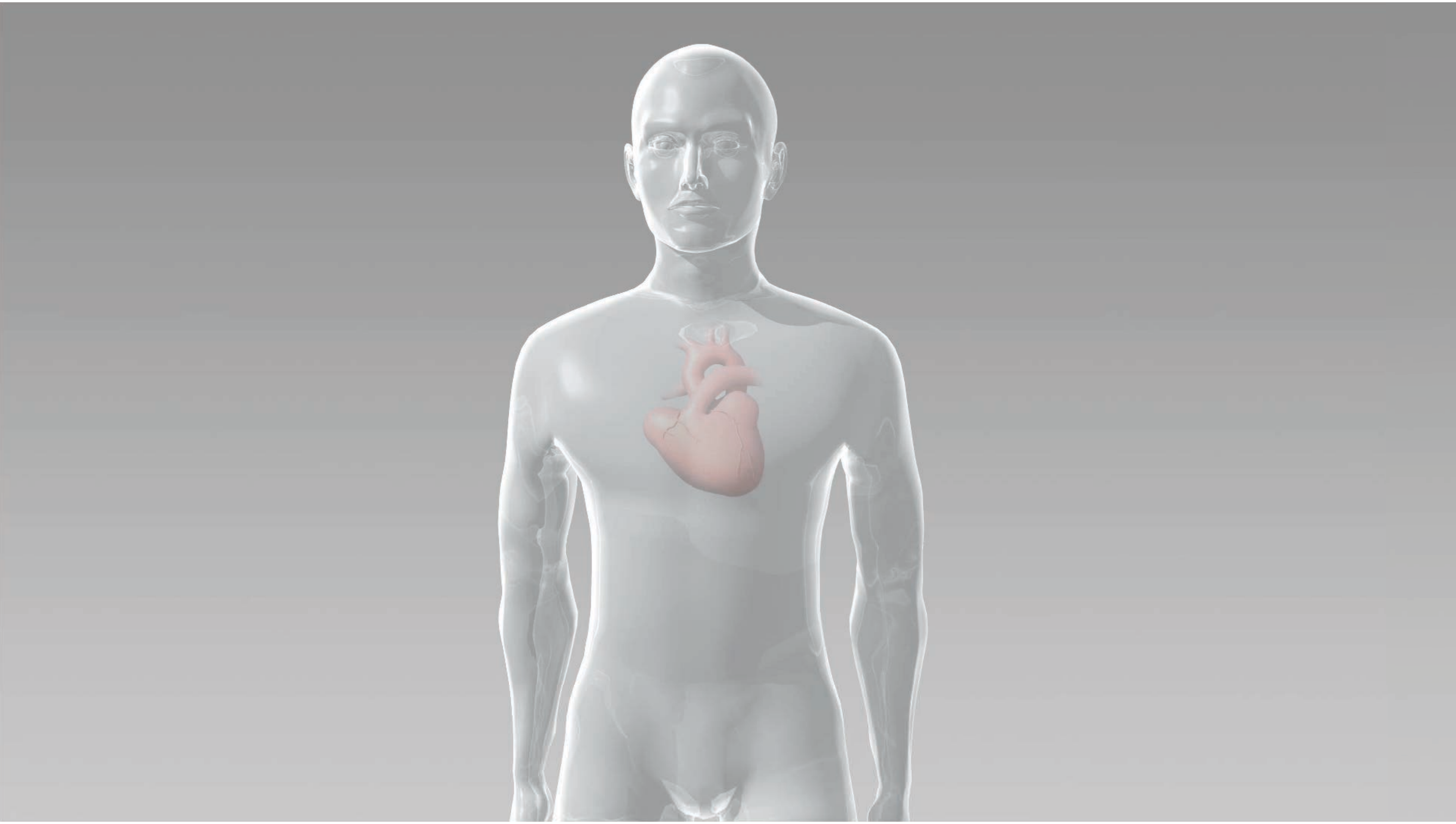
Engineering Inspired → **BioInspired**



But not everything is integrated…..

