Nanotechnology for Sustainable Food: Opportunities and Challenges

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Center for the Environmental Implications of NanoTechnology (CEINT)

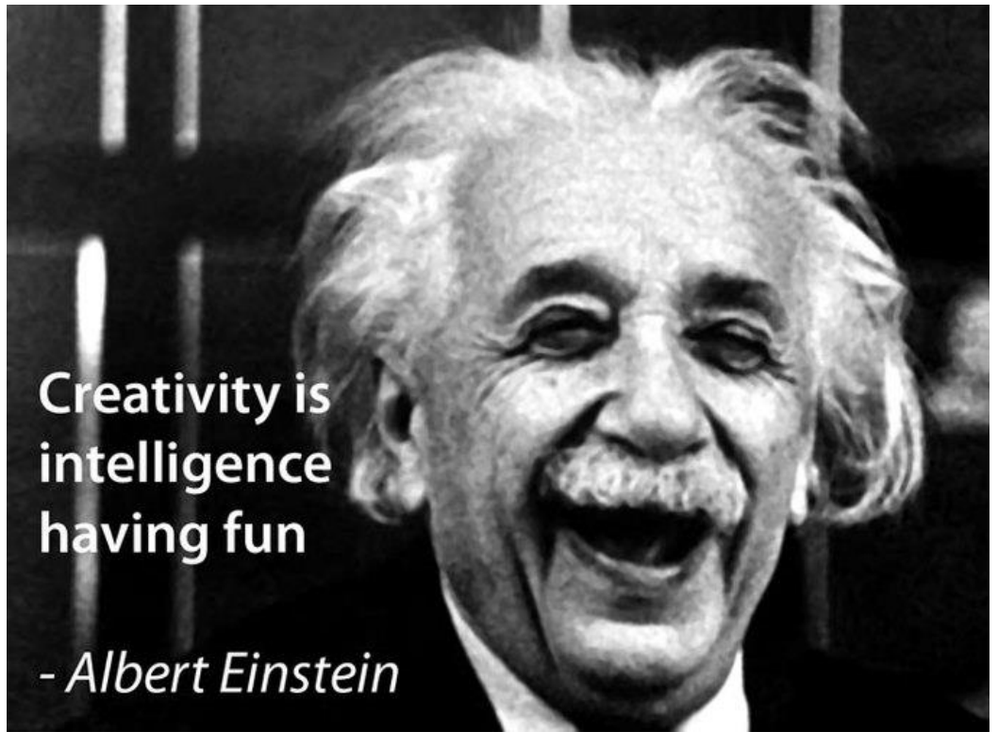
NSF NanoScience Grantees Meeting, 2016




Acknowledgements

CBET-1541807
EF-1266252

Bill Cooper-Environmental Engineering

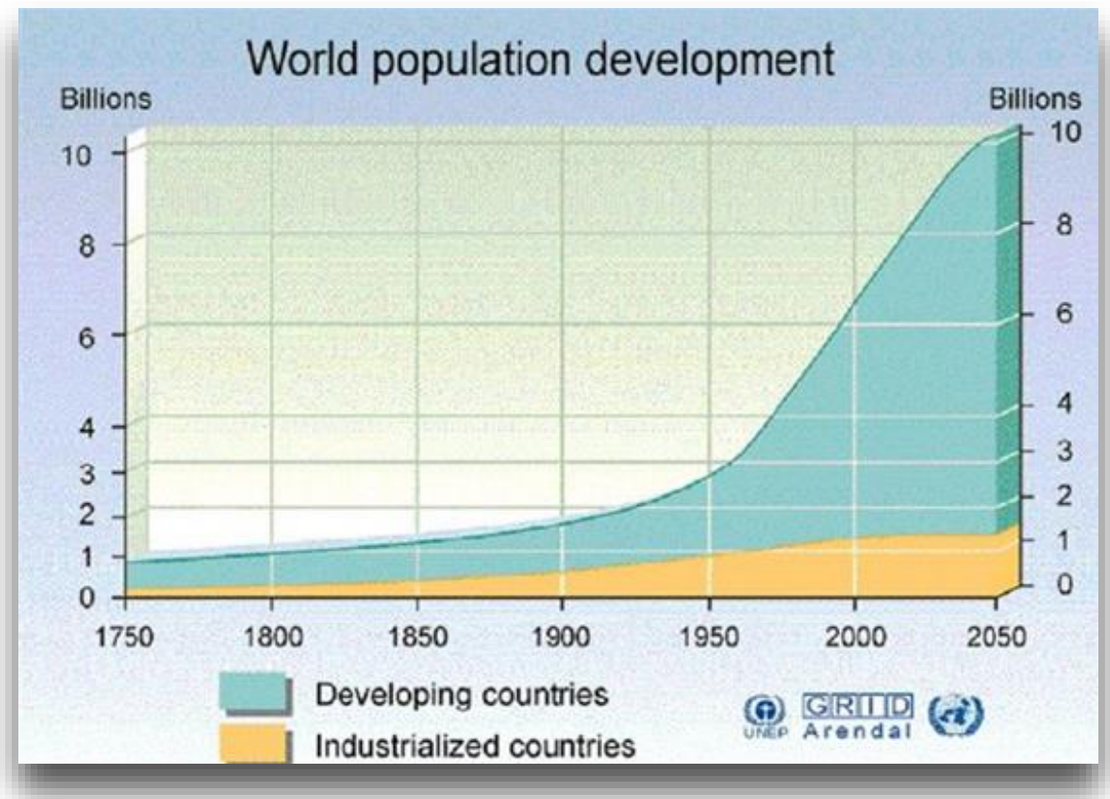


Workshop Organizing Committee:
Mark Wiesner, Christine Hendren, Maxamilion Sarpafour, Barbara Karn, Wunmi Sadik, Meagan Mauter, Josh Viers, Jason White

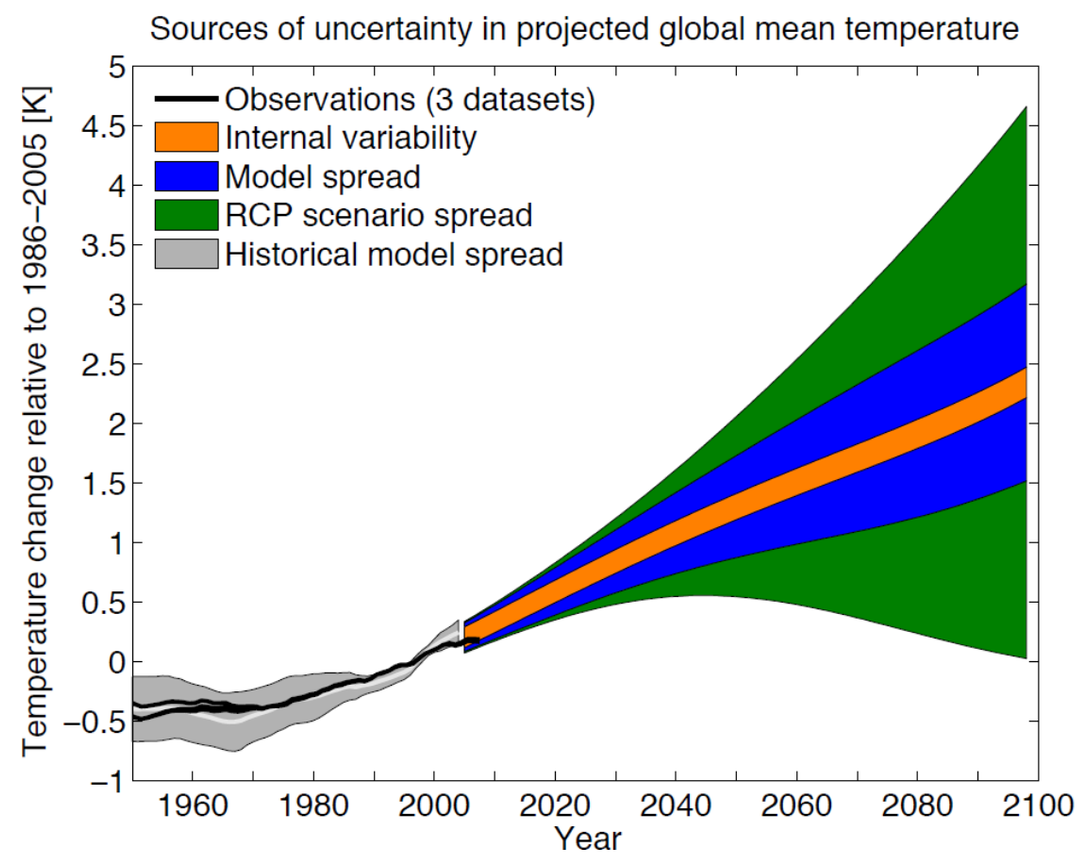
https://faculty.ce.cmu.edu/lowry/files/2016/02/NSF-FEW-WorkshopReport-final-dec-2015.pdf

What will Earth look like in 2050?

