Hydroelectric Power Plant on a Chip

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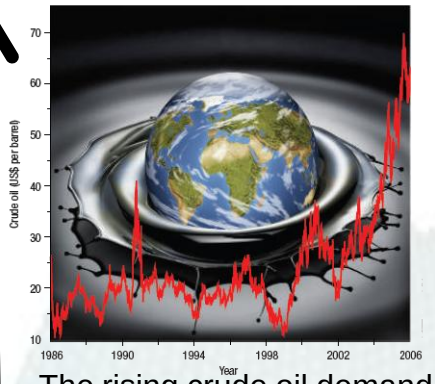
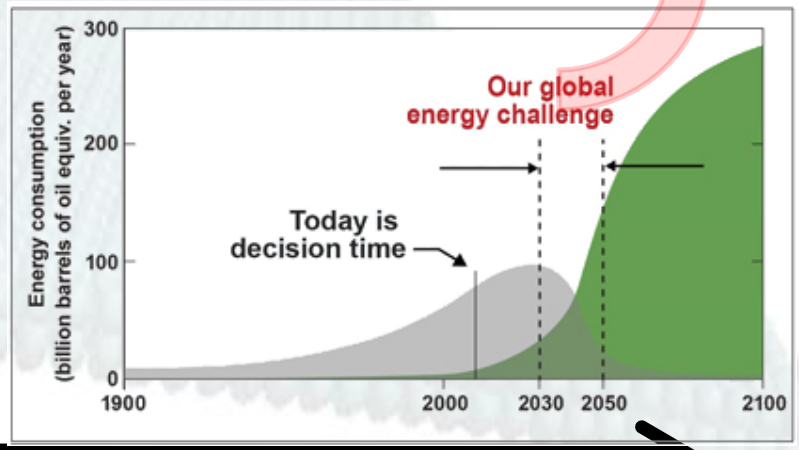
Energy Harvesting and Conversion



The rising crude oil demand

The growing abyss between the energy supply and demand poses a challenge to develop advanced conversion technologies

Human civilization witnessed of newer energy sources harvested to obtain greater power density



Power Density

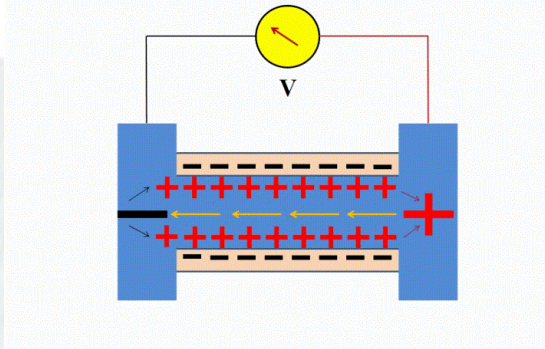
Time

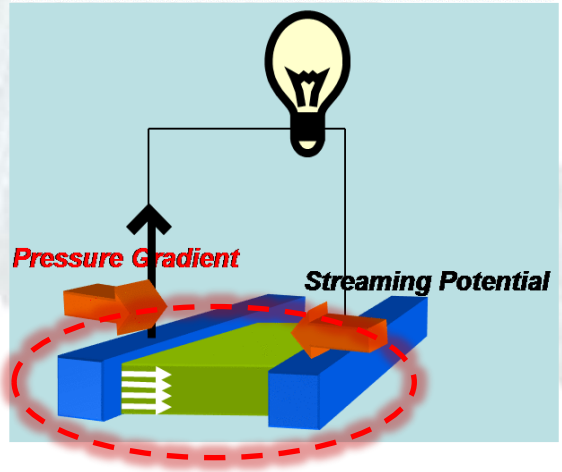
Image source : http://www.instructables.com/,http://stupendodog.blogspot.in,http://www.dreamstime.com/,http://www.waterwheelplace.com/

The Fundamental Principle

- On the application of an external force (which itself may be due to surface energy), a saline solution in a tiny channel starts flowing
- This saline solution carries free ions that migrate with the flow
- In this process, there is a voltage developed across the channel, which, when connected with an external resistor, supports current flow

  - ❑ Green energy
    - No combustion/fossil fuels
  - ❑ Remote power generation
    - Portable and self sustaining
  - ❑ 'On-chip' integration & parallelizability
    - Integrated with mixers/analyzer