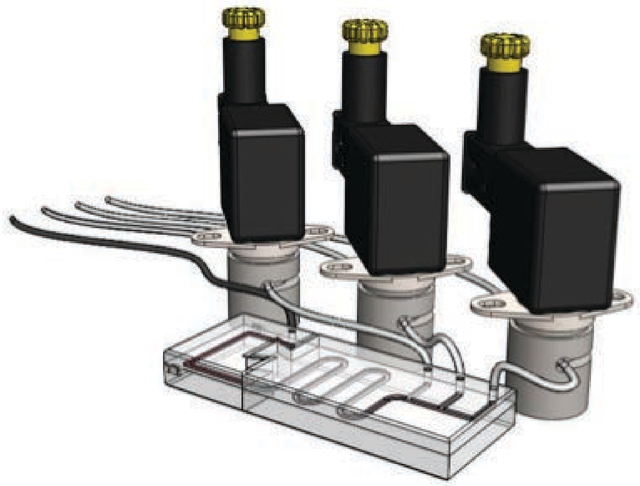


Bioinspired Fluidics



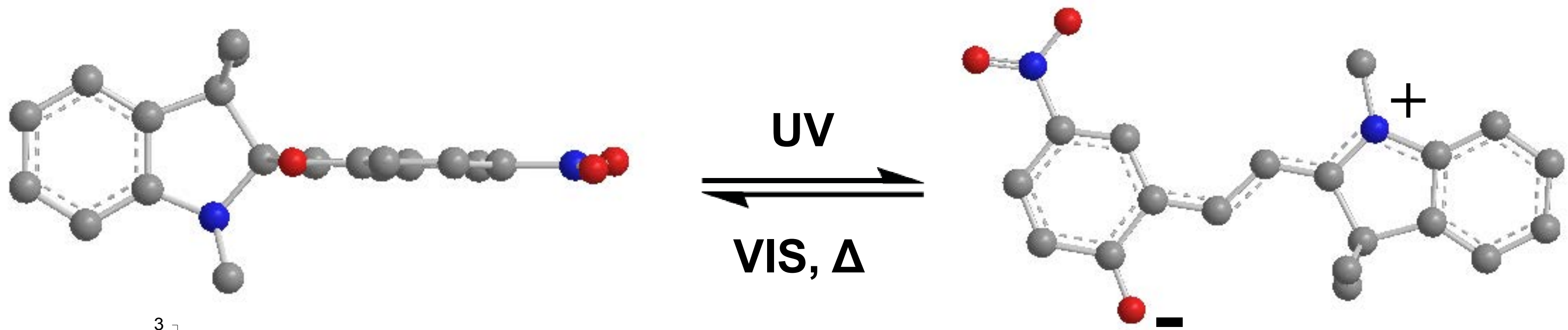
How to advance fluid handling in LOC platforms: re-invent valves (and pumps)!

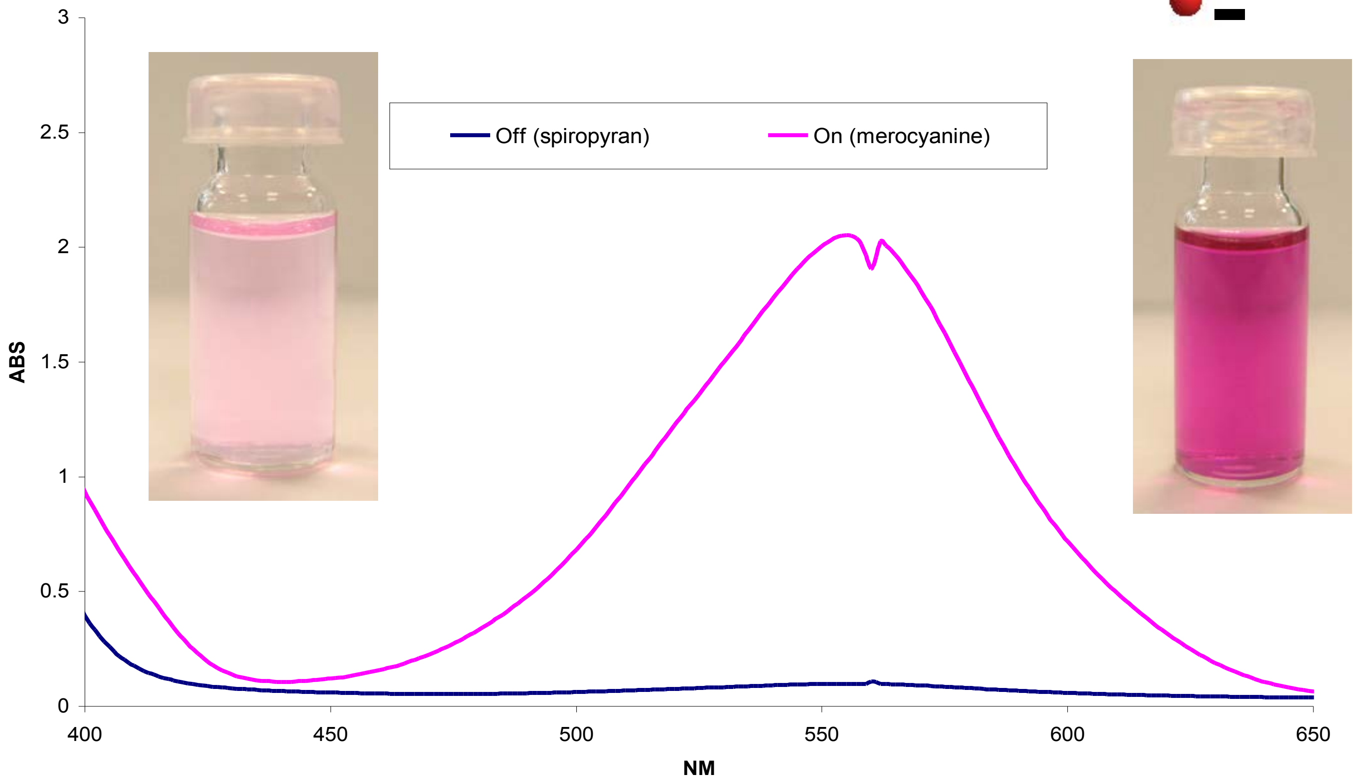
- **Conventional valves cannot be easily scaled down - Located off chip: fluidic interconnects required**
  - Complex fabrication
  - Increased dead volume
  - Mixing effects
- **Based on solenoid action**
  - Large power demand
  - Expensive