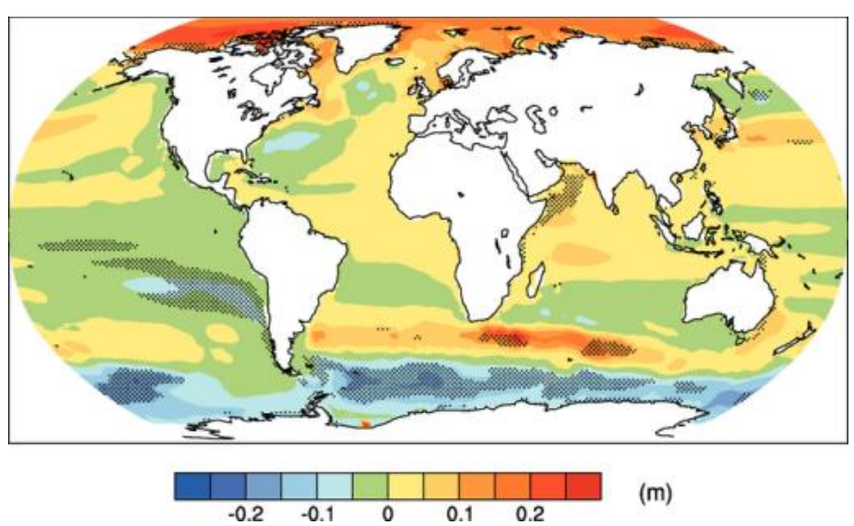
50% more people



Hotter



Kirtman, et al. 2013: Near-term Climate Change: Projections and Predictability. In: Climate Change 2013: The Physical Science Basis. IPCC



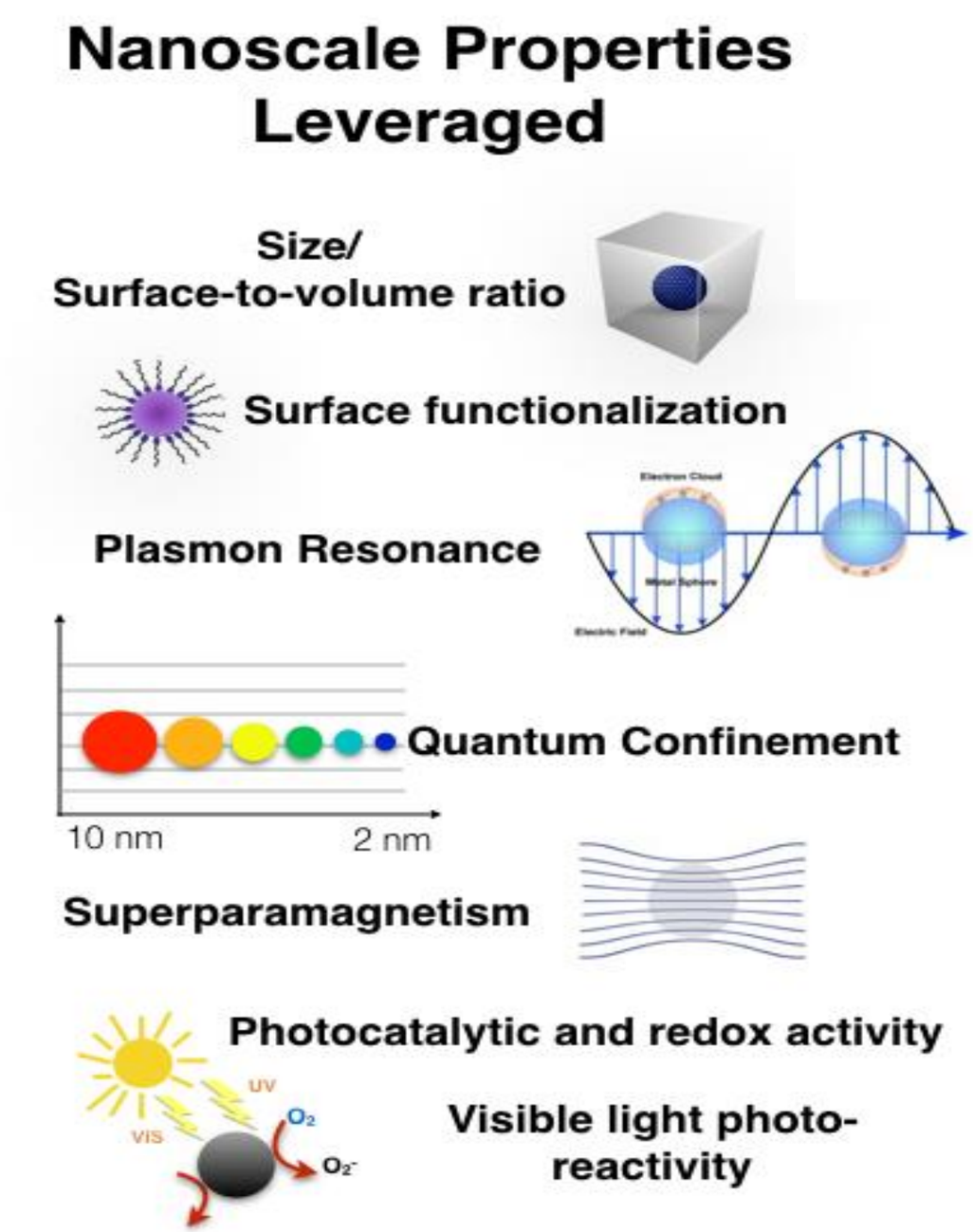
Higher sea level

Climate change and population growth places enormous stresses on our ability to reliably and *sustainably* provide food, energy, and water (FEW) to society

- **Unsustainable food production**
  - 6 % to 30 % of energy use is consumed in the agro-food chain
  - >20 % of global greenhouse gas emissions
  - >70 % of global water use
  - Inefficient use of agrochemicals:
    90 % of pesticides and 50-70 % of applied nitrogen are lost to run-off
- **Environmental degradation**
- **Soil Degradation**
  - Poor nutritional value of foods
- **Significant food waste and food-borne illness**

Foley et al., *Nature* 2011; Mueller et al., *Nature* 2012; UNESCO WWAP, 2012; UNESCO IHE, 2013

