The Emerging Field of Plasma Agriculture

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Major Global Challenges

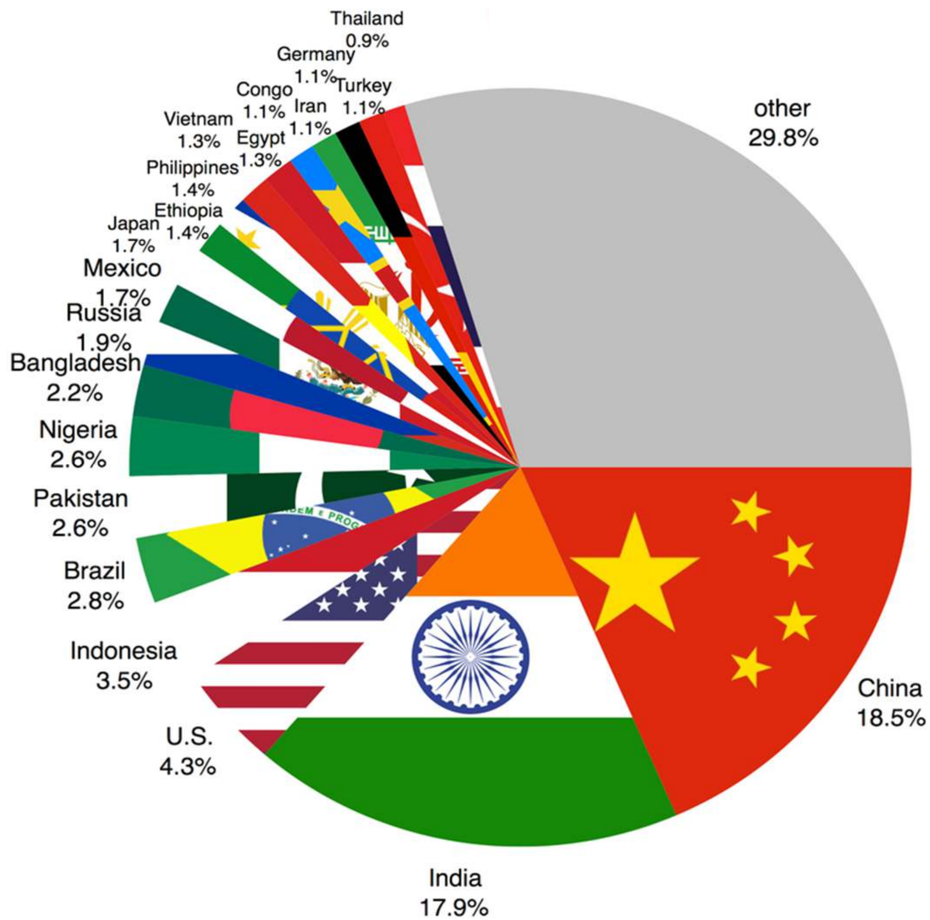
The National Academies of Sciences, Engineering, and Medicine have identified 7 major global challenges in the 21st century that science and technology must help solve:

1. Energy and the Environment
2. Global Health
3. Water Resources
4. Agriculture and Food Security
5. International Security
6. Population
7. Human Rights

The National Academies of SCIENCES ENGINEERING MEDICINE

Percentage Distribution of World's Population

World population as of 2018 is estimated to be 7.6 billion people.



