Electric, electronic and digital functions in cellulose, paper and plants

Laboratory of Organic Electronics @ LiU
Magnus Berggren

LINKÖPINGS UNIVERSITET

Laboratory of Organic Electronics

RISE acreo

- Laboratory Director – Magnus Berggren
- Organic Bioelectronics – Daniel Simon
- Organic Energy Material – Xavier Crispin
- Printed Electronics – Isak Engquist
- Modelling and Theory – Igor Zozoulenko
- Organic Nanocrystals – Eric Glowacki
- Organic Nanoelectronics – Simone Fabiano
- Organic Photonics – Magnus Jonsson
- Electronic Plants – Eleni Stavrinidou

- Printed Electronics – Göran Gustafsson
- Printed Electronics Arena – Tommy Höglund

Linköping University
Campus Norrköping, Sweden

Printed Electronics Arena, LiU, Campus Norrköping
Swedish Research Laboratory for Printed Electronics (KAW)

PEA
Printed Electronics Arena

Selected by the European Commission as a mKPL Demonstrator


Printing, patterning, coating and lamination

Smart packages


Ink development

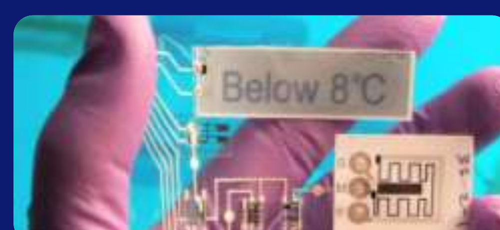

Electrochromic displays


Printing processes


Body area network


Collaborations


Electronic skin patches



Spinning out companies


in vivo electronics

Electronics on Paper - Sensor Labels

Printed Organic Electronics and Si-chips manufactured on labels, skin patches and packages

Conducting polymer

Printing machines for electronic papers (DP Patterning)

Displays printed on paper (ThinFilm)

Electronic sensors on medical packages (Doctors without borders)

Electronic labels (Invisense)

e-Band aids (Absorbest)

Electronic skin patches for diagnostics and monitoring

biocomlab.se

Neurological diseases
(8% of global population)

- Skin Patches
  Printed Organic Electronics on
  Paper and Foils
  Organic Electrochemical Transistors

  - Organic Electronic Ion Pump
    Neurotransmitters
    Chemical circuits

    - Body Area Network
      Capacitive Coupling
      13.56 MHz

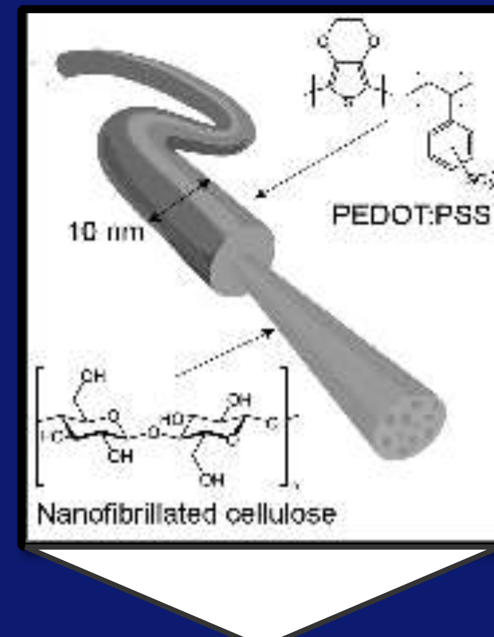
Power Papers

Our society is lacking green and cost-effective storage of electrical energy.
Therefore, production of electricity must at all time match the demand, which gives
poor utilization of capacity.
Since 2015,
electricity from renewable sources is cheaper than from fossil fuels.
Green, large-scale and cost-effective storage of electricity is a prerequisite for the transition to a society free from fossil energy

Power Papers - Supercapacitors and batteries from nano-structured/fibrillar cellulose