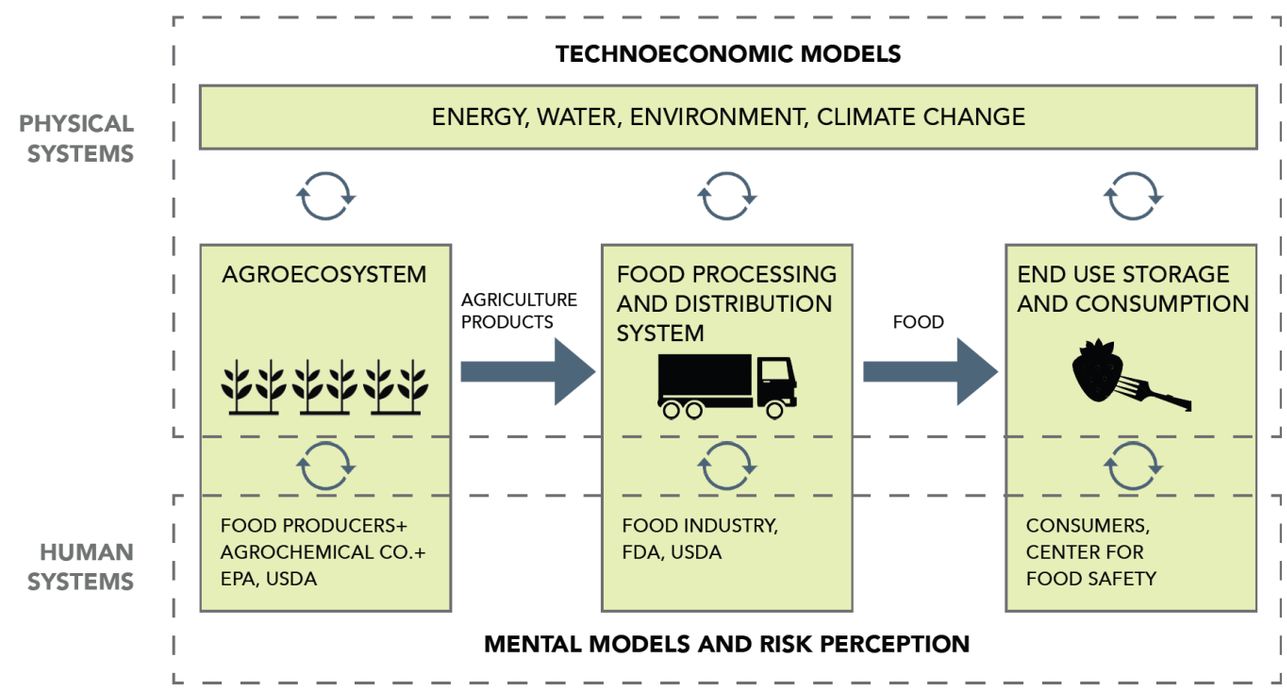
How Can Nanotechnology Improve Sustainability of FEW Systems?



Benefits

- Lower water and energy inputs
- Lower environmental footprint
- High density spatial and temporal data
- Resource recovery
- More nutritional foods
- Decrease food waste

SYSTEM: FOOD VALUE CHAIN FROM FARM TO FORK

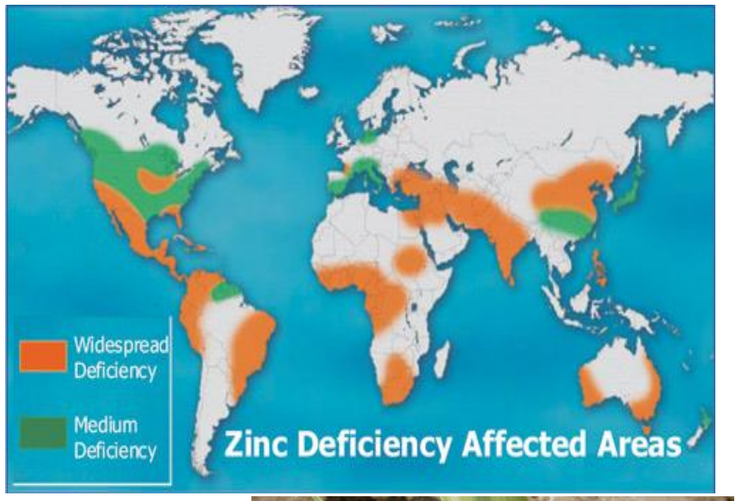


NSF Workshop Report

Role of Nanotechnology in Achieving Sustainability at the Food-Energy-Water-Nexus

https://faculty.ce.cmu.edu/lowry/files/2016/02/NSF-FEW-WorkshopReport-final-dec-2015.pdf

Some key opportunities in agriculture

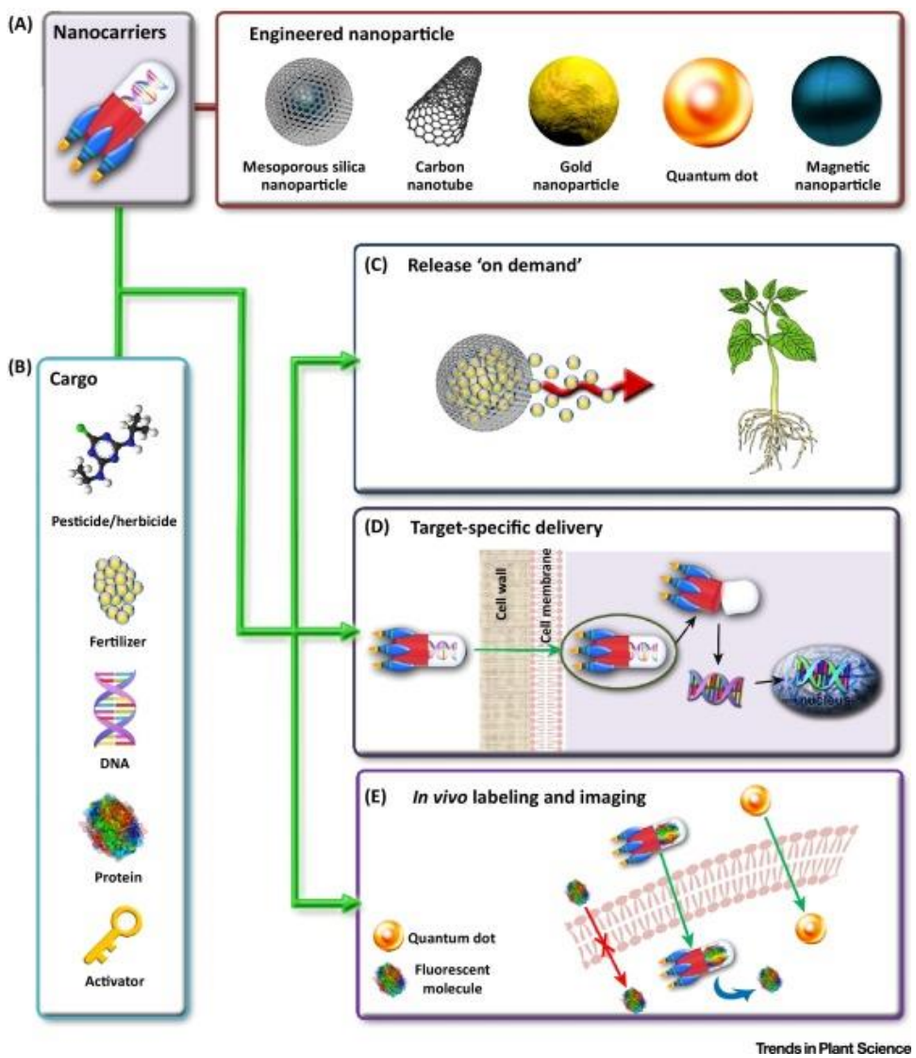


- Improve nutritional value of foods
  - Micronutrient deficient soils
  - Small size of NPs enables uptake by plants
  - Deliver at rates that are optimal for plant growth and increased nutritional value of the produced foods