Reference: http://www.worldometers.info/world-population/population-by-country/

Distribution of World's Population into Urban Areas

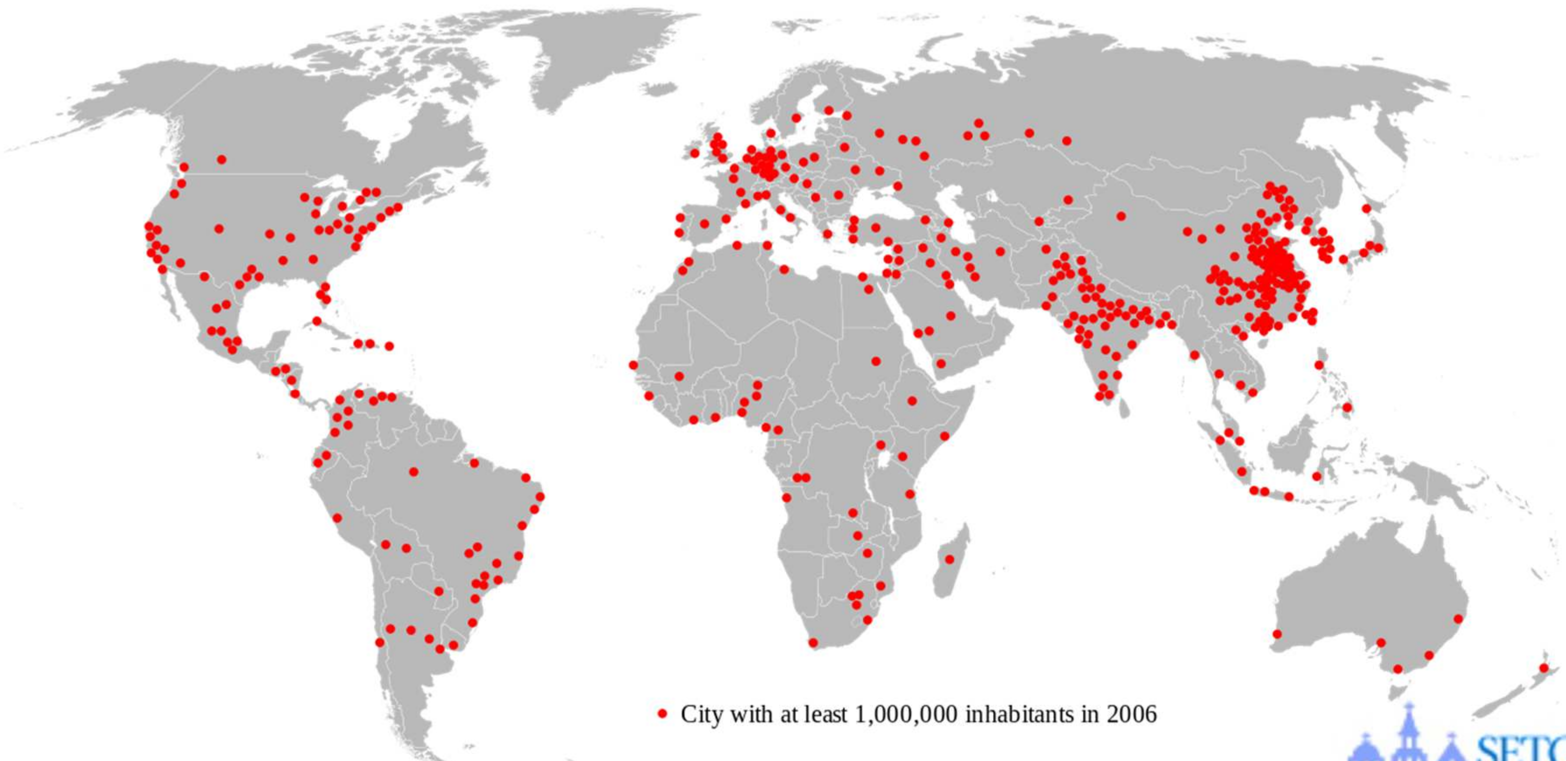
Year	World Population	Urban Population	Urban Population %
900	250,000,000	2,500,000	1%
1600	500,000,000	5,000,000	1%
1804	1,000,000,000	30,000,000	3%
1927	2,000,000,000	300,000,000	15%
1951	2,583,816,786	770,386,513	30%
1963	3,210,271,352	1,118,019,327	35%
1981	4,537,845,777	1,799,434,461	40%
1995	5,751,474,416	2,568,062,984	45%
2007	6,706,418,593	3,344,752,515	50%
2017	7,550,262,101	4,110,778,369	54%

Reliable Data

Reference: From 1950 to current year: elaboration of data by United Nations, Department of Economic and Social Affairs, Population Division.