Solution: soft-polymer (biomimetic) valves fully integrated into the fluidic system

Photoswitchable Actuators

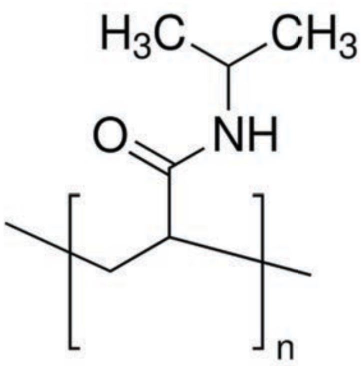


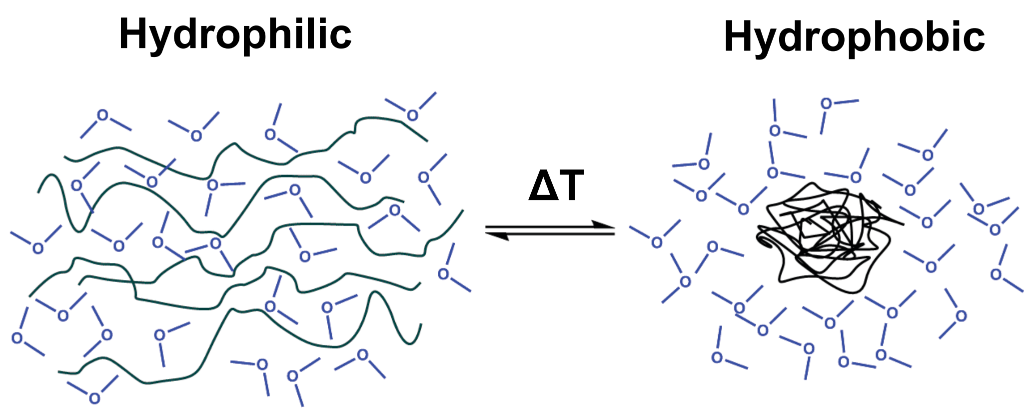


Poly(*N*-isopropylacrylamide)

- pNIPAAM exhibits inverse solubility upon heating
- This is referred to as the LCST (Lower Critical Solution Temperature)
- Typically this temperature lies between 30-35^{o}C, but the exact temperature is a function of the (macro)molecular microstructure
- Upon reaching the LCST the polymer undergoes a dramatic volume change, as the hydrated polymer chains collapse to a globular structure, expelling the bound water in the process