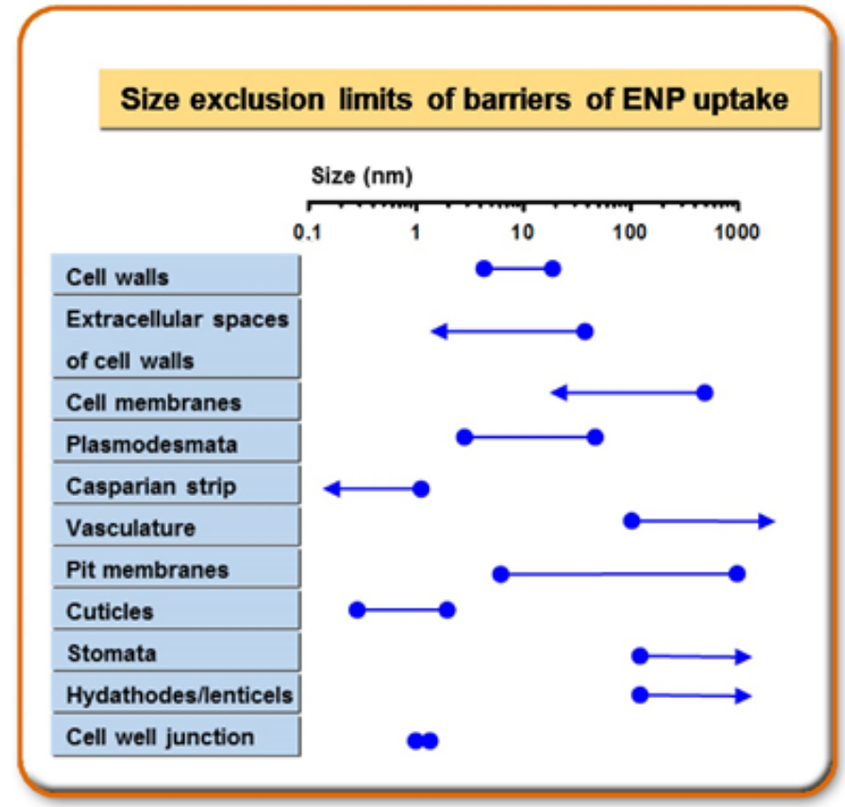
- Increase photosynthesis rates
  - Food and biofuels production
- Increase resistance to crop diseases
  - Fungus, virus

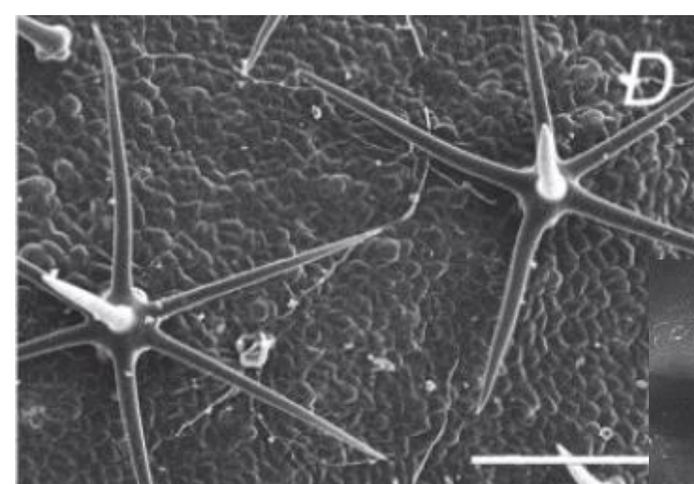
Why Nano?-Agrochemicals

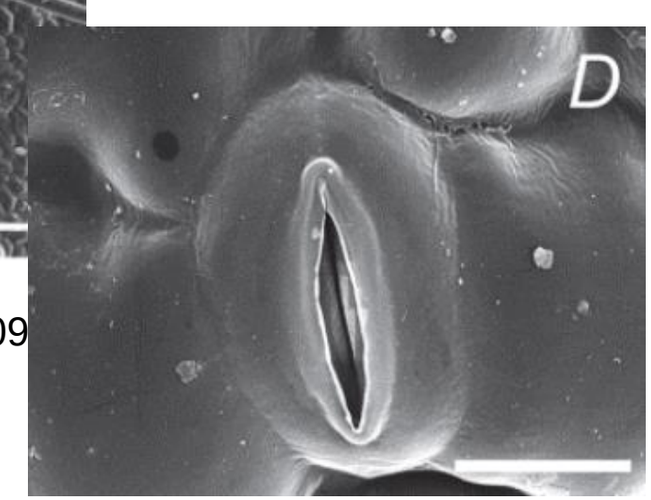
- Key Attributes
  - Solubility/dispersability
  - Controllable surface properties
  - Size



Wang et al., 2016 *Trends in Plant Science* 21(8), Pages 699–712







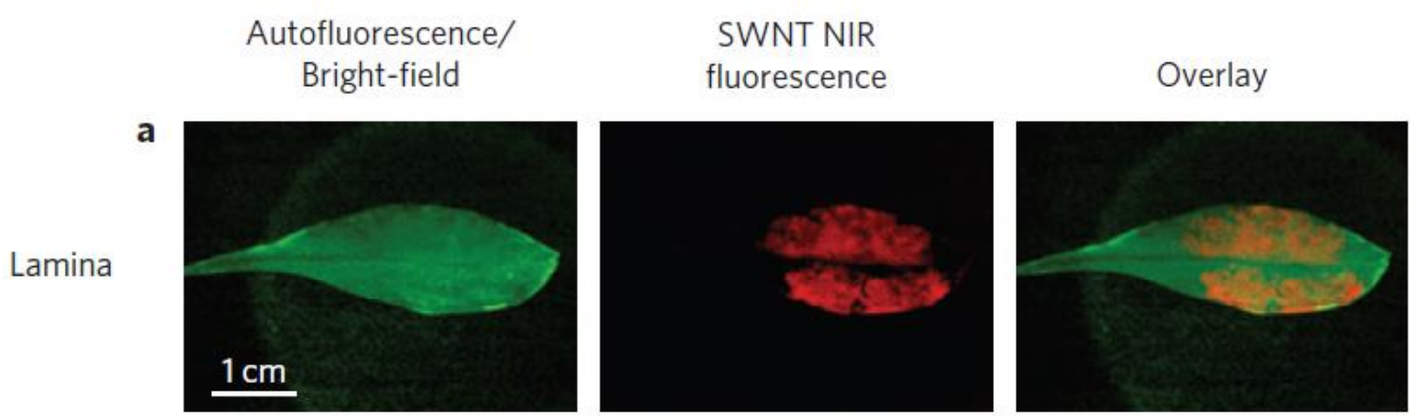
Fu et al., 2013 *Photosynthetica* 5 p. 109

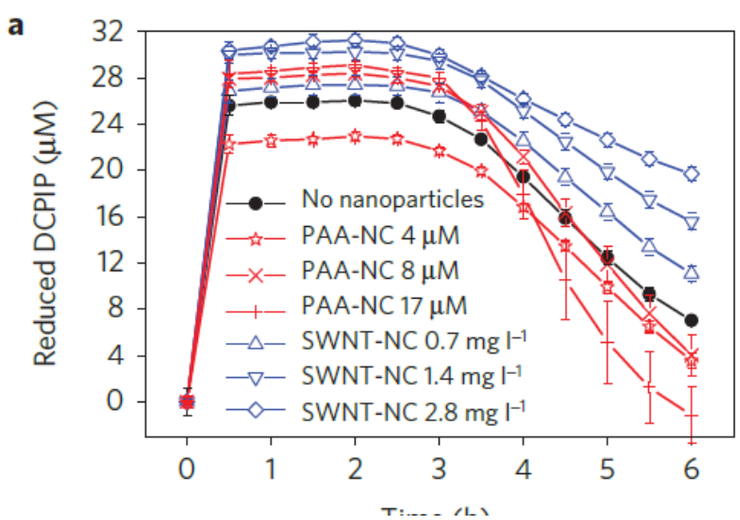
Bionic Plants

ARTICLES
PUBLISHED ONLINE: 16 MARCH 2014 | DOI: 10.1038/NMAT3890
nature materials

Plant nanobionics approach to augment photosynthesis and biochemical sensing

Juan Pablo Giraldo[1], Markita P. Landry[1], Sean M. Faltermeier[1], Thomas P. McNicholas[1], Nicole M. Iverson[1], Ardemis A. Boghossian[1,2], Nigel F. Reuel[1], Andrew J. Hilmer[1], Fatih Sen[1,3], Jacqueline A. Brew[1] and Michael S. Strano[1]*





Giraldo et al., 2014 *Nat Mat*. DOI: 10.1038/NMAT3890

Nanomaterials Increase Resistance to Soil Fungus

Environmental Science Nano

ROYAL SOCIETY OF CHEMISTRY

PAPER

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Cite this: DOI: 10.1039/c6en00146g

The use of metallic oxide nanoparticles to enhance growth of tomatoes and eggplants in disease infested soil or soilless medium

Wade H. Elmer*[a] and Jason C. White[b]

Table 2 Effect of nanoparticles (NP) of Cu, Mn, and Zn oxides on growth of greenhouse-grown eggplant transplants in soil infested with *Verticillium dahliae*. Values are in g (dry weight)