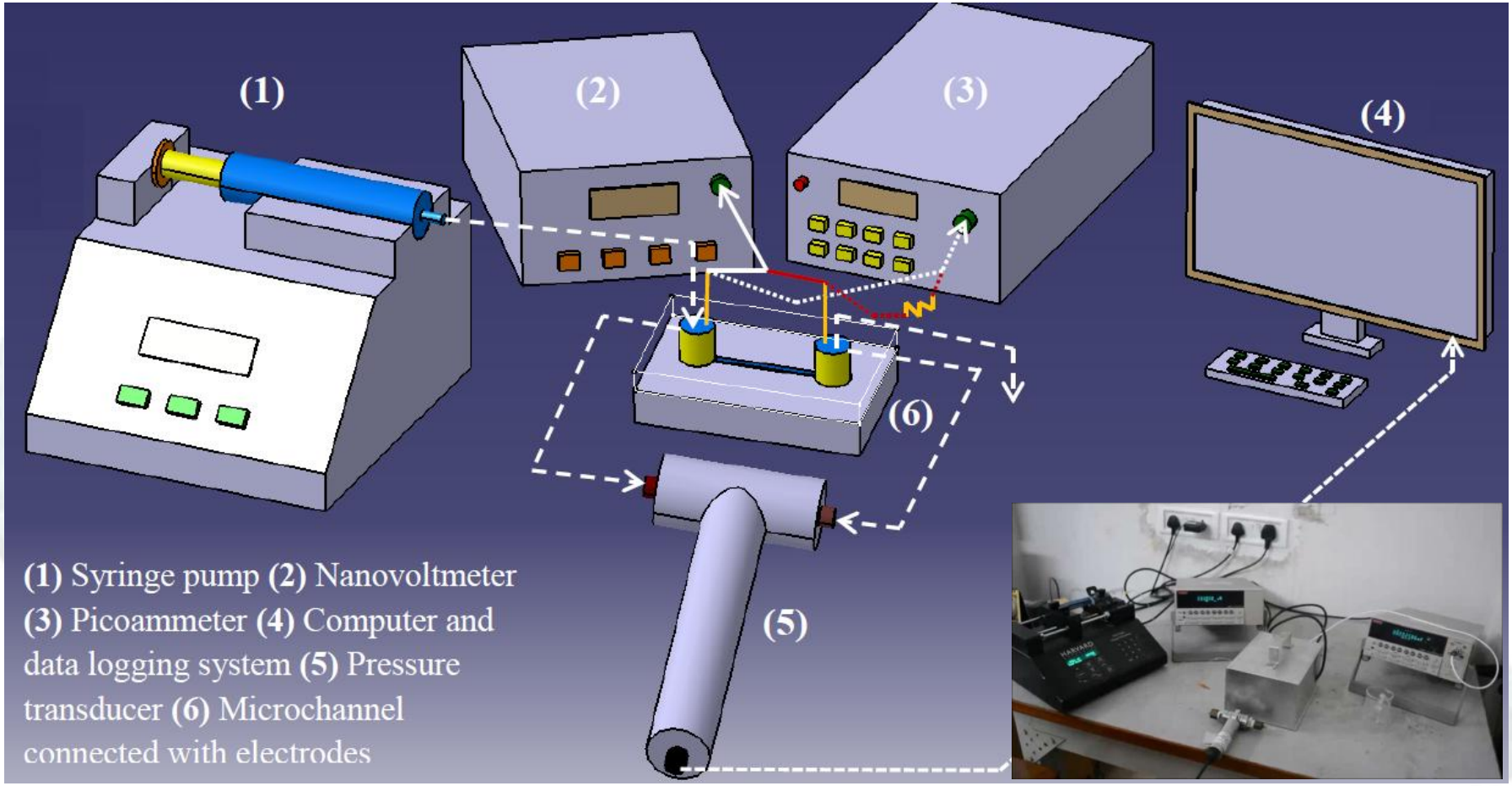


However!

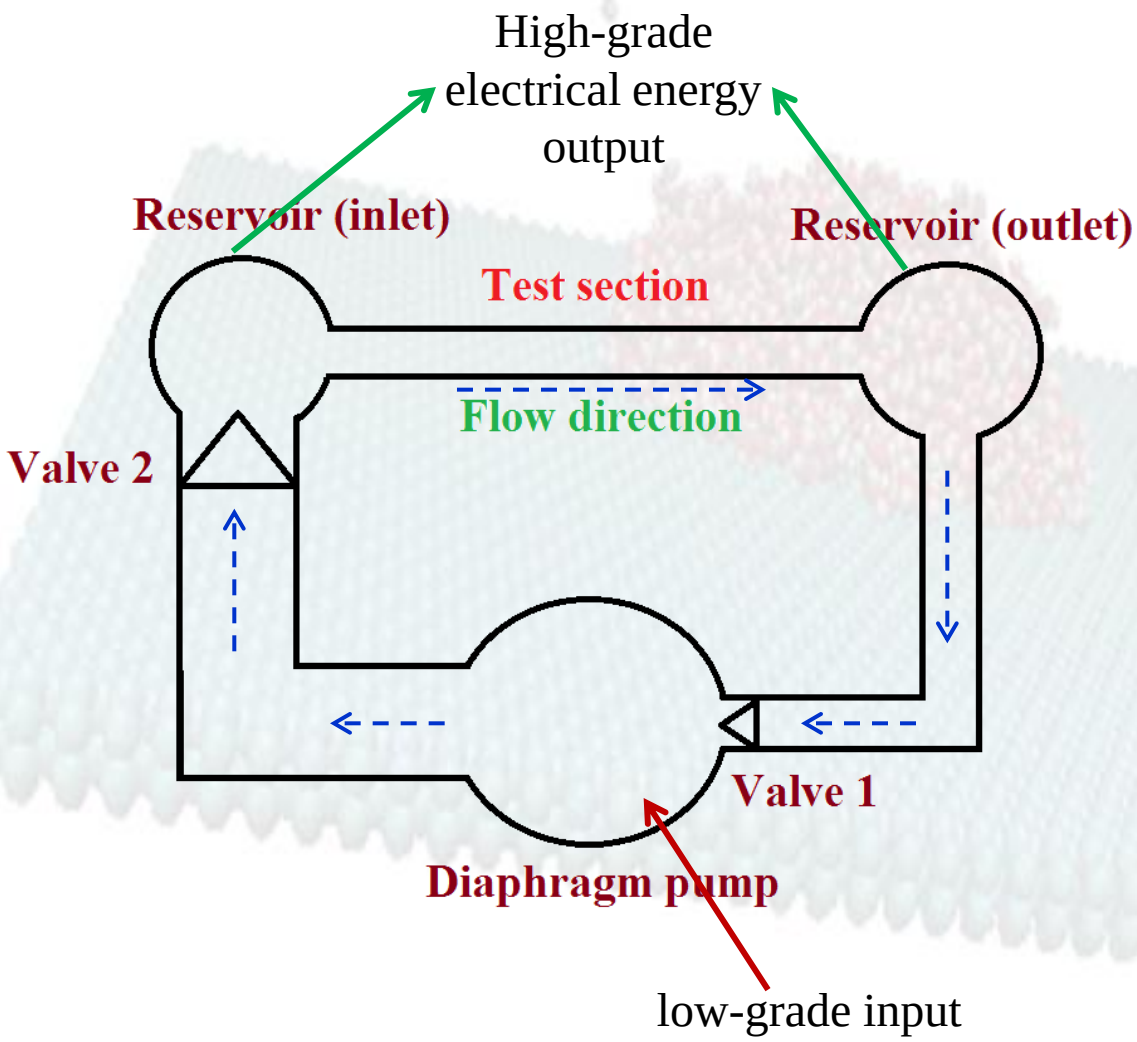
- ❑ Low conversion efficiency??
- ❑ Expensive fabrication technologies
- ❑ Implementation challenges