pNIPAAM

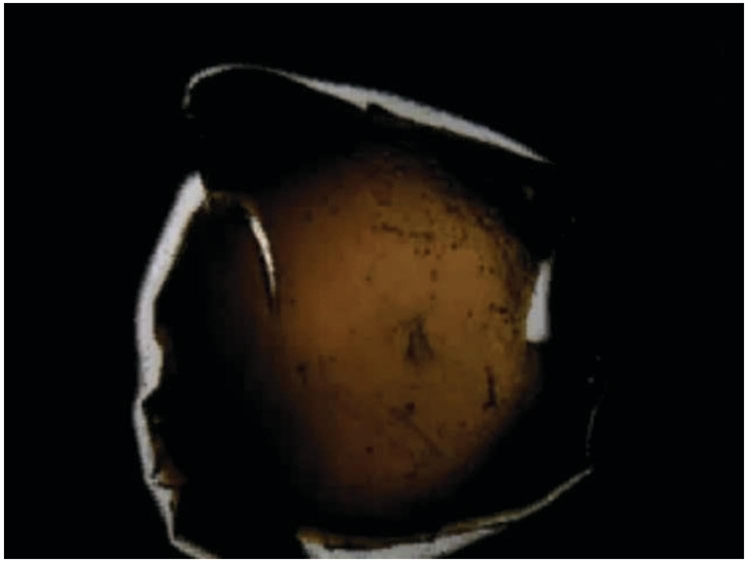


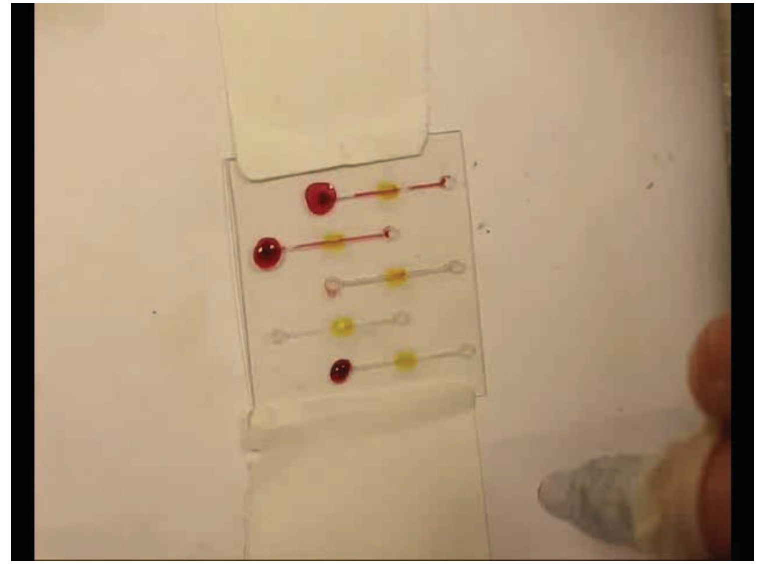


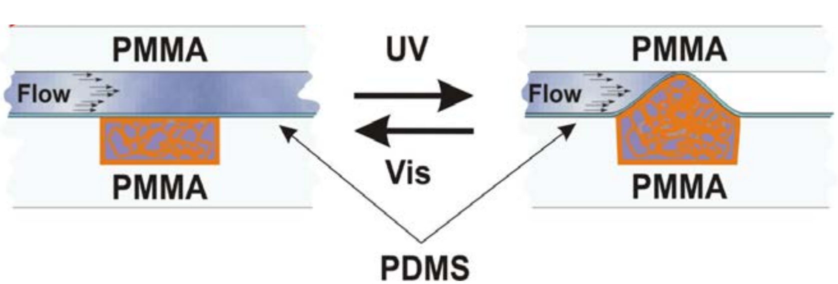
Hydrated Polymer Chains

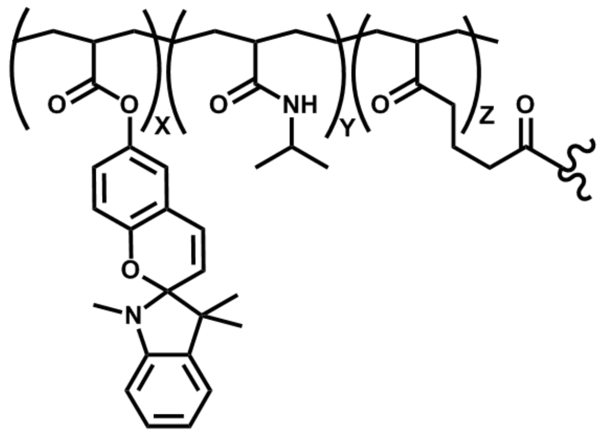
Loss of bound water -> polymer collapse

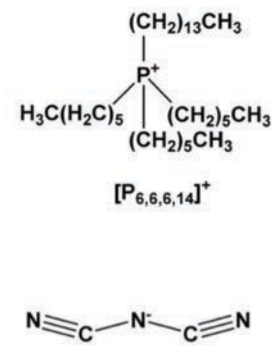
Photo-actuator polymers as microvalves in microfluidic systems