Electronic plastics

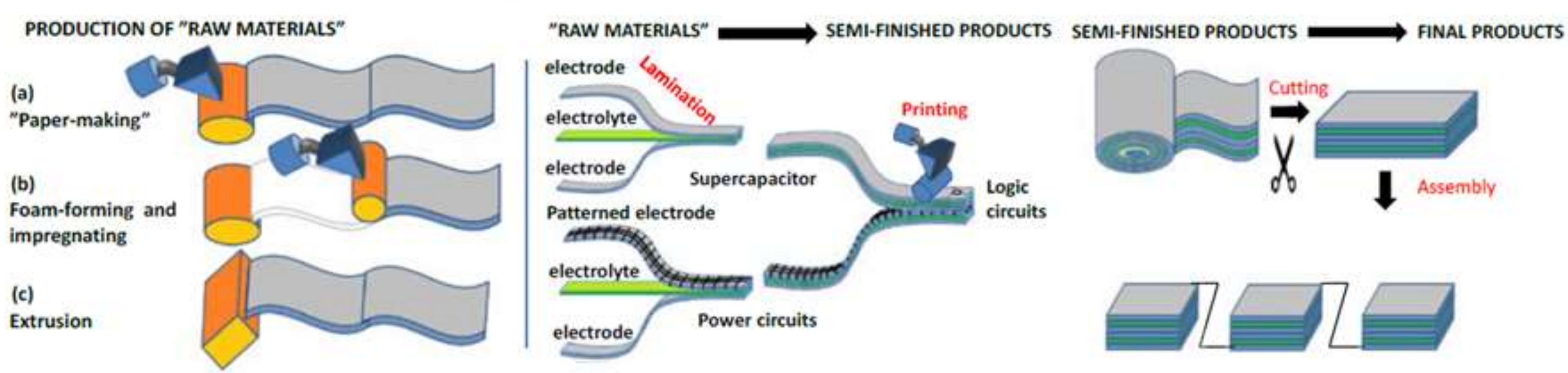
From the forest



An organic mixed ion–electron conductor for power electronics
Abdellah Malti, Jesper Edberg, Hjalmar Granberg, Zia Ullah Khan, Jens W Andreasen, Xianjie Liu, Dan Zhao, Hao Zhang, Yulong Yao, Joseph W Brill, Isak Engquist, Mats Fahlman, Lars Wågberg, Xavier Crispin, Magnus Berggren, Advanced science, vol. 3, (2) 2016