	Non-inoculated	Inoculated with *V. dahliae*	
Treatment[a]	Fresh weight (g)	Fresh weight (g)	Area under the disease progress curve[c]
Control	14.2 ab	8.9 a[b]	114 a
CuO bulked	14.2 ab	10.6 ab	69 b
CuO NP	17.2 b	14.6 b	36 b
$CuSO_4$	14.7 ab	12.6 ab	69 b

- CuO NPs increased growth and fruit yield in fungus infested soil
- CuO NPs did not kill fungus in soil
- CuO NPs boosted plant defense to fungus

CeO_2 NPs increases salt tolerance of Canola

Contents lists available at ScienceDirect

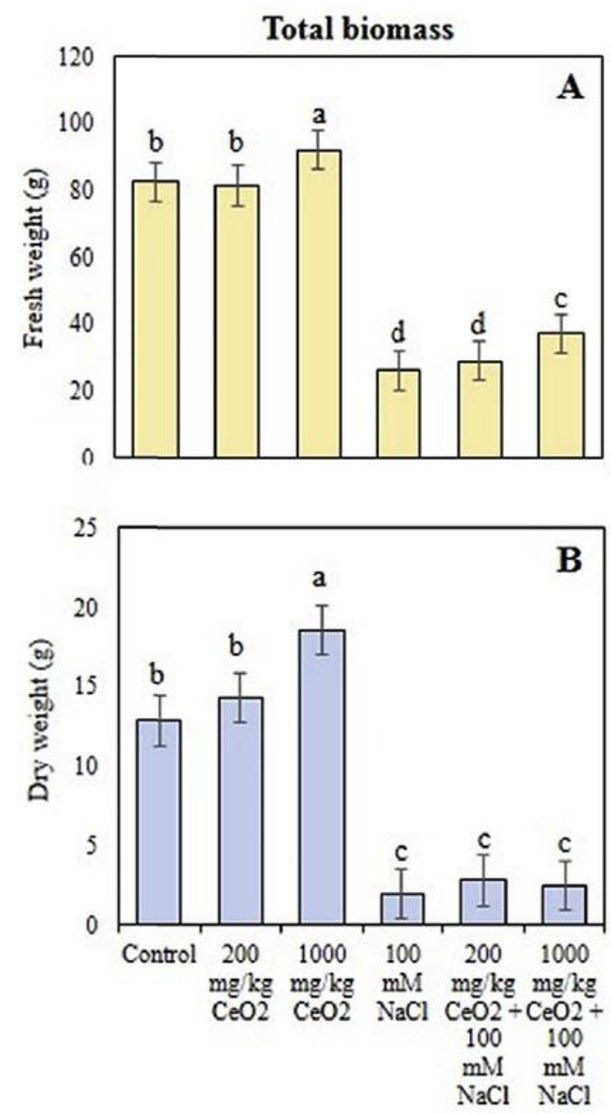
Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

The impact of cerium oxide nanoparticles on the salt stress responses of *Brassica napus* L.☆

Lorenzo Rossi [a], Weilan Zhang [a], Leonardo Lombardini [b], Xingmao Ma [a,*]

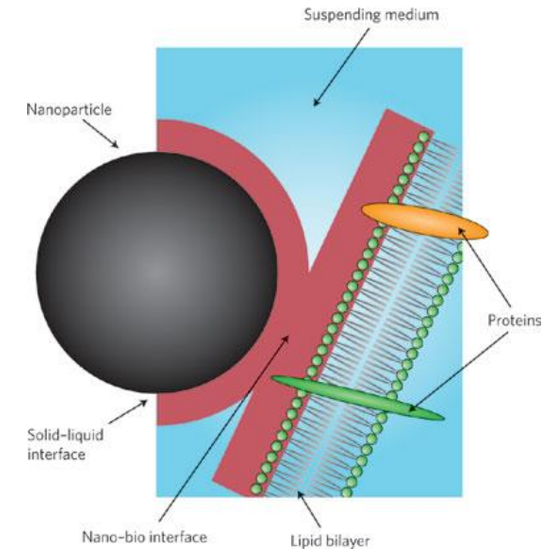
[a] Zachry Department of Civil Engineering, Texas A&M University, TAMU 3136, College Station, TX 77843-3136, USA
[b] Department of Horticultural Sciences, Texas A&M University, TAMU 2133, College Station, TX 77843-2133, USA



Rossi et al., 2016 *Env. Pollut*. 219

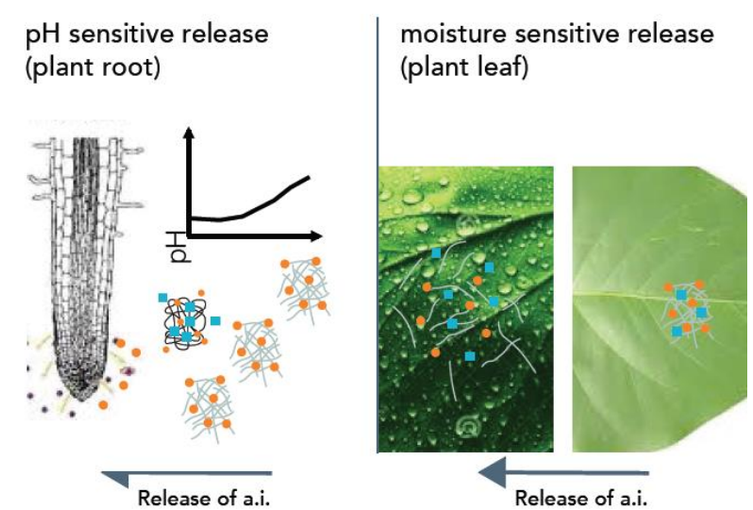
Fundamental Challenges

- Interfacial targeting and selectivity
  - How do we get the NPs where they need to be?
  - Nano-bio interactions



Nel et al., 2009 Nature

- Triggers for release (e.g. pH or light)
  - Need to be able to deliver materials when and where you need them



- Robust for use in complex matrices

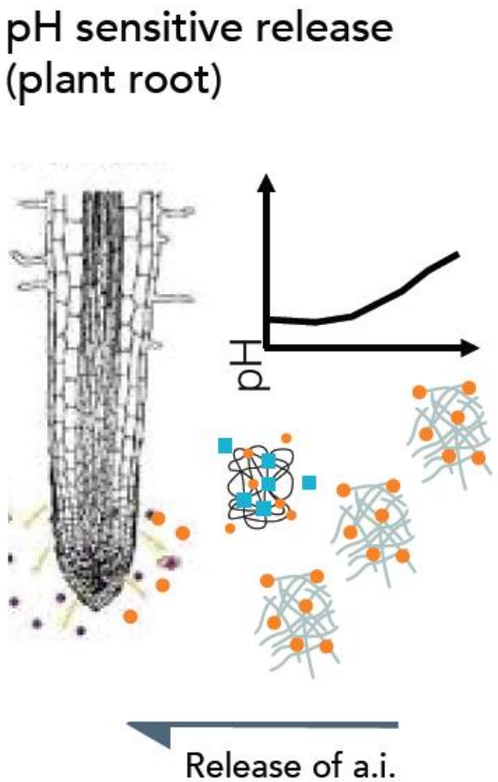
- Need to make the business case
  - Technoeconomic analysis

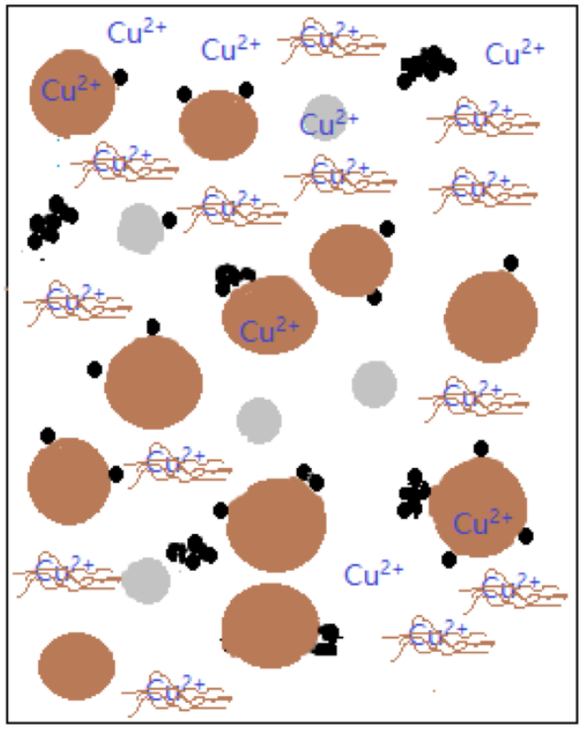
Key Questions

- What factors control uptake of nanoparticles or ions derived from nanoparticles?
  - Solubility
  - Coating type/charge
  - Size

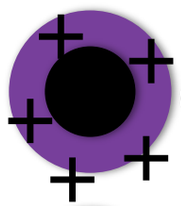
- How do nanoparticles behave in unsaturated soils?
  - Timed release of micronutrients
  - Bioavailability
  - Potential for exposure to nanoparticles

- Will the public accept nanomaterials in food production and their food?