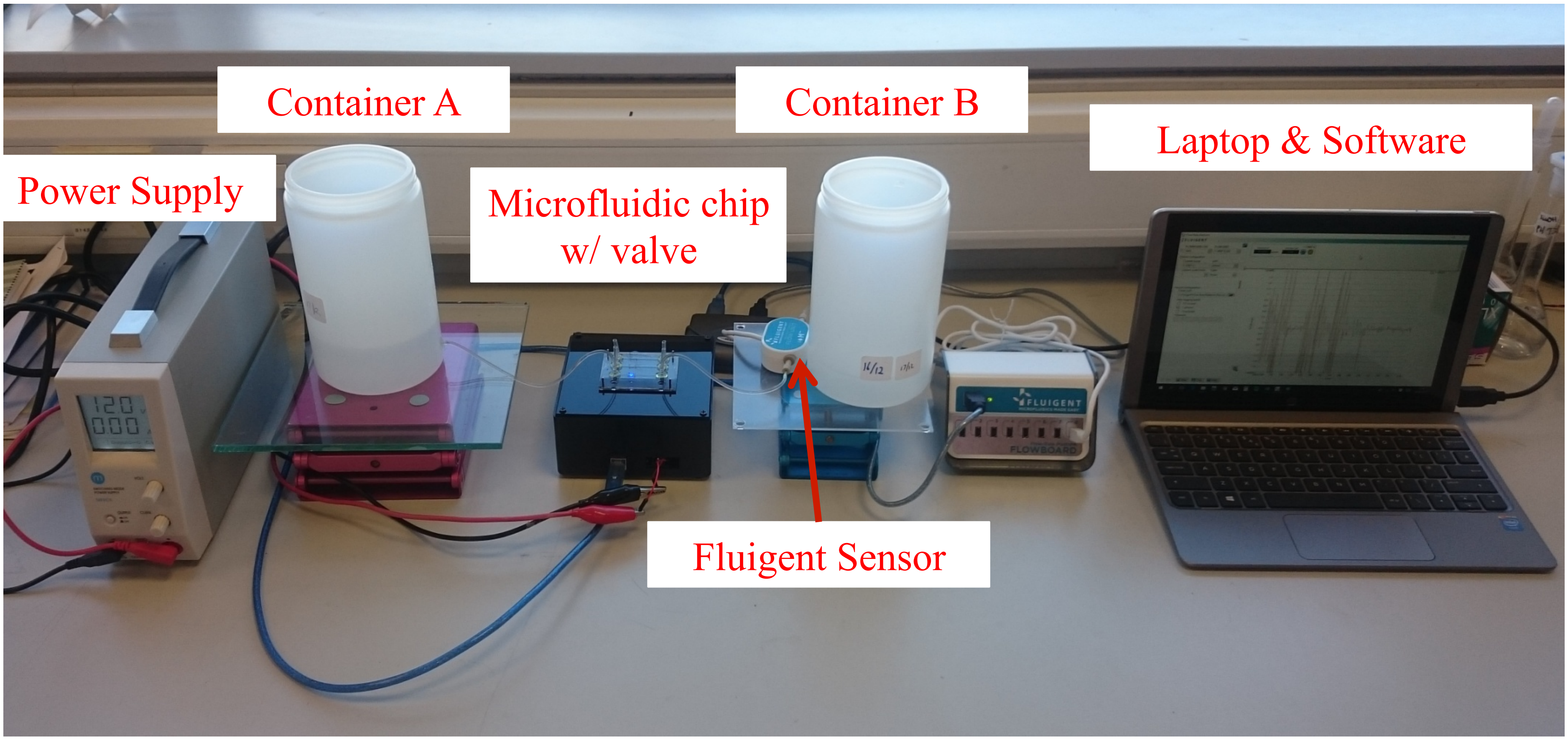


(b)

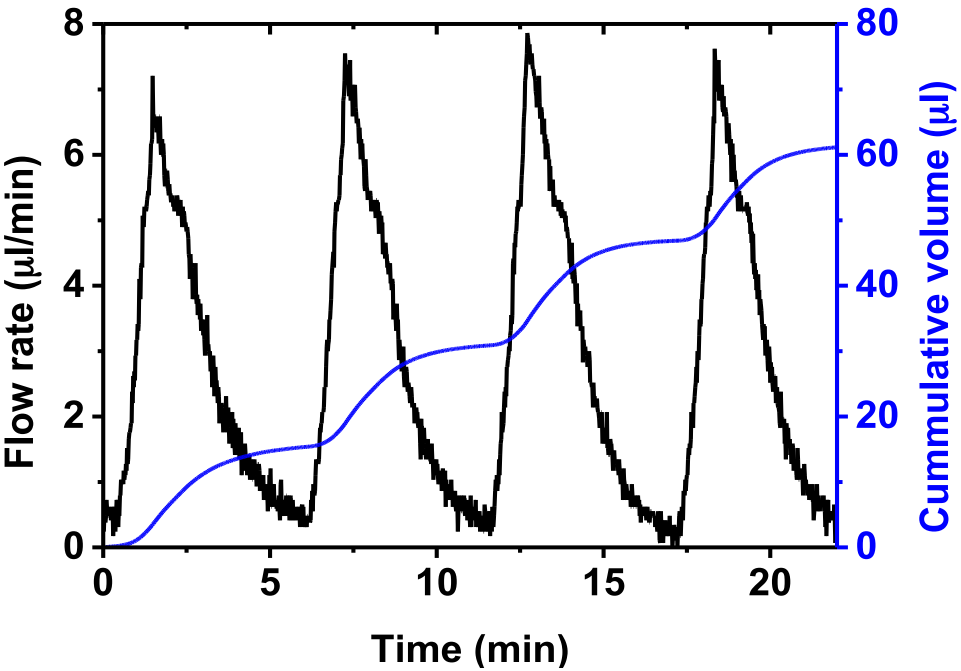
trihexyltetradecylphosphonium dicyanoamide $[P_{6,6,6,14}]^{+}[dca]^{-}$

Ionogel-based light-actuated valves for controlling liquid flow in micro-fluidic manifolds, Fernando Benito-Lopez, Robert Byrne, Ana Maria Raduta, Nihal Engin Vrana, Garrett McGuinness, Dermot Diamond, Lab Chip, 10 (2010) 195-201.