Image Source: http://www.andrew.cmu.edu/

Plant on a Chip

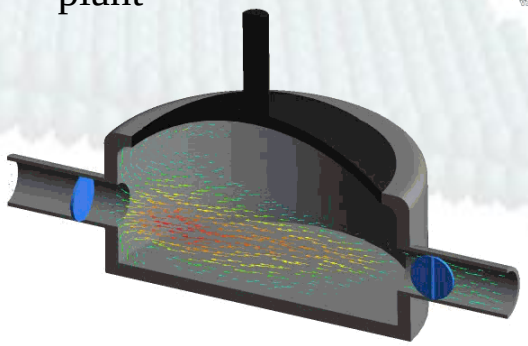


Continuous Generation of Power



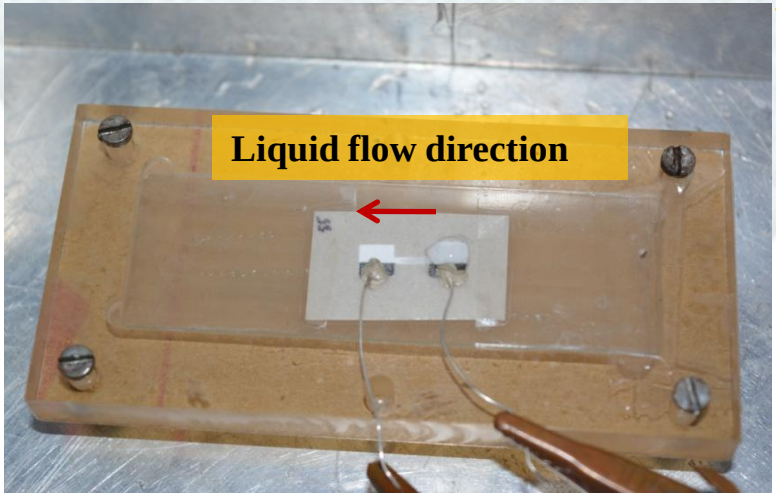
The IDEA

- Energy harvested as a by-product of any vibratory or reciprocating motion can be used to run the diaphragm pump.
- Diaphragm pump creates suction and thus a continuous circulation of the fluid
- Quasi perpetual energy system mimicking a large scale power-plant

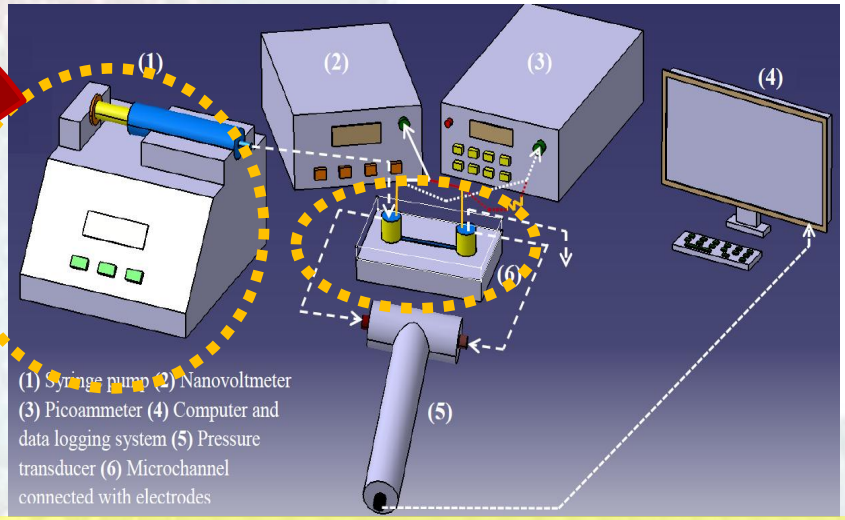


Hydroelectric Power Plant with Paper and Pencil

- Disposable
- Electrode fabrication with pencil sketch
- No pumping power; surface energy can be exploited for energy conversion.
- No clean room facility for mass fabrication