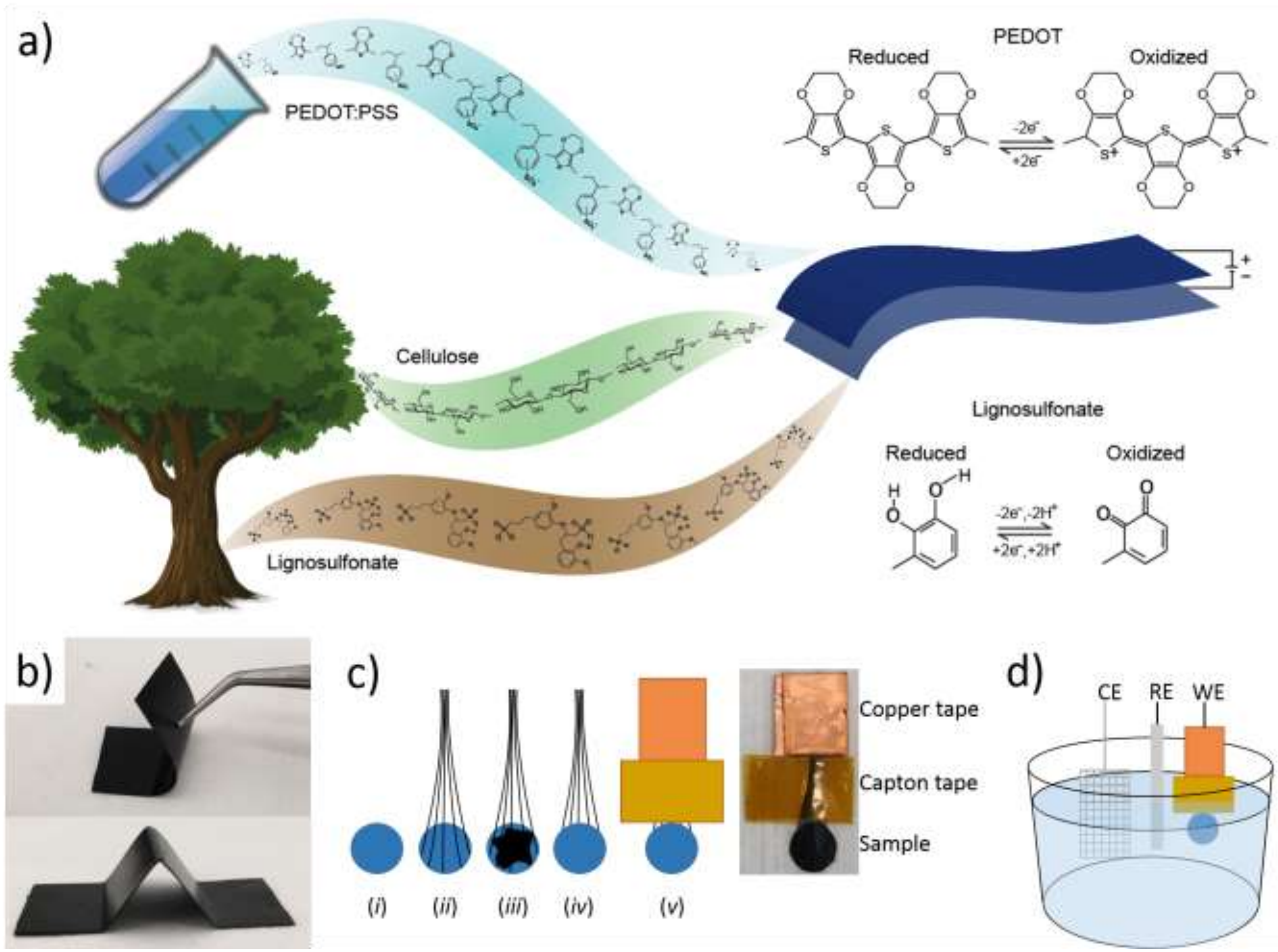
Power Papers

Specifications → Material formulations → Production → Test and Prototypes

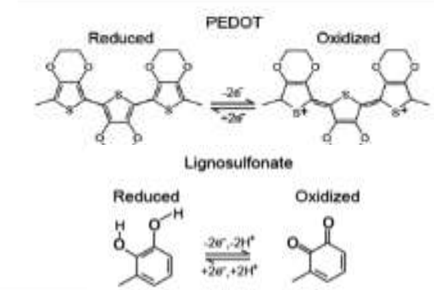


Power Papers

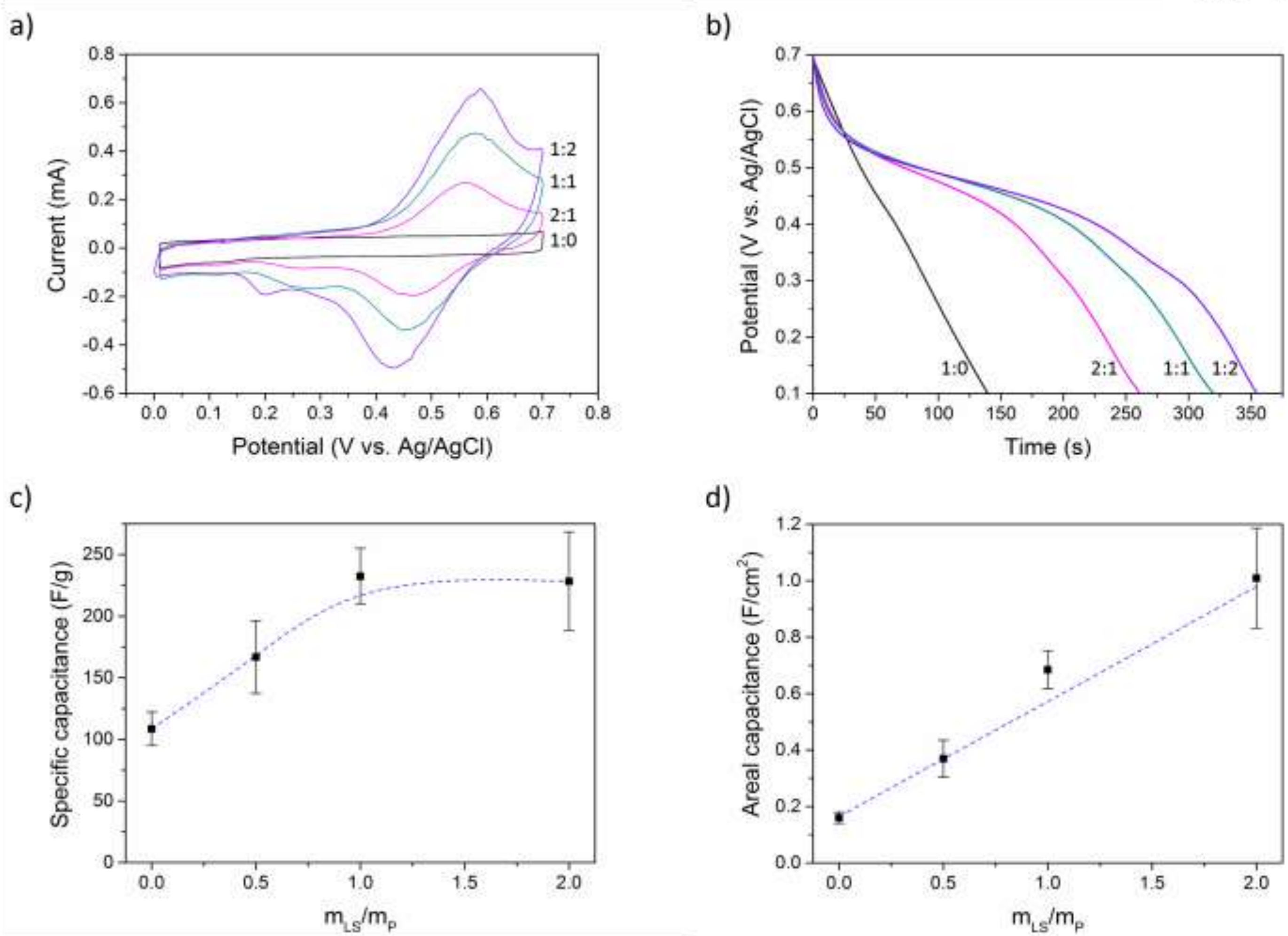
Boosting the capacitance with Lignosulfonates



Recent progress



Boosting the capacitance with Lignosulfonates



Boosting the Capacity of All-Organic Paper Supercapacitors Using Wood Derivatives
J Edberg, O Inganäs, I Engquist, M Berggren - Journal of Materials Chemistry A, 2017