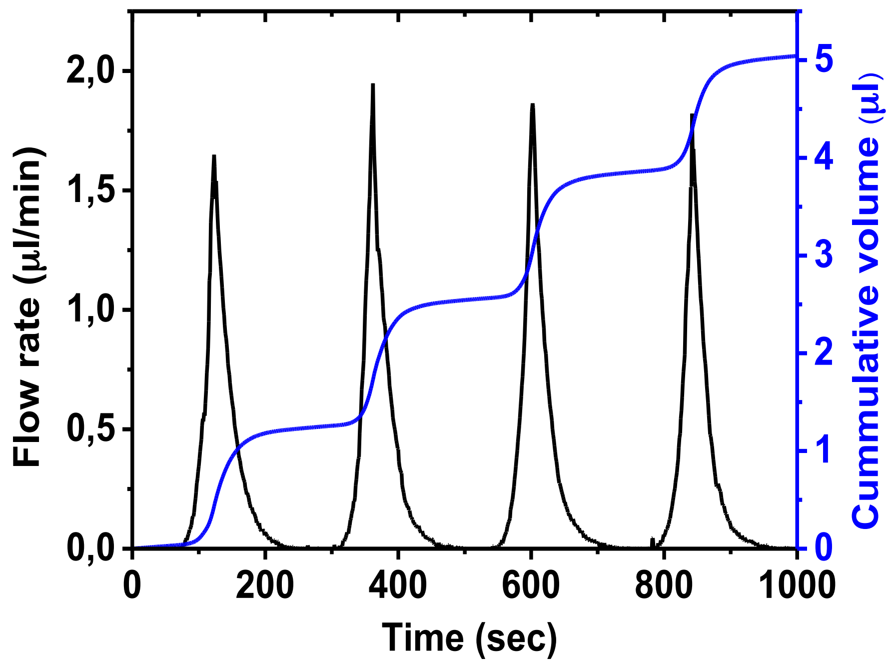
System Components



Optimisation of valve dimensions



1.7 mm mask

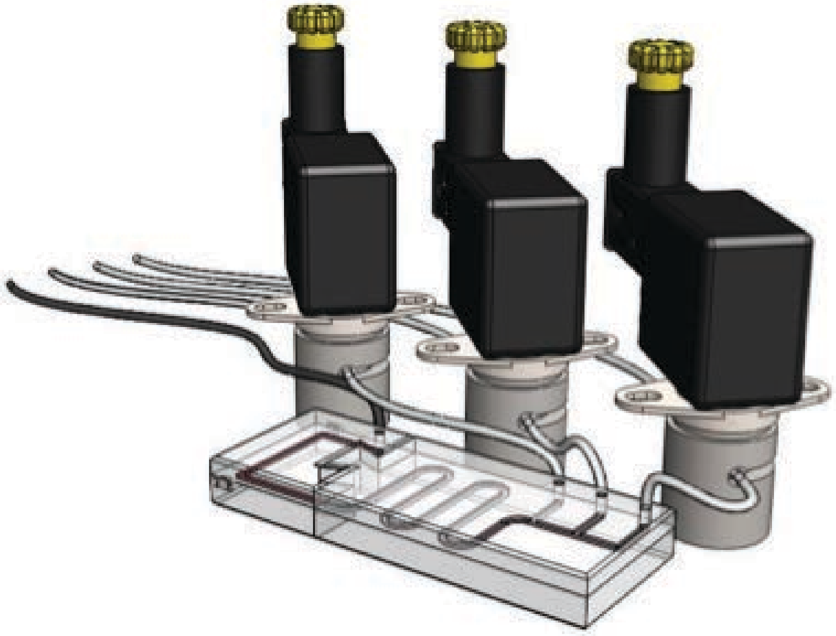


1.6 mm mask

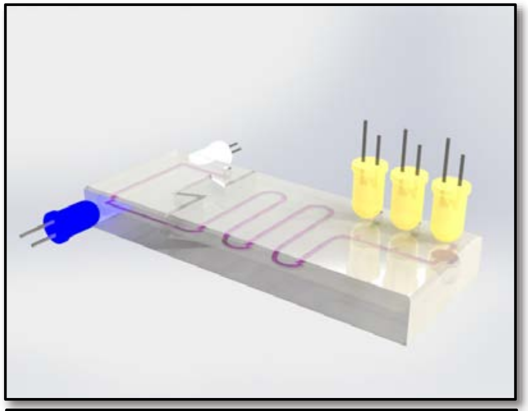
First example of actuating polymer gels as reusable valves for flow control on minute time scales (> 50 repeat actuations)

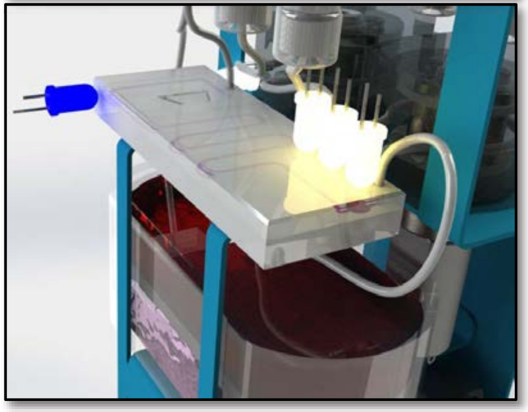
From ‘*Molecular Design of Light-Responsive Hydrogels, For in Situ Generation of Fast and Reversible Valves for Microfluidic Applications*’, J. ter Schiphorst, S. Coleman, J.E. Stumpel, A. Ben Azouz, D. Diamond and A. P. H. J. Schenning, Chem. Mater., 27 (2015) 5925−5931. **(cover article)**

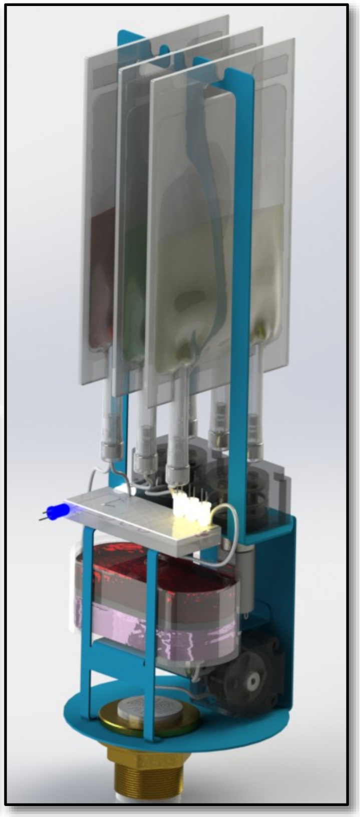
Can we go from this:

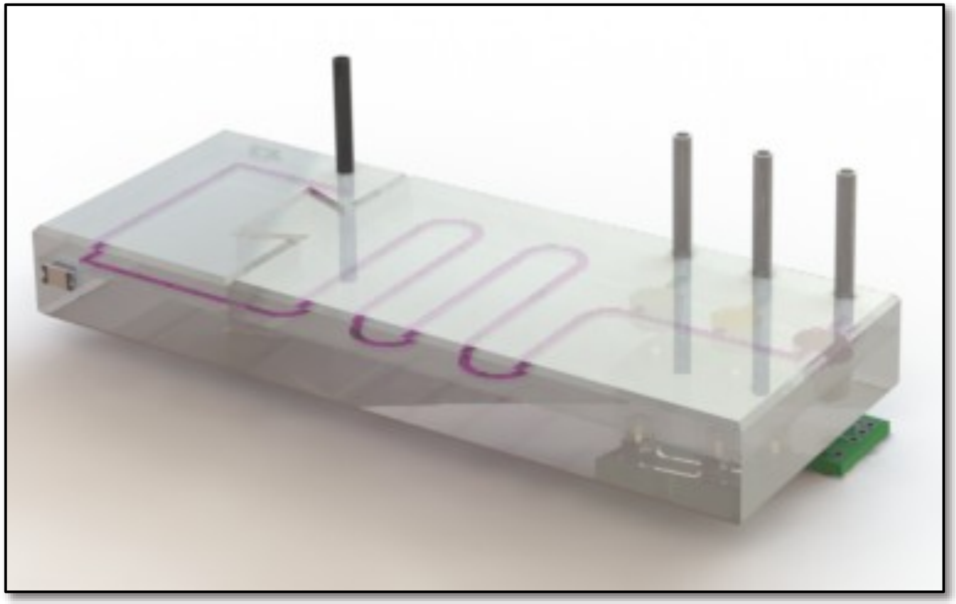


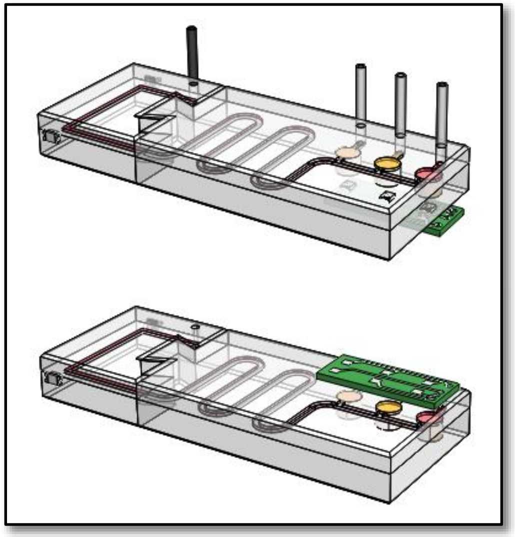
To Photo-Fluidics & Detection





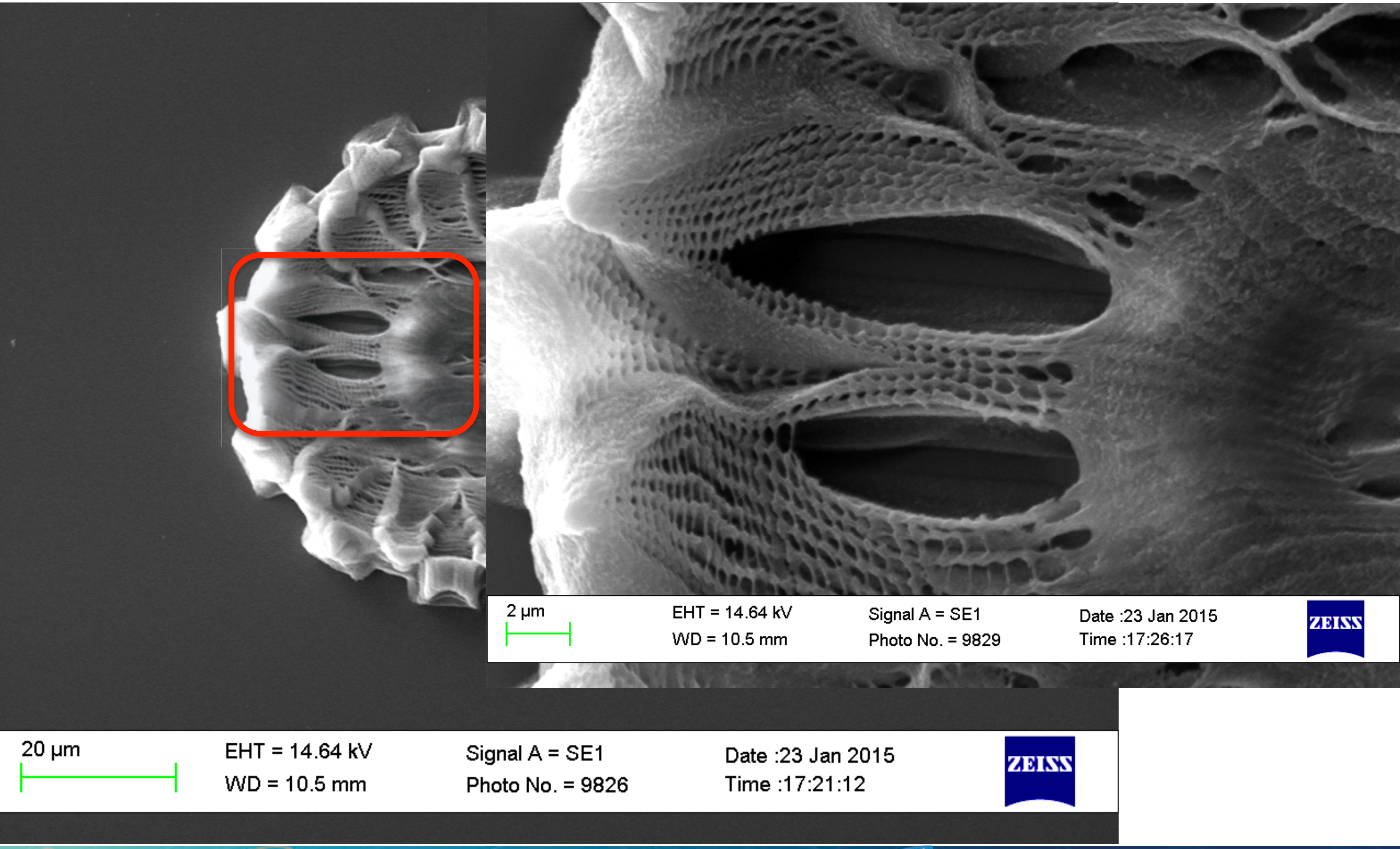






- **Fluidic handling completely integrated into the microfluidic chip**
  - Valves actuated remotely using light (LEDs)
  - Detection is via LED colorimetric measurements
  - Photo-controlled uptake and release

'Daisy' – Micro/Nano Scaled Porous Structure



Merging of Materials, Devices and Data

Data and Information; IOT

Devices and Platforms

MATERIALS

Physics Chemistry Biology Engineering

(photonics, electronics, fluidics, 4D materials)

Sensing our Environment: From Innovative Materials to Autonomous Sensors & Earth Observation

Technologies for monitoring the quality of natural waters and drinking water, and compliance of wastewater with regulatory standards, are set to change dramatically in terms of price and performance. The impact of 'big environmental data' will be truly revolutionary for businesses and for citizens.

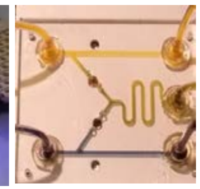
Water quality issues do not respect national borders – pollution arising from one state can affect neighboring states, and the effects of climate change arise from human activity on a global scale. The scale of the opportunity for new technologies and associated services and businesses is therefore global – solutions developed for one scenario will be adaptable for many related applications and locations. Services will be 'cloud' based, capable of accessing and analyzing data from multiple sources and locations, and providing environmental information that can be highly localized or global in range.

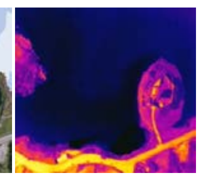