Distribution of World's Population in Cities

In 1804 about 3% of the world's population (1 billion people) lived in cities. This proportion was 15% by 1927, 50% by 2007, and 54% in 2017 with currently over 400 cities with 1 million inhabitants and 19 cities with over 10 million inhabitants. By 2050, the proportion of city inhabitants may reach 70% of the world's population (est. 9.8 billion).



Reference: http://www.prb.org/Publications/Lesson-Plans/HumanPopulation/Urbanization.aspx. 2012.

World's Top Ten Largest Urban Areas

1975		2000		2025	
1. Tokyo, Japan	26.6	1. Tokyo, Japan	34.5	1. Tokyo, Japan	36.4
2. New York- Newark, USA	15.9	2. Mexico City, Mexico	18	2. Bombay, India	26.4
3. Mexico City, Mexico	10.7	3. New York-Newark, USA	17.9	3. Delhi, India	22.5
4. Osaka-Kobe, Japan	9.8	4. São Paulo, Brazil	17.1	4. Dhaka, Bangladesh	22
5. São Paulo, Brazil	9.6	5. Bombay, India	16.1	5. São Paulo, Brazil	21.4
6. Los Angeles-Long Beach-Santa Ana, USA	8.9	6. Shanghai, China	13.2	6. Mexico City, Mexico	21
7. Buenos Aires, Argentina	8.8	7. Calcutta, India	13.1	7. New York-Newark, USA	20.6
8. Paris, France	8.6	8. Delhi, India	12.4	8. Calcutta, India	20.6
9. Calcutta, India	7.9	9. Buenos Aires, Argentina	11.9	9. Shanghai, China	19.4
10. Moscow, Russian Federation	7.6	10. Los Angeles-Long Beach-Santa Ana, USA	11.8	10. Karachi, Pakistan	19.1

Reference: United Nations, *World Urbanization Prospects*, Department of Economic and Social Affairs, Population Division (2007).

Distribution of Population in USA

About 82% of the US Population (327 million) live in urban areas.

268 million people live in urban areas vs. 59 million people living in rural areas

By 2050 the US population is expected to be 438 million with 87% living in urban areas (382 million vs. 57 million in rural areas).

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The State of New Jersey

The MSA definition is titled the New York City-Newark-Philadelphia, NY-NJ-PA Metropolitan Statistical Area, and includes a population of **20.2 million people** by 2015 Census estimates, roughly 1 in 16 Americans and nearly 7 million more than the second-place Los Angeles metropolitan area.

New Jersey – The Garden State

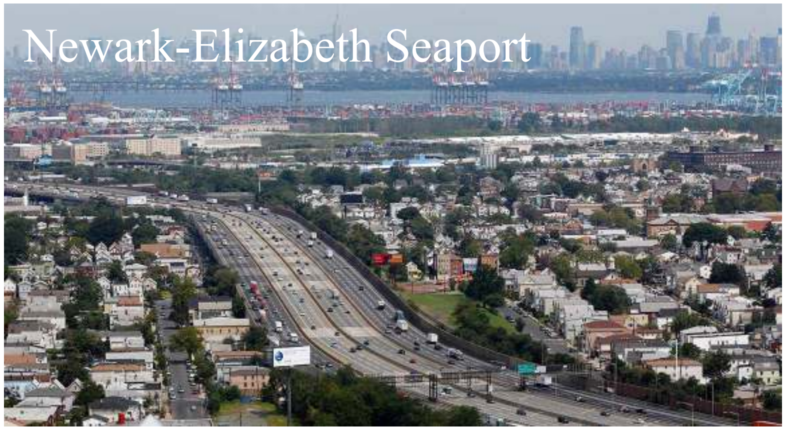
New Jersey – The Garden State

There is a long tradition from colonial times through the 20th century to the present of New Jerseyans growing in their home gardens.

New Jersey's Agriculture

Agriculture is New Jersey's third largest industry, behind pharmaceuticals and tourism, generating $65 billion a year. The state ranks second in the country in production of both culinary herbs and blueberries, and it boasts more horses than Kentucky. It has over 9,000 farms which encompass over 806,000 acres, or 17 percent of the state, a designation that includes nurseries, vineyards and orchards, horse farms, and produce and livestock farms.