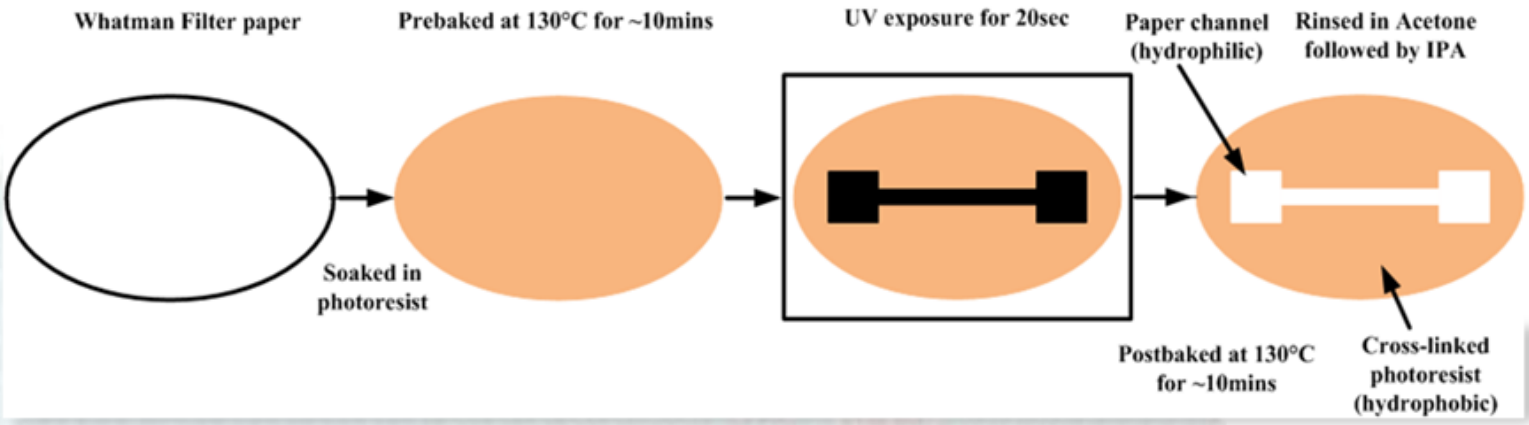
Plant on a Paper



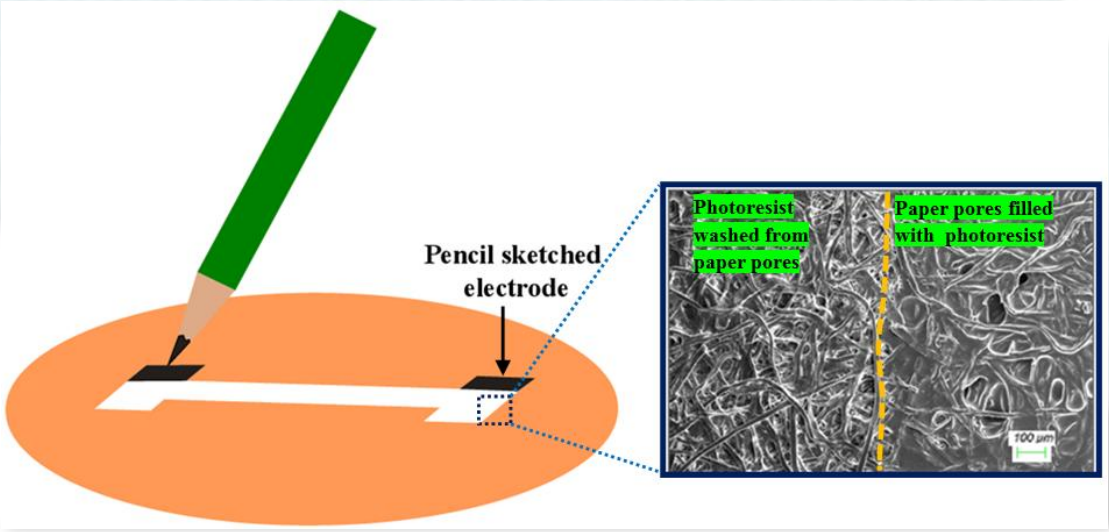
Plant on a Chip

Fabrication

❑ Channel fabrication

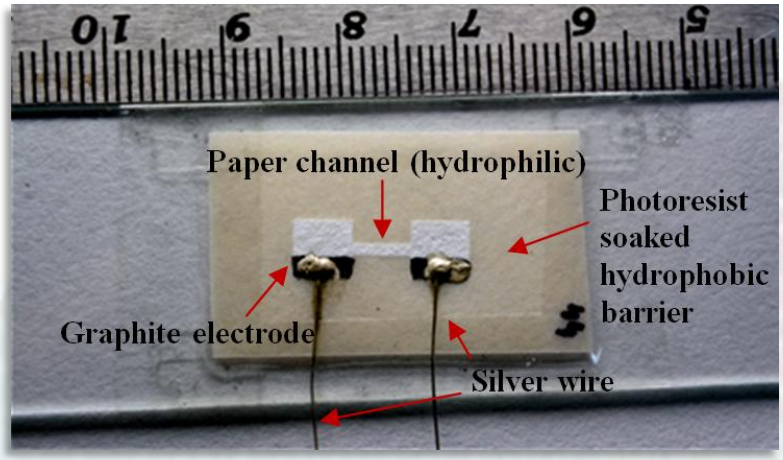


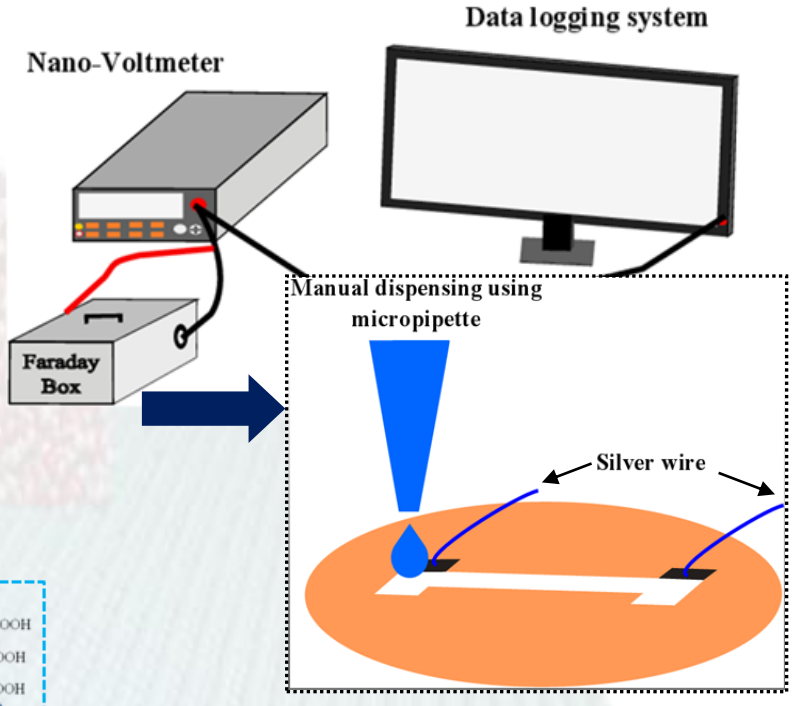
❑ Electrode sketching and wiring: electrical connection