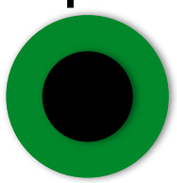




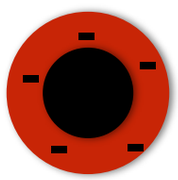
CeO_2 NP Uptake and Translocation



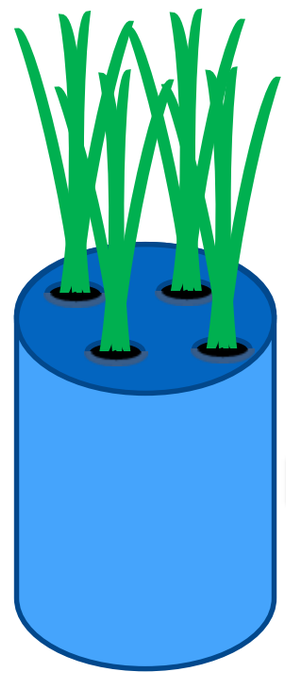
Positively charged, diethylaminoethyl-dextran coated CeO_2



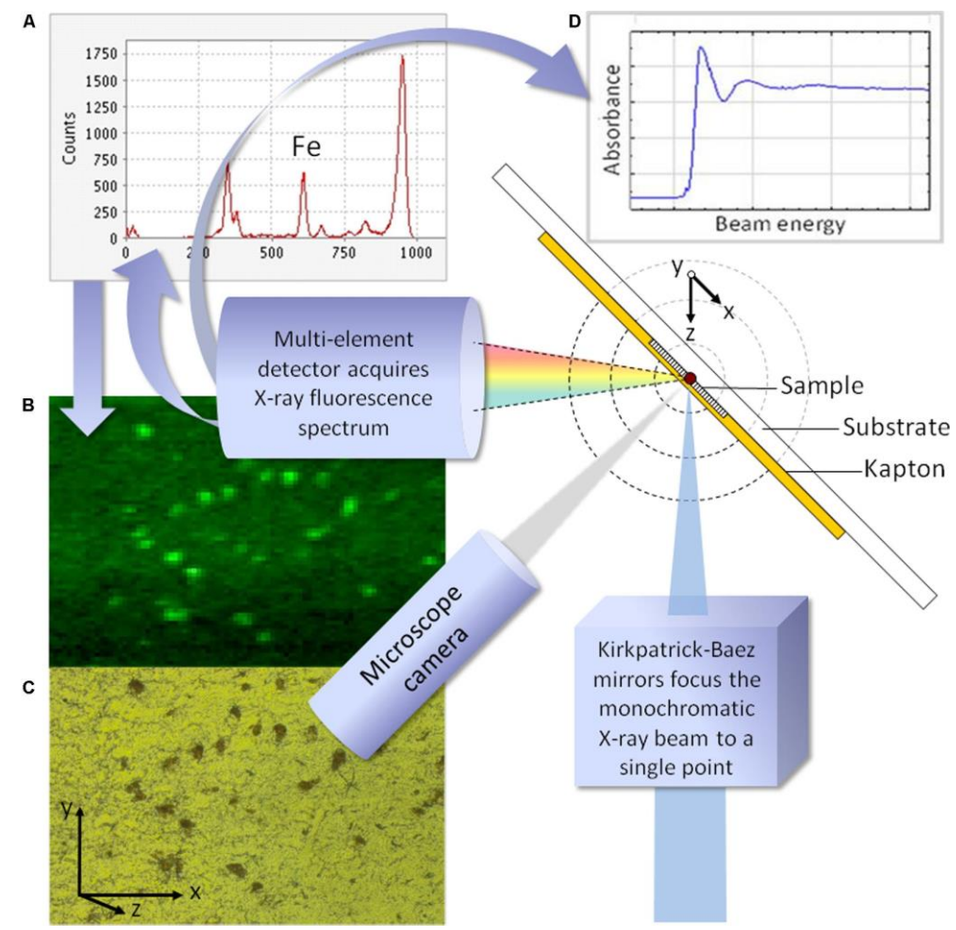
Neutral dextran coated CeO_2



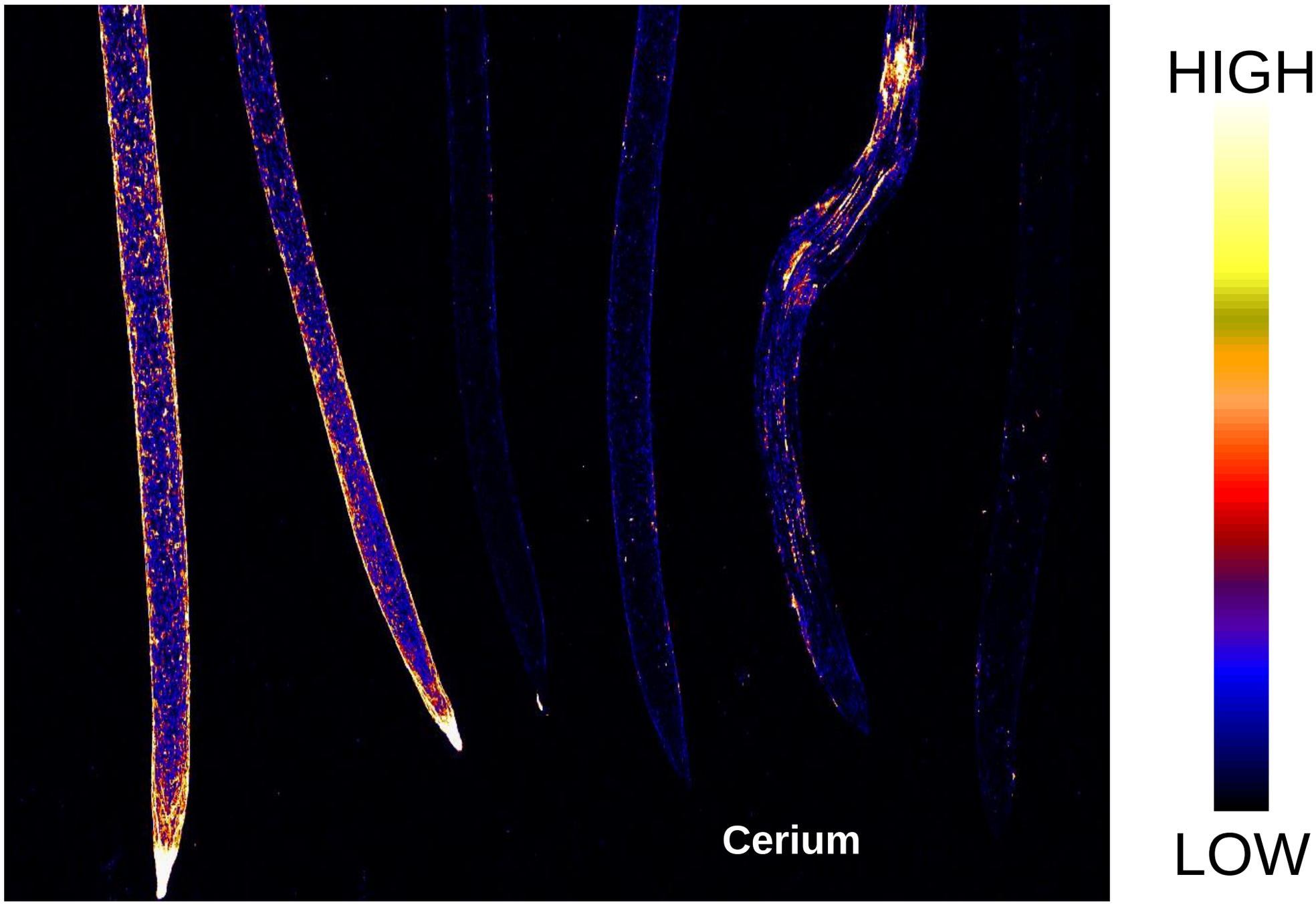
Negatively charged carboxylmethyl-dextran coated CeO_2