New Jersey is an Urban State



As of 2017 about 95% of NJ's inhabitants live in urban areas. It's population density is 470 inhabitants per km^2.

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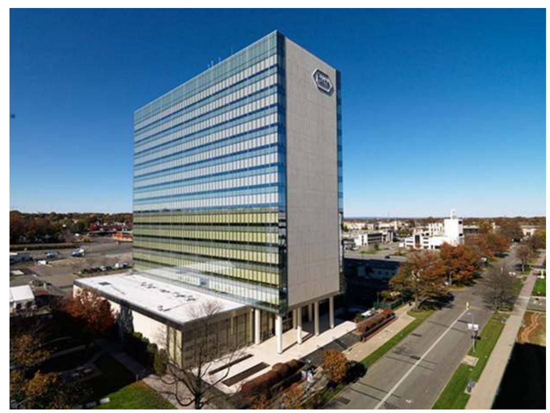
South Orange, New Jersey

Newark, NJ



Nutley, NJ

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Urban Decay in Newark, NJ

Community Gardens in Newark, NJ

Over the last decade there has been an increase in community gardens in abandoned residential and commercial properties around the city. This had been coordinated efforts by non-profits and in some cases private citizens re-appropriate lots as urban farms.

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Rooftop Farming in Newark, NJ

Philip's Academy, Newark, NJ

New Jersey Institute of Technology, Newark, NJ

Vertical Farming in Newark, NJ

AeroFarms
The Future of Urban Agriculture

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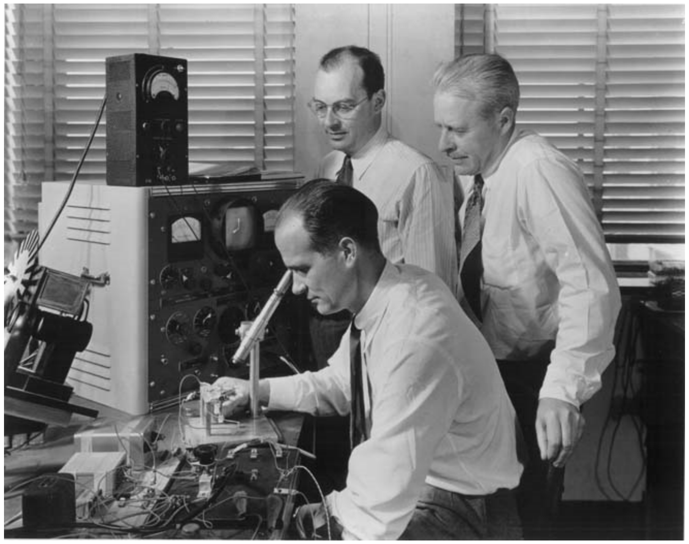
Shipping Container Farms