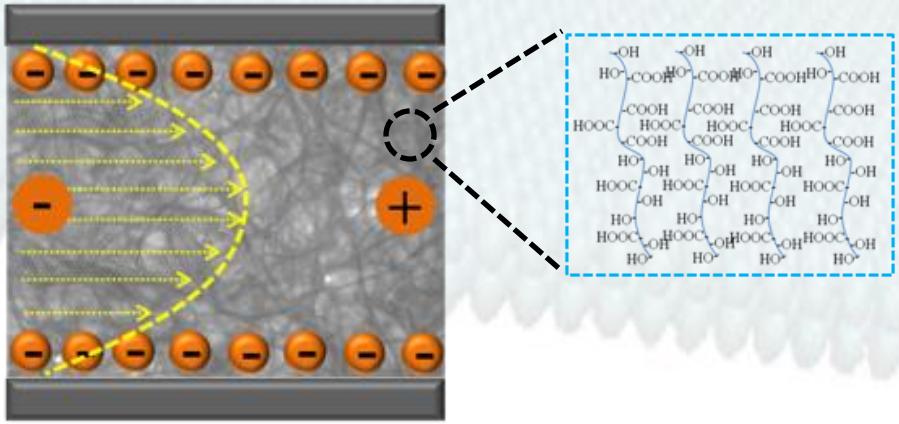


Hydroelectric Power Plant on a Paper Strip

❑ **Complete 'Paper-and-pencil' based device**



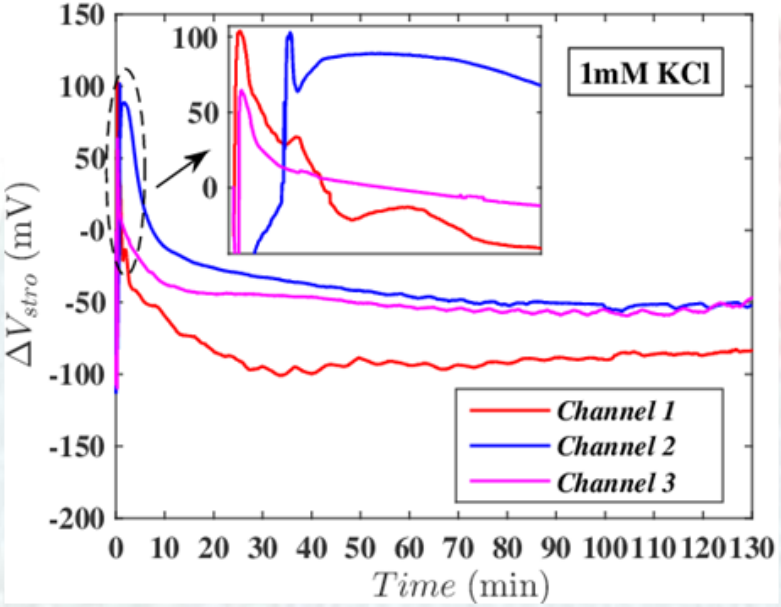


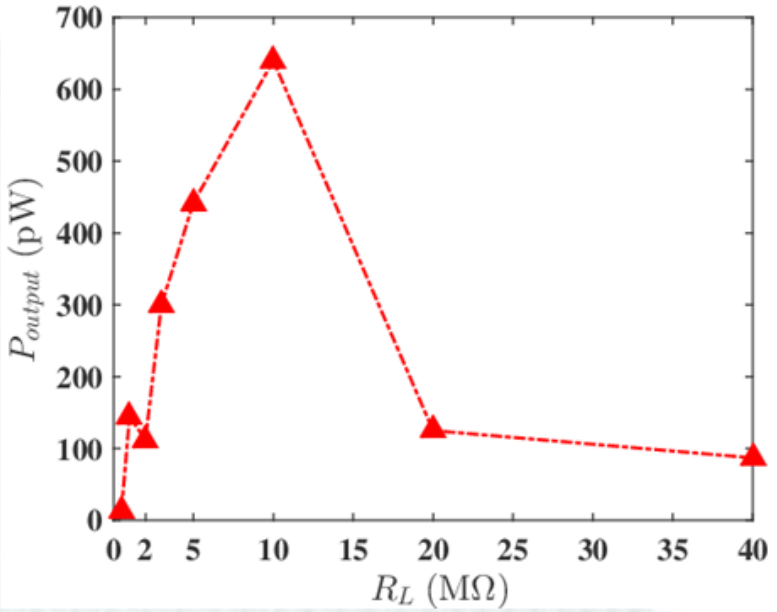


➢ **50 µl salt solution** (KCl) is dispensed at the inlet reservoir pad.