Realising the potential of these technologies requires input that is truly multidisciplinary in nature, and encompassing a wide variety of stakeholders. This symposium will bring together experts in water analysis and monitoring, innovative instrumentation, satellite remote sensing of water status, and water treatment to discuss current and future trends and developments in technologies related to water. Participants will be drawn from University, industry and agency backgrounds, from Europe and North America. Key topics will include the rapidly evolving nature of water quality sensing devices, the integration of information from multiple sources (in-situ sensors, satellite remote sensing, and drone based multispectral imaging), and the increasing use of mobile phones by citizens to perform sophisticated environmental analytical measurements and share data (citizen science and 'crowd' sensing). The symposium is supported by NAPES (a European Multipartner project focused on developing next generation water quality sensing technologies – www.napes.eu), The National Centre for Sensor Research (www.ncsr.ie) and the DCU Water Institute .

Confirmed Speakers:

Prof. Dermot Diamond DCU, Prof. Jed Harrison University of Alberta; Prof. Graham Mills, University of Portsmouth; Mr. Coleman Concanon, EPA Ireland; Breda Moore, TE Laboratories; Mr. Liam Curran, Enterprise Ireland; Dr. Bas van der Grift, Deltares

NAPES
NEXT GENERATION ANALYTICAL PLATFORMS FOR ENVIRONMENTAL SENSING

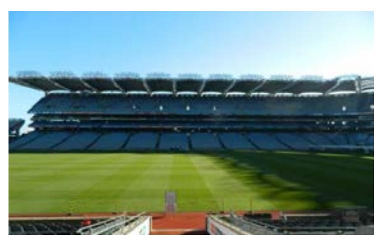




Date: 27th & 28th March 2017

Venue:

Croke Park, Jones Road, Dublin 3, Ireland.



Contact Details: Angela Lally

Angela.lally@dcu.ie

NAPES WORKSHOP

Croke Park Convention Centre, Dublin

27/28 March 2017

Contact: angela.lally@dcu.ie

Cead Mile Failte oraibh uilig!!

sfi DCU UCC OÉ Gaillimh NUI Galway UCD DUBLIN

Thanks to…..

- Members of my research group
- NCSR, DCU
- Science Foundation Ireland, INSIGHT Centre & Enterprise Ireland
- EU Framework Funding
- Academic and Industry Research Partners

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Project no: 269302
Materials and Advanced Sensor Knowledge Exchange

COMMON SENSE

MARINE SENSORS - MARINE MONITORING

Thank you for your Attention

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