The Future in Urban Agriculture

Intellectual & Technological Infrastructure

Research & Development



Bell Laboratories

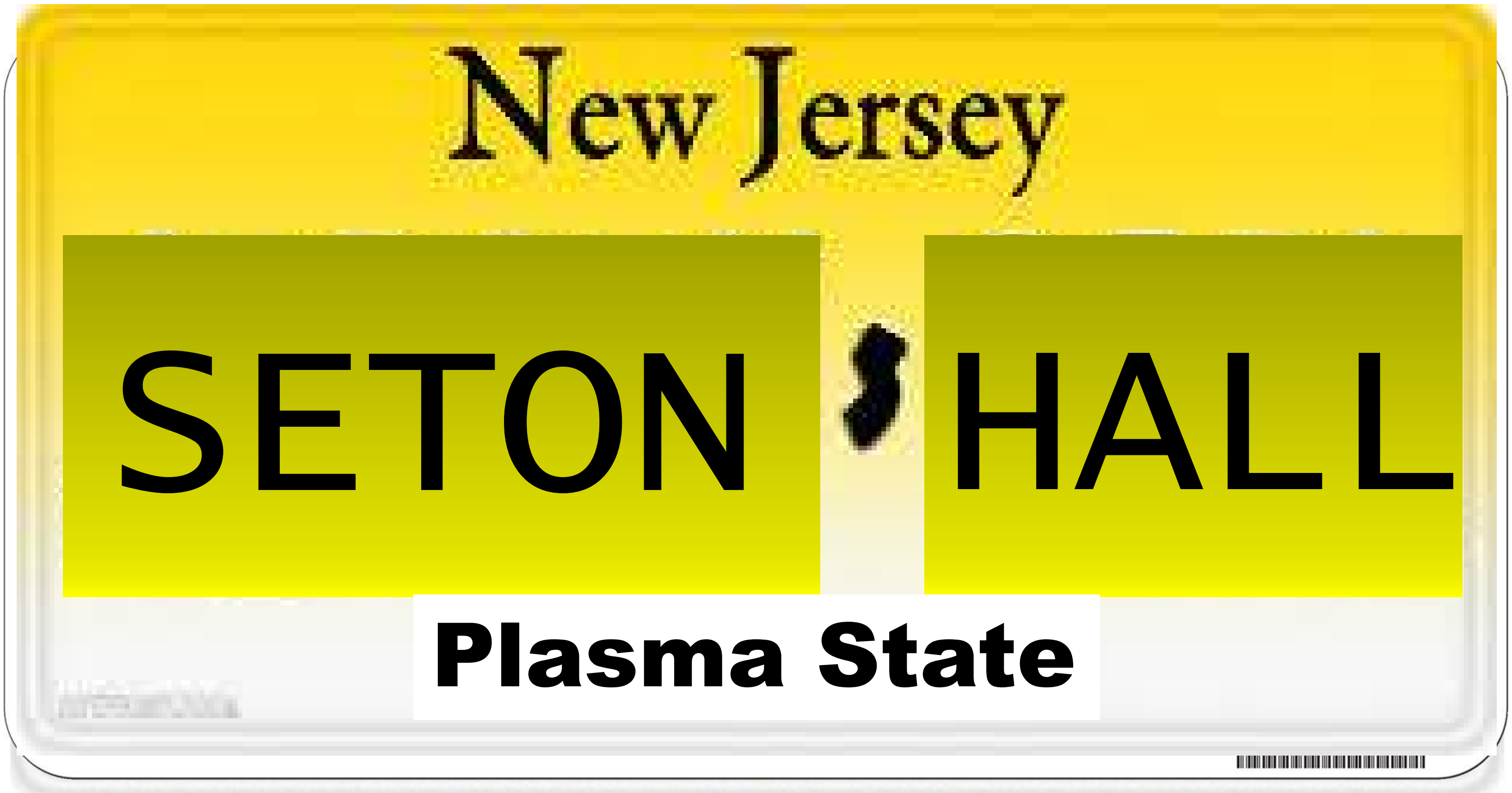
Information Technology

Johnson & Johnson
PHARMACEUTICAL RESEARCH & DEVELOPMENT, L.L.C.