Power Papers - Large scale storage of electricity

LIGNA ENERGY

Disruptive energy storage technology from the forest

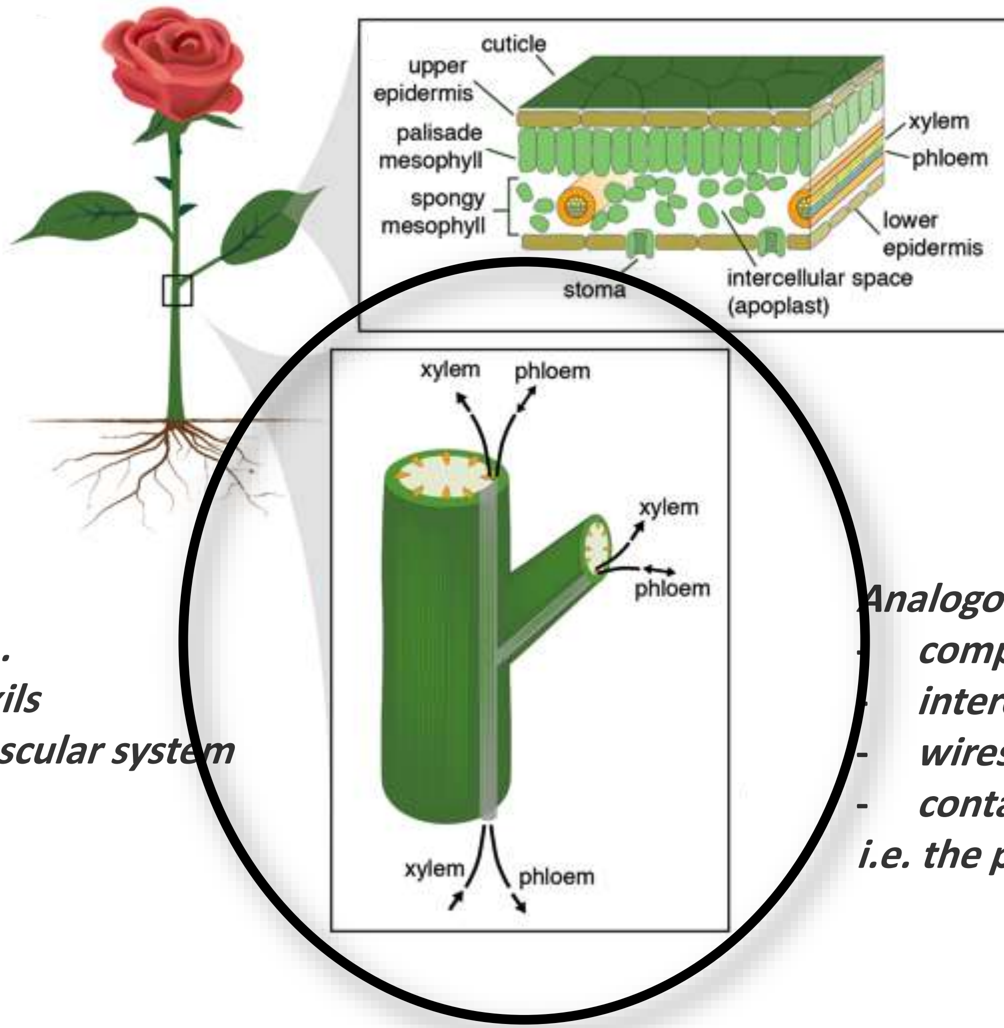
Plants

e.g. Rosa floribunda

Science Advances; DOI: 10.1126/sciadv.1501136

Plants

e.g. Rosa floribunda



A plant is composed of

- *leaves, petals, roots, ..*
- *branches, petioles, axils*
- *phloem and xylem vascular system*
- *stoma and root hairs*