➢Uniform experimental conditions, **RH: ~ 50% and T: 22-24^{0}C** is maintained.

Das et al., Lab on a Chip 2018

Open Circuit Voltage and Output Power

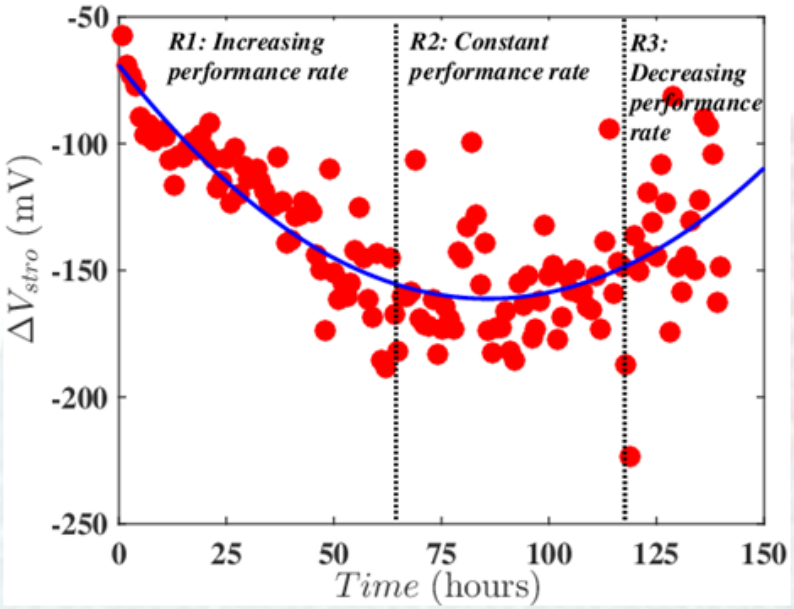


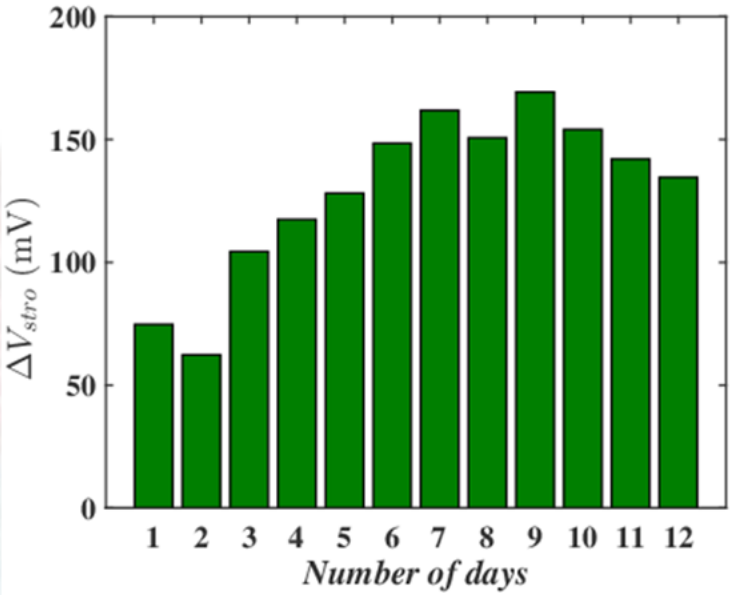


❖ The measure voltage in the range of ~ **50-100 mV**.