Wheat

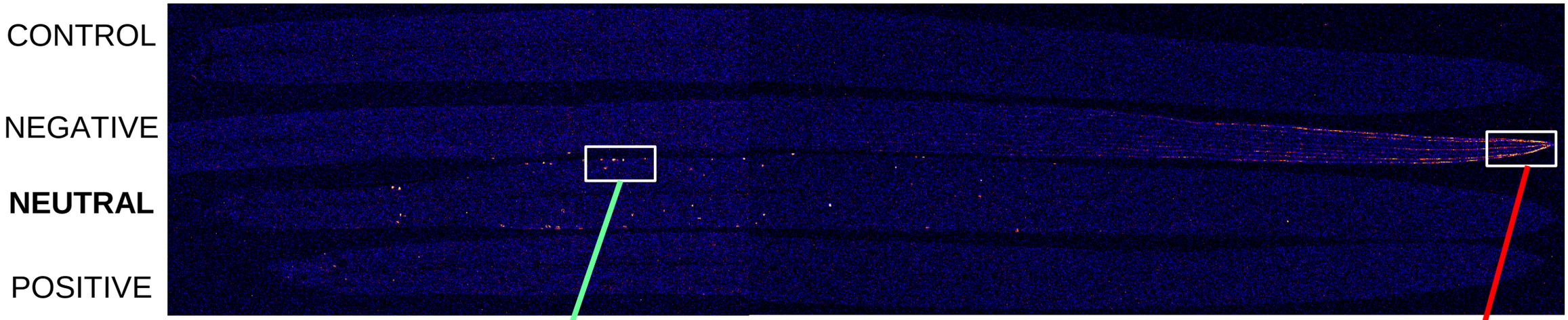


Roots Exposed to CeO_2 NPs for 8 hr



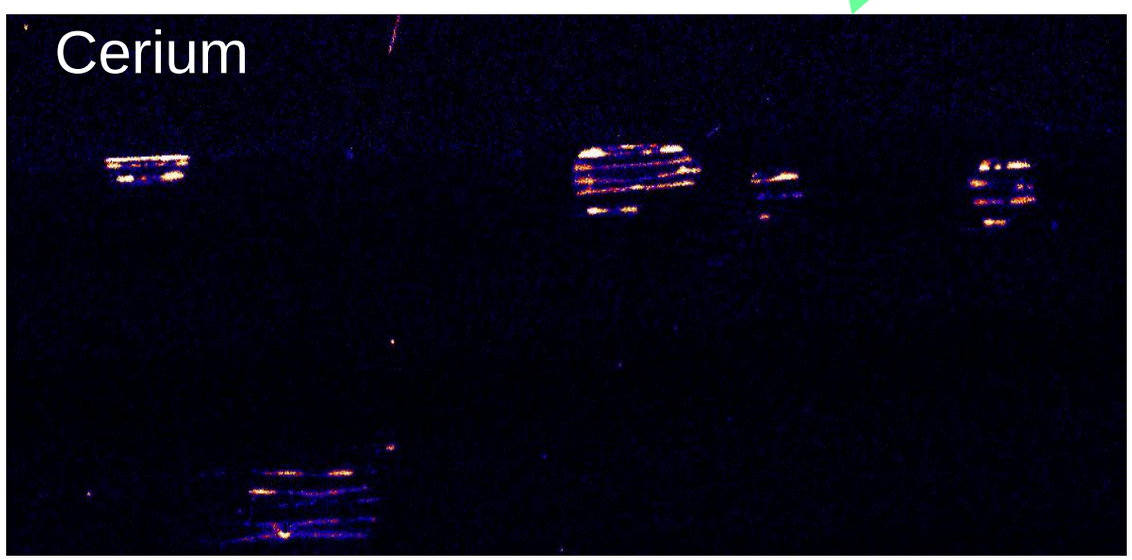
POSITIVE **NEUTRAL** **NEGATIVE**

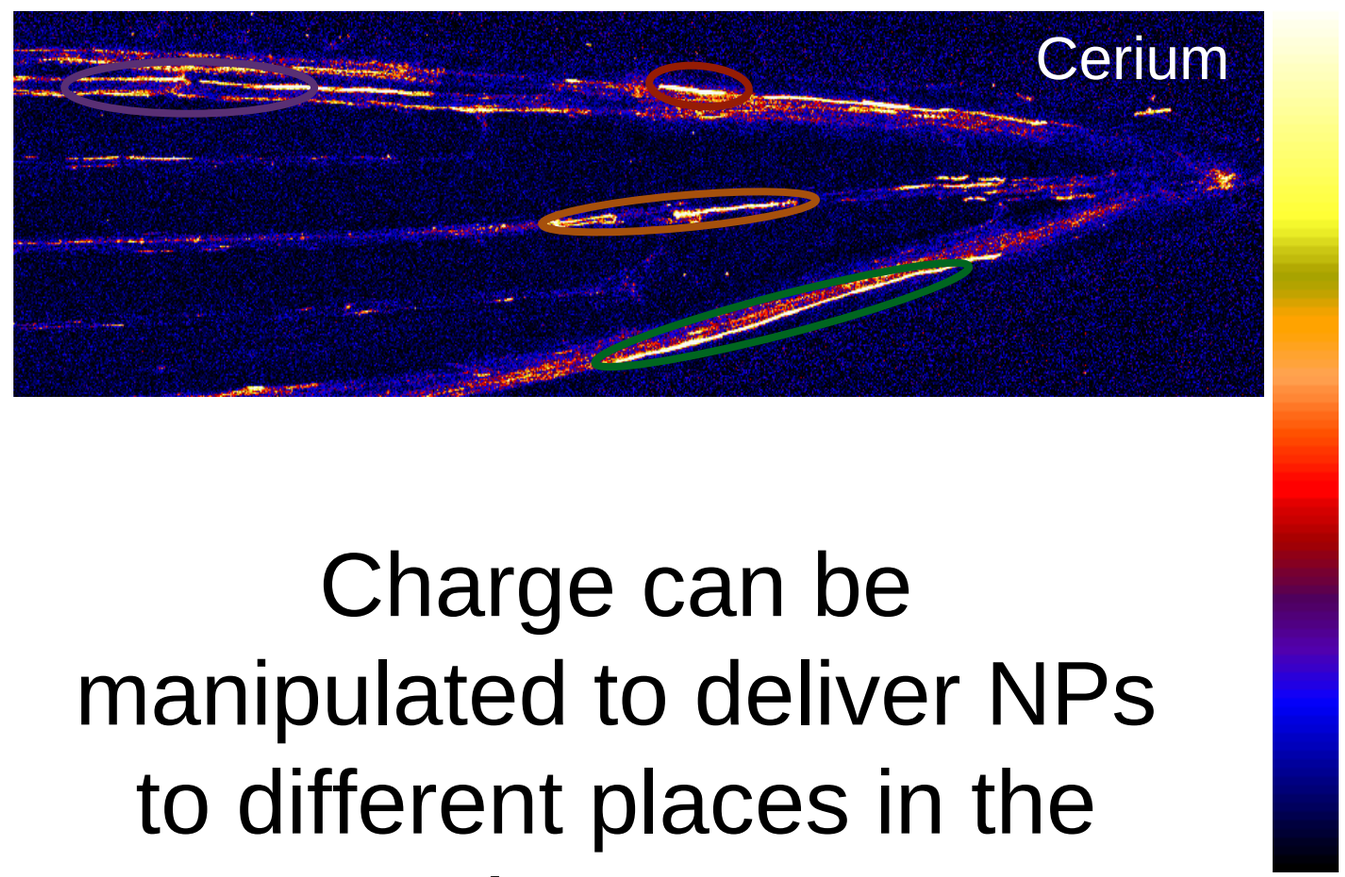
Charge on CeO_2 NPs affects translocation pathways