Analogous to

- *components*
- *interconnects*
- *wires*
- *contacts*

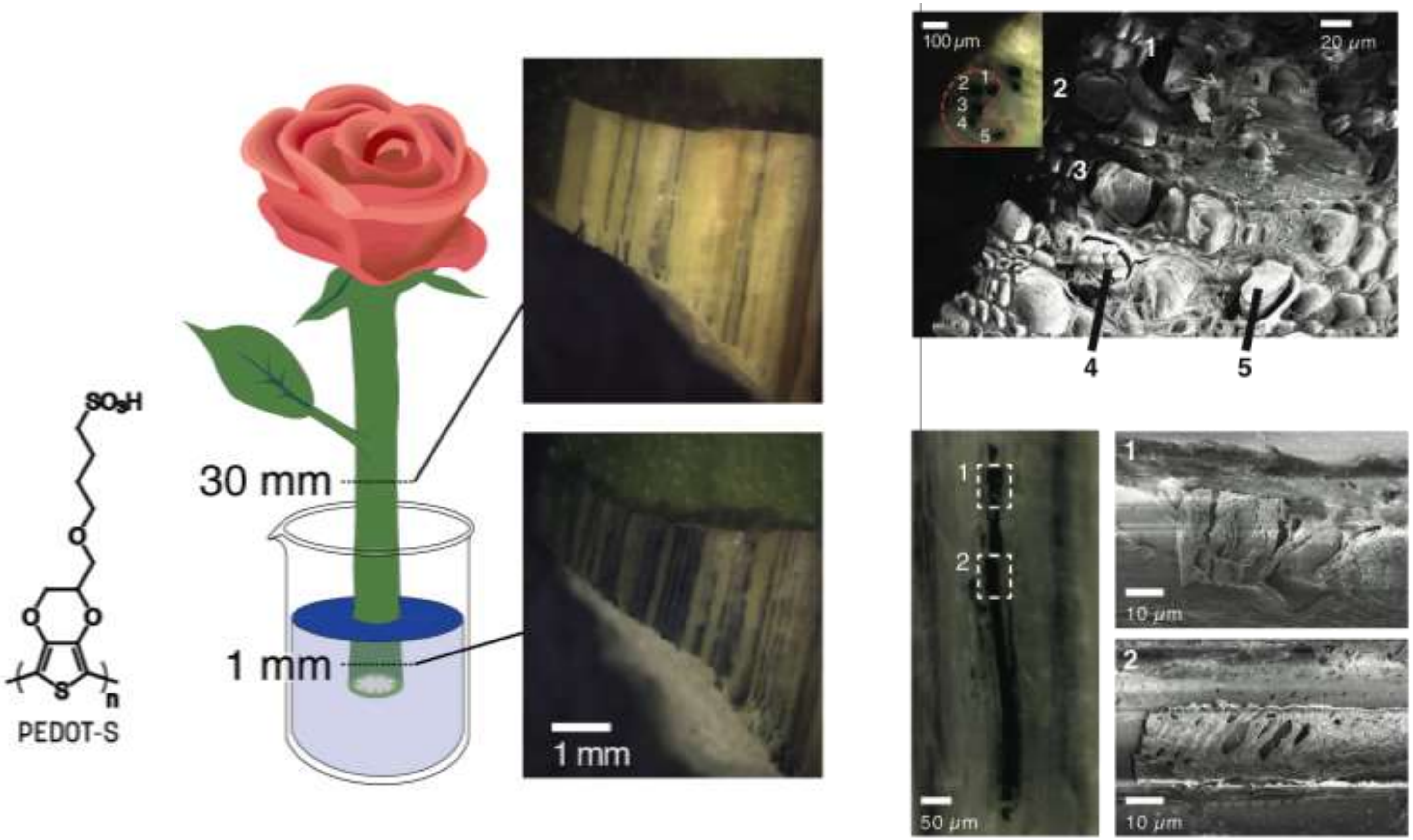
i.e. the parts of circuits

Our vision

Using the chemical signals, tissue constructs, vascular system and overall shape of gymnosperms and angiosperms as the integral part and template to manufacture organic bioelectronics, *in vivo*.

Science Advances; DOI: 10.1126/sciadv.1501136

Conducting wires in the vascular tissue



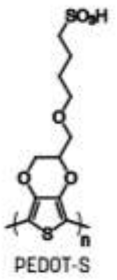
PEDOT-S self organizes in xylem vascular tissue, conductivity 0.13 S/cm

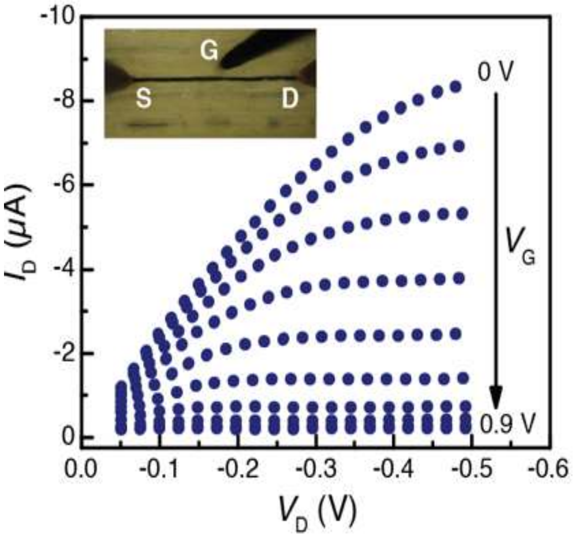
Science Advances; DOI: 10.1126/sciadv.1501136

Xylem circuits

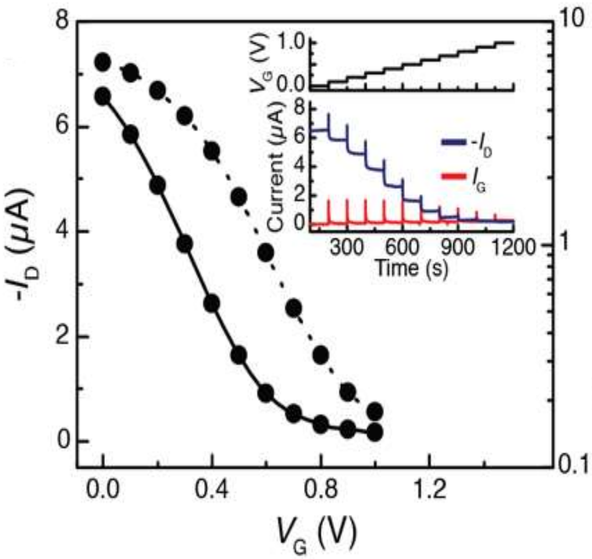
OECTs and logic circuits along the xylem of a *Rosa floribunda*