❖The maximum output power for single channel is measured to be ~ **640 pW** for the external resistance of **10 MΩ.**

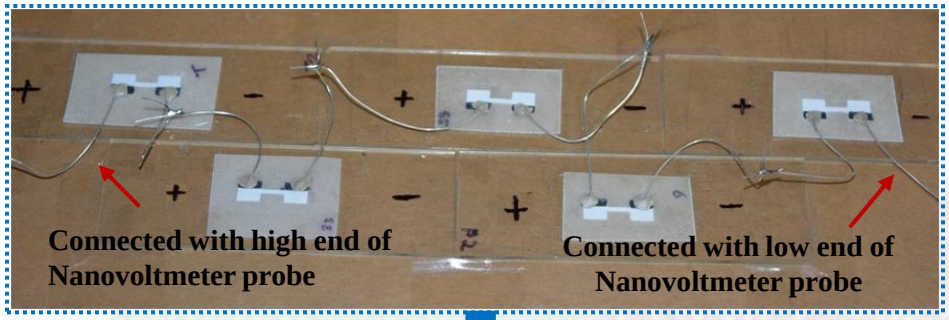
Performance Test

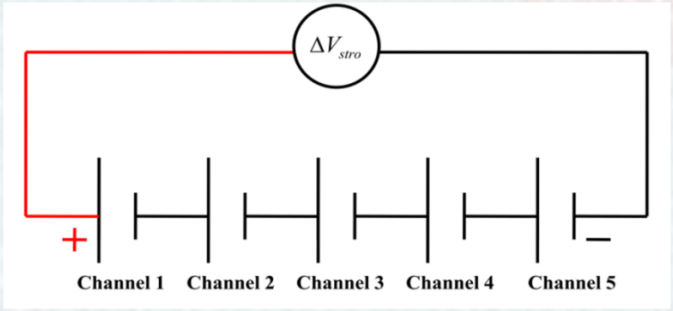


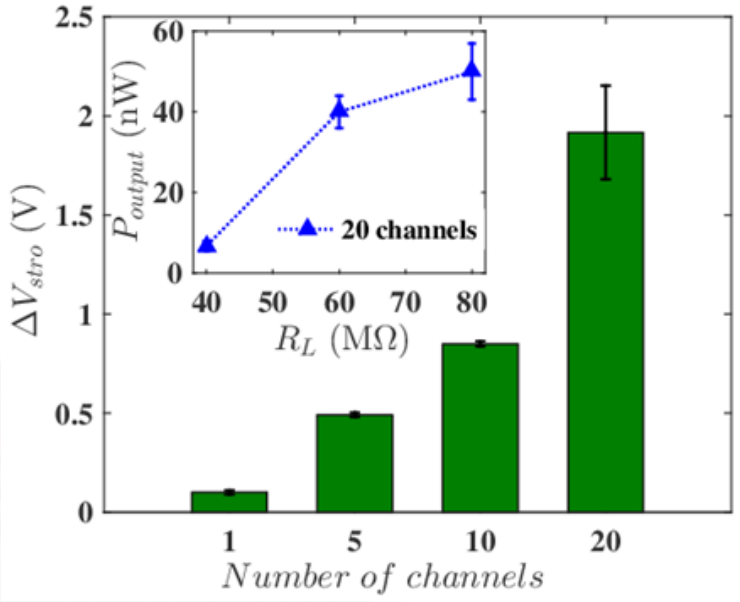


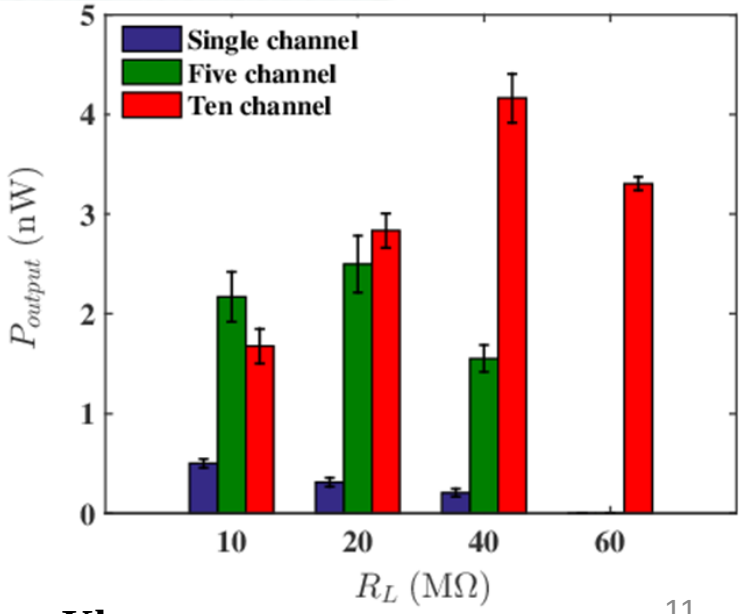
- Cyclic test consists of **12 hours** of continuous measurement followed by **10-12 hours** of drying.
- The device performance remains same even after **~ 140 hours** of continuous operation.
- Due to **crystallization of KCl** in cellulose matrix after continuous usage, the effective pore size gets reduced.
- Enhances the driving pressure gradient and thus higher flow rate than initial **(1 - 2.04 µl/min)**; induces higher voltage.