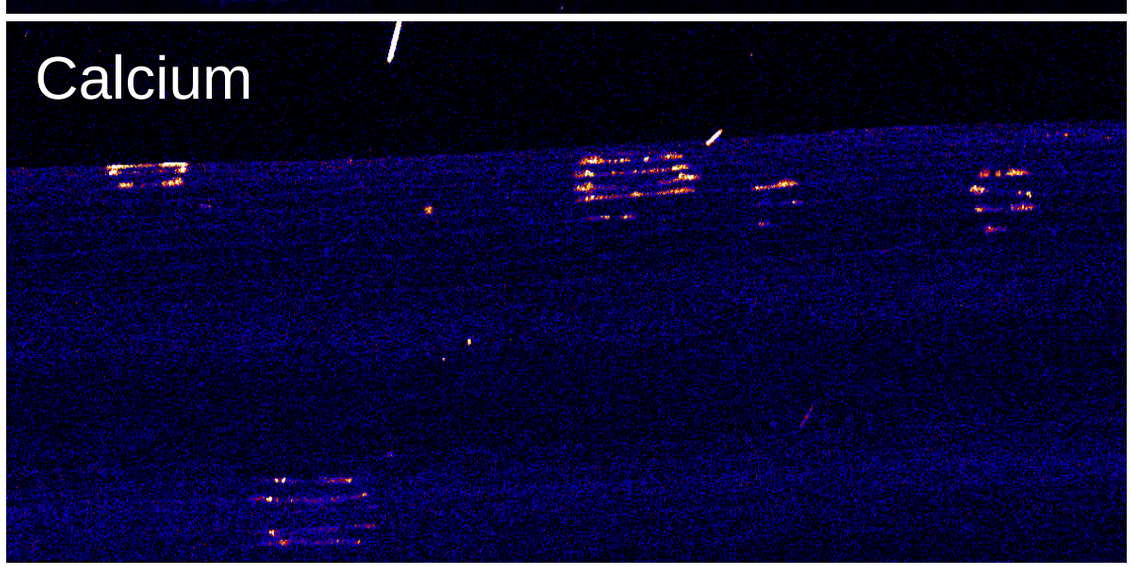


Neutral

Negative

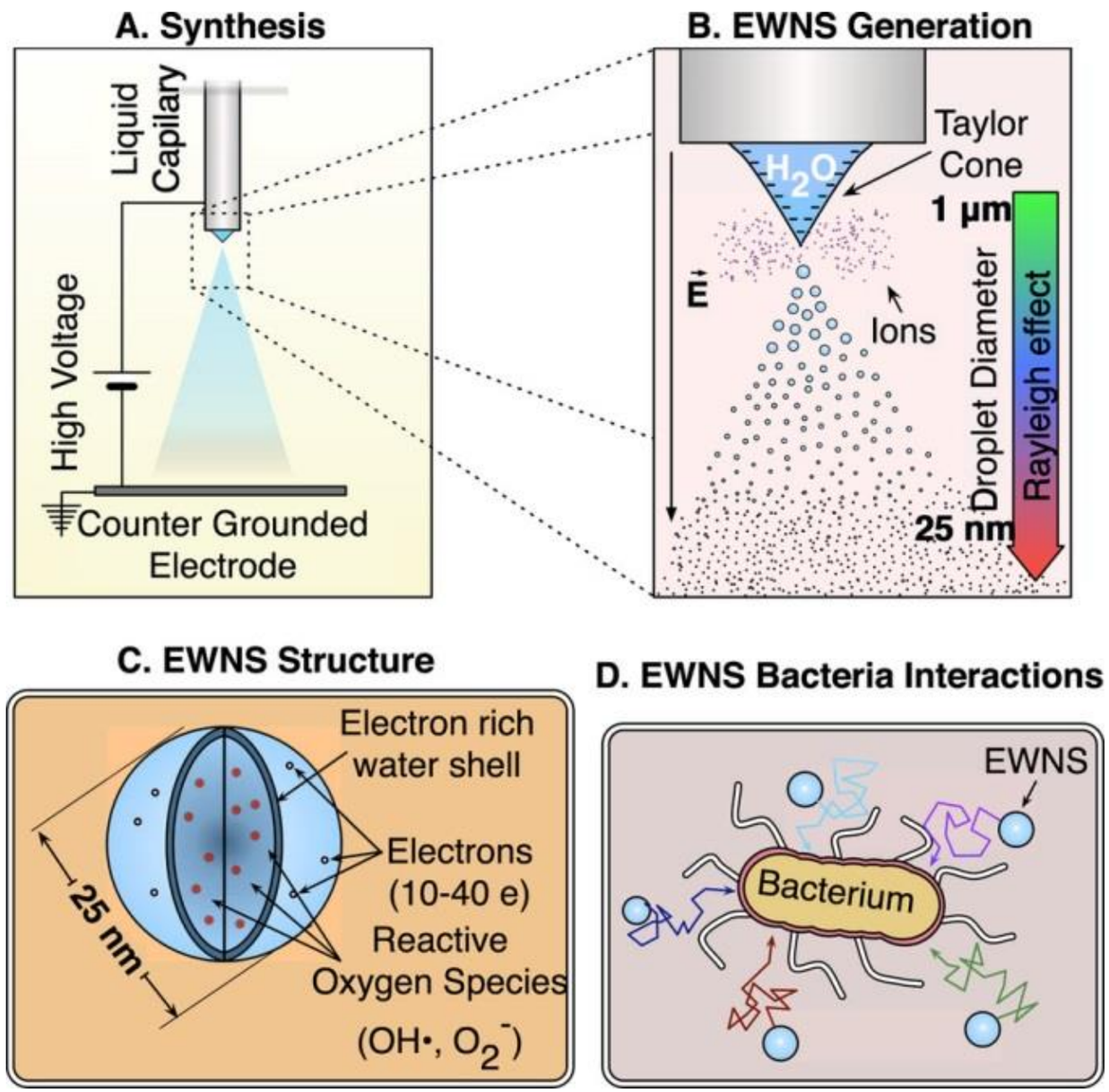






Charge can be manipulated to deliver NPs to different places in the leaves

Why Nano?-Pathogen Control



Pyrgiotakis et al, 2016 Scientific Reports doi:10.1038/srep21073

Pathogen control using ONLY water, i.e. “chemical-free”
ROS lifetime is many hours
Tunable with size

Cross-cutting scientific challenges

- Selectivity and sensitivity
- Biocompatibility
- Durable for use in highly complex soil, water, food or waste matrices

Cross-cutting technoeconomic challenges

- Slow technology diffusion into commerce
- Uncertainty in the cost-to-value ratio of technology innovation
- Life-cycle issues (manufacturing to end of life/recovery)

Cross-cutting social challenges

- Stakeholder involvement
- Safety and public perception (utilizing nanomaterials in water or food systems)
- Communication tools to support regulatory and social acceptance
- Overcoming regulatory challenges

Conclusions

- Many opportunities exist for “nanomaterials” to improve food production and distribution:
  - Sensors, pathogen control, efficient delivery of agrochemicals, resource recovery, animal health
- A great deal of research is needed to:
  - Improve selectivity and robustness
  - Demonstrate ability to function in “real” systems
  - Evaluate benefit-to-risk ratio at a systems level
  - Gain public and regulatory acceptance
- Need to prove the case for nano