PEDOT-S self organizes in xylem vascular tissue, conductivity 0.13 S/cm

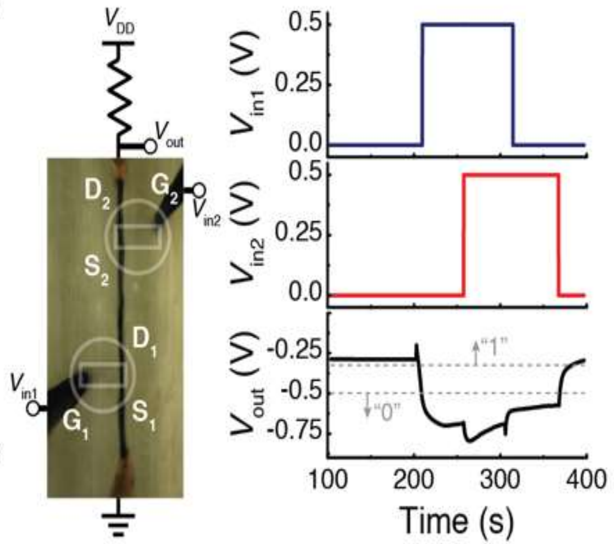




Output characteristics of a xylem-OECT.
The inset shows the xylem wire as source (S) and drain (D) with gate (G) contacted through the plant tissue



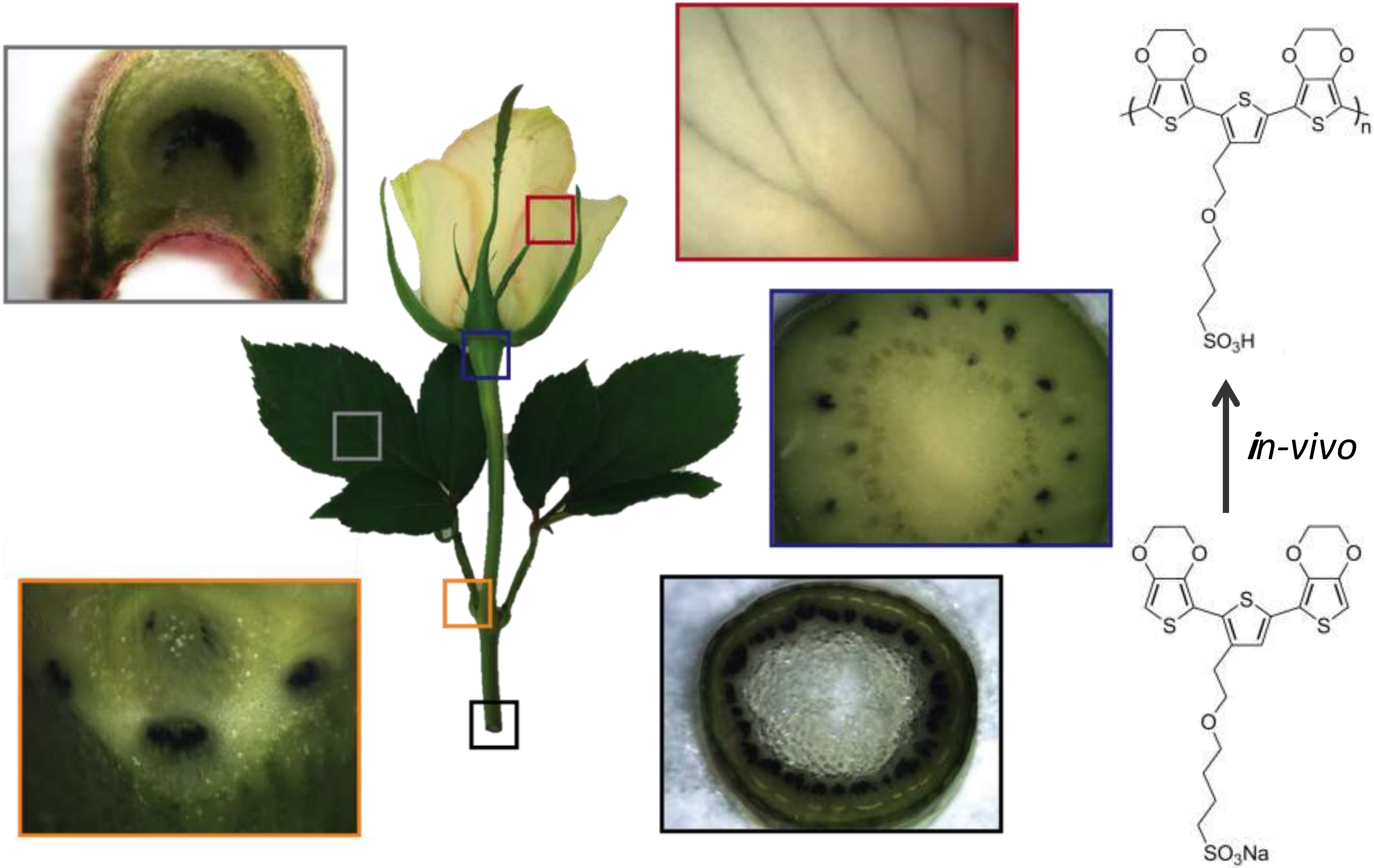
Transfer curve of a xylem-OECT
V_D = -0.3 V