Multiplexing



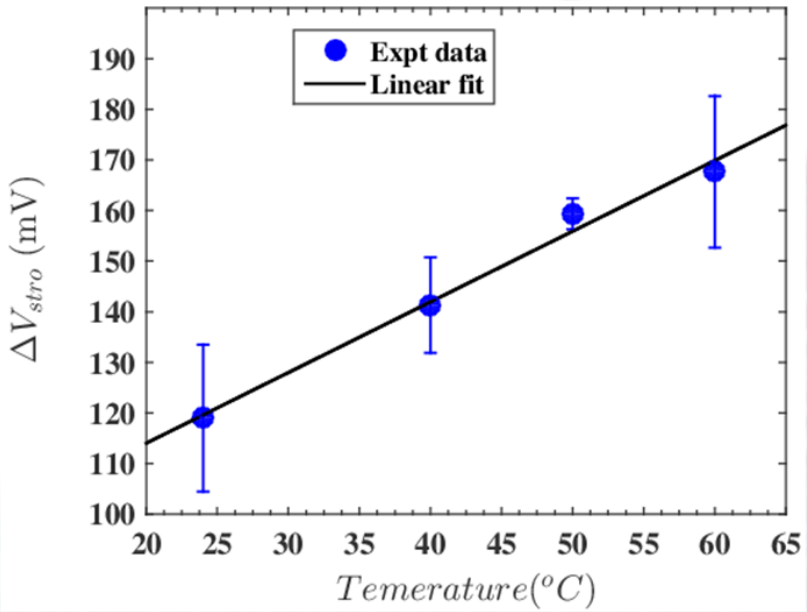


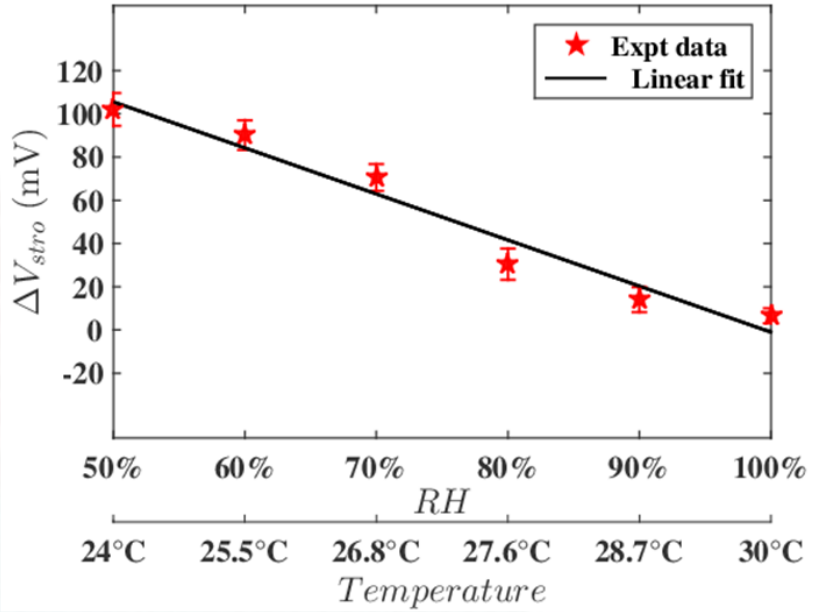




- **Multiplexing** for improving the **output power**.
- Maximum potential is **2.1 V** for **20 channels** connected in series connection.
- Optimum **output power** is seen against **10MΩ** for **single channel** whereas 20MΩ , 40MΩ and 80MΩ for channel combination 5, 10, and 20 respectively.

Environmental Impact





- Maximum induced voltage of **~ 180 mV** at 60°C.
- Increase in **temperature** increases the **evaporation rate**, leading to higher induced potential.
- Increase in **humidity** reduces the **evaporation rate** which further decreases the induced potential.
- The device can be very effective at **hot and dry locations**.

Summary and Outlook

- Simple ‘paper-and-pencil’ based energy generation system for empowering portable sensors
- Green energy source
- Energy generation without requiring any input power
- Device can perform consistently for more than 12 days
- Performance can be enhanced with massive parallelization
- Augmented power output by exploiting roughness-hydrophobicity coupling, fluid rheology etc.

What Next?

- Integration with point-of-care diagnostic devices or other smart sensors.
- Commercialization.

Thank You