Logical NOR gate constructed along a single xylem wire

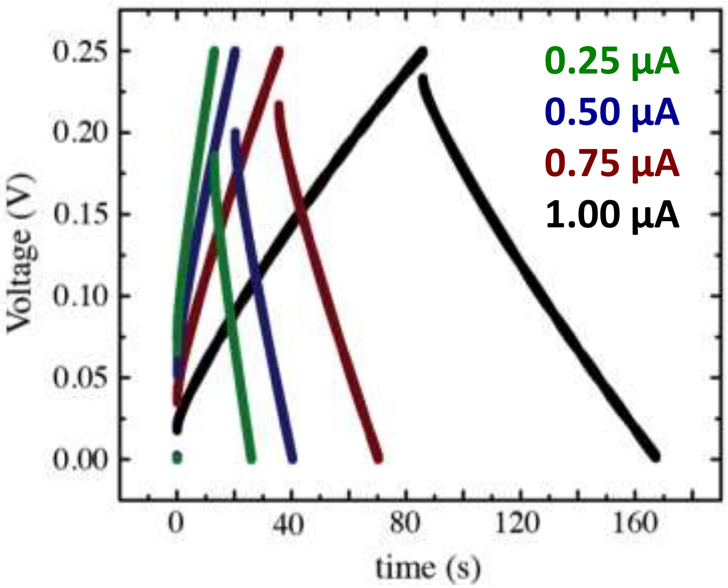
Science Advances; DOI: 10.1126/sciadv.1501136

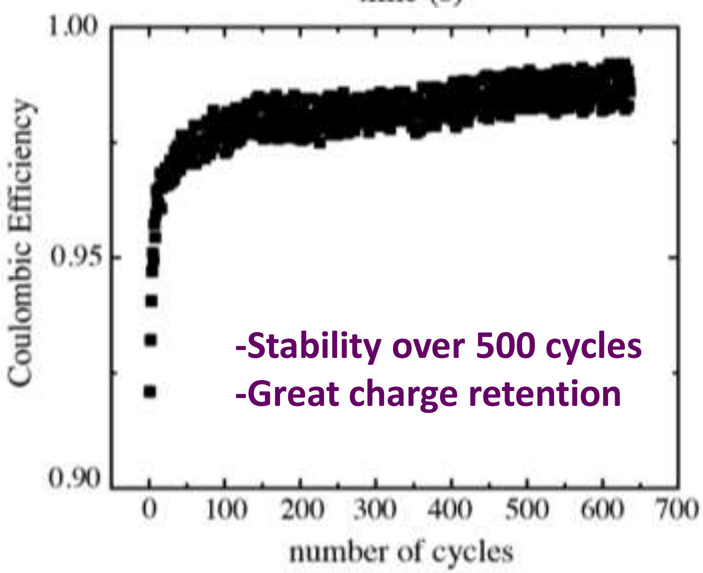
In vivo-polymerization in plants



E. Stavrinidou, R. Gabrielsson et al., PNAS doi/10.1073/pnas.1616456114

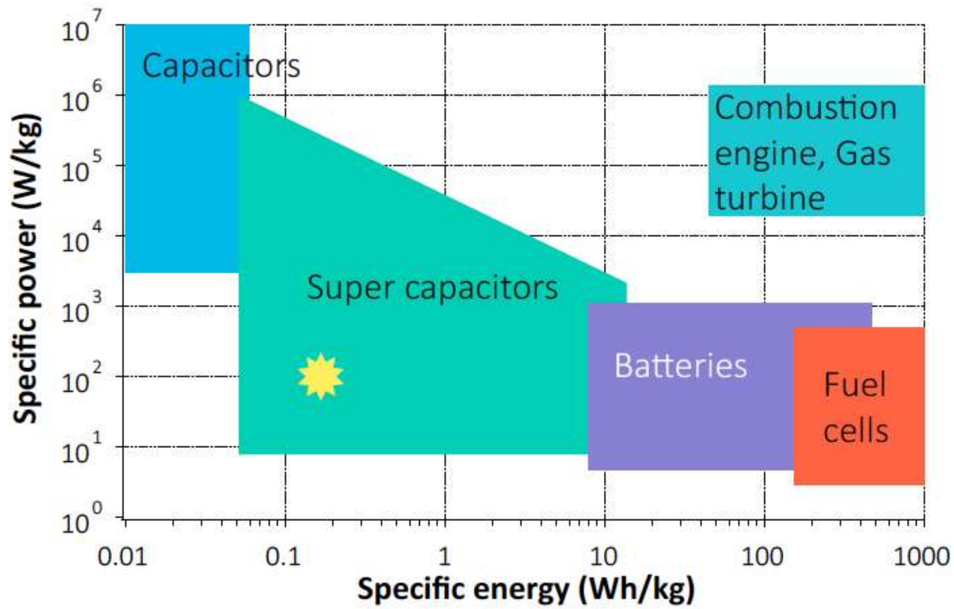
Rose Supercapacitor





-Stability over 500 cycles
-Great charge retention

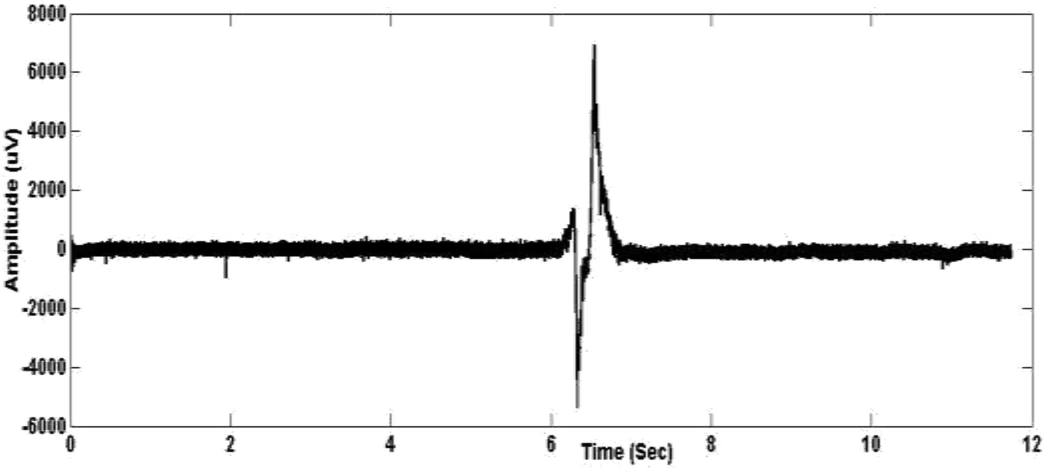
Max results:
1.7 cm xylem wire, Q=65µC , C=0.25mF @ 13 S/cm



E. Stavrinidou, R. Gabrielsson et al., PNAS doi/10.1073/pnas.1616456114

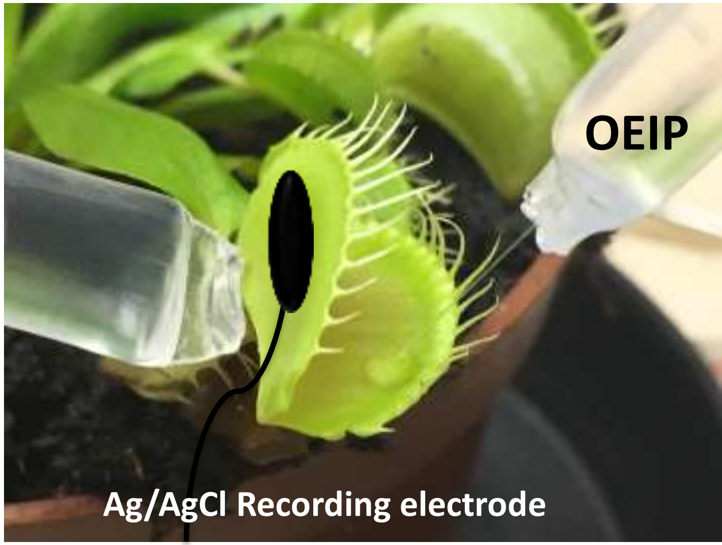
Unraveling electrical signaling in plants

- Fast and slow electrical signals in plants
- Defense mechanism
- Nastic movements



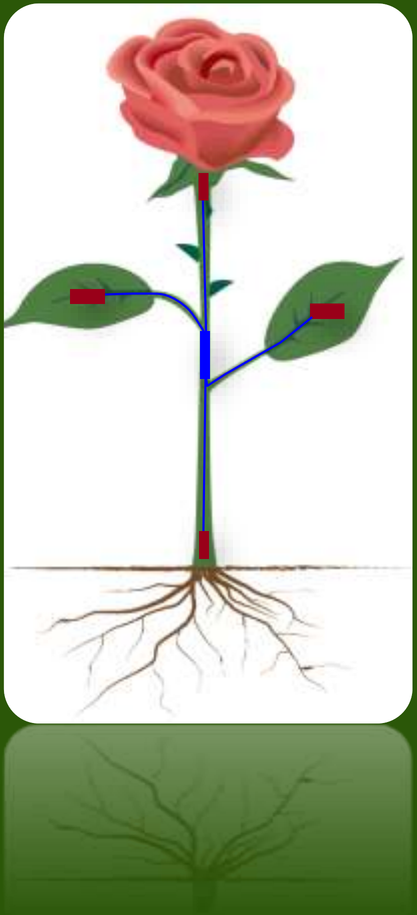
Investigation of Action potentials in plants
in response to different ions and phyto-hormones delivered by OEIP

Venus Flytrap
Carnivorous plant



Y. Mulla et al, Unpublished results

e-Plants (towards plant area networks)



Devices and circuits manufactured inside plants
Plant area networks
Analogue and digital circuits in plants

- phytohormones, physical and chemical parameters
  - phloem (unidirectional) and xylem (up) vascular system
    - growth (gene expression), physiology and defence mechanisms (pathogens

Add an "artificial neuronal system" and circuit technology to improve plant functionality and to derive novel green technology

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@ ITN, Linköping University

G.Gustafsson, D. Nilsson
@Acreo RISE

J. Wikner
@ ISY, Linköping University

George Malliaras
Jonathan Rivnay
Ilke Uguz
@ EMSE, France

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