MERCK

Pharmaceutical
&
Biotechnology

New Jersey – Plasma State



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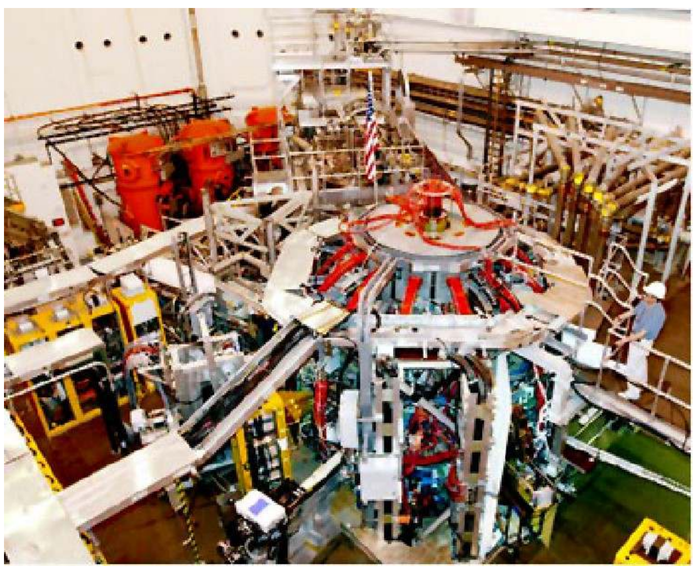
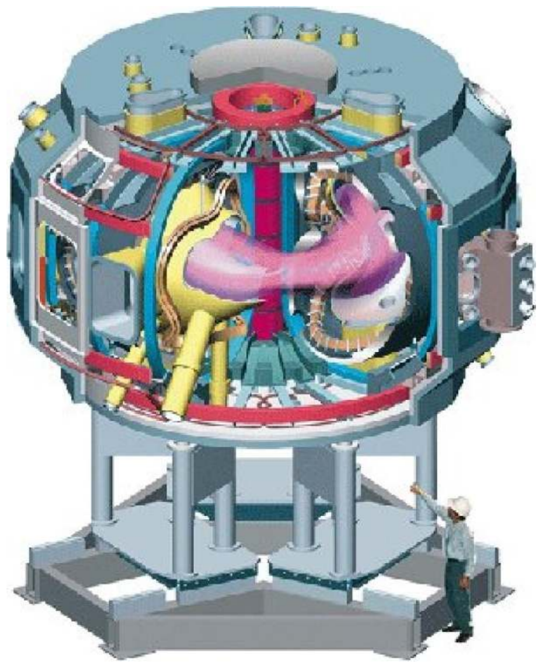
The U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) is a collaborative national center for plasma and fusion science. Its primary mission is to develop the scientific understanding and the key innovations which will lead to an attractive fusion energy source. Associated missions include conducting world-class research along the broad frontier of plasma science and technology, and providing the highest quality of scientific education.



National Spherical Torus Experiment (NSTX)



Two Types of plasmas

High-temperature plasmas (Hot Plasmas)

$T_i \approx T_e \geq 10^7$ K

e.g., fusion plasmas

$T_i \approx T_e \approx T_g \leq 2 \times 10^4$ K

e.g. arc plasma at normal pressure

Low-temperature plasmas (Cold Plasmas)

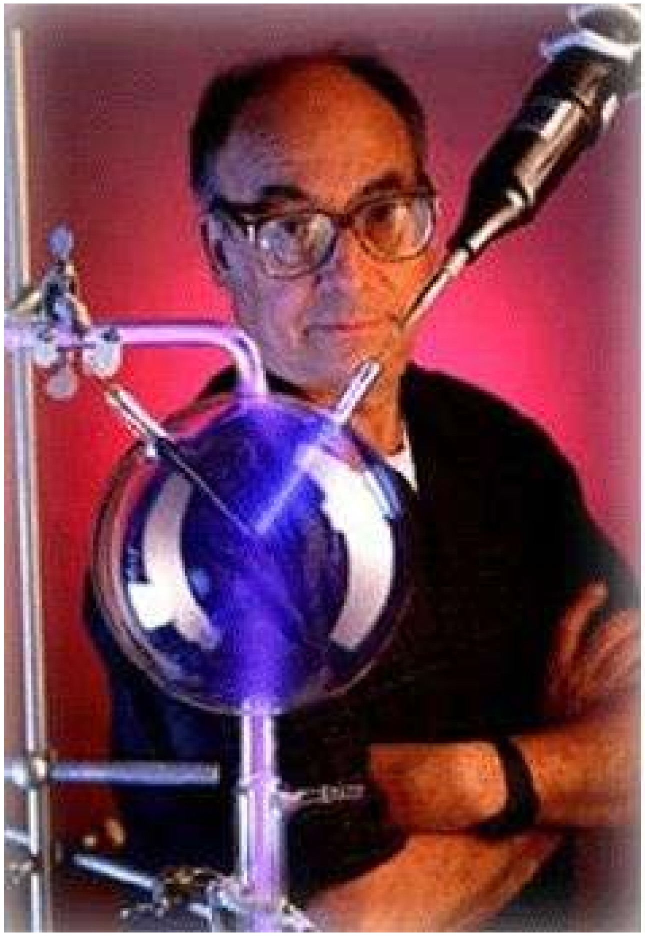
$T_i \approx T_g \approx 300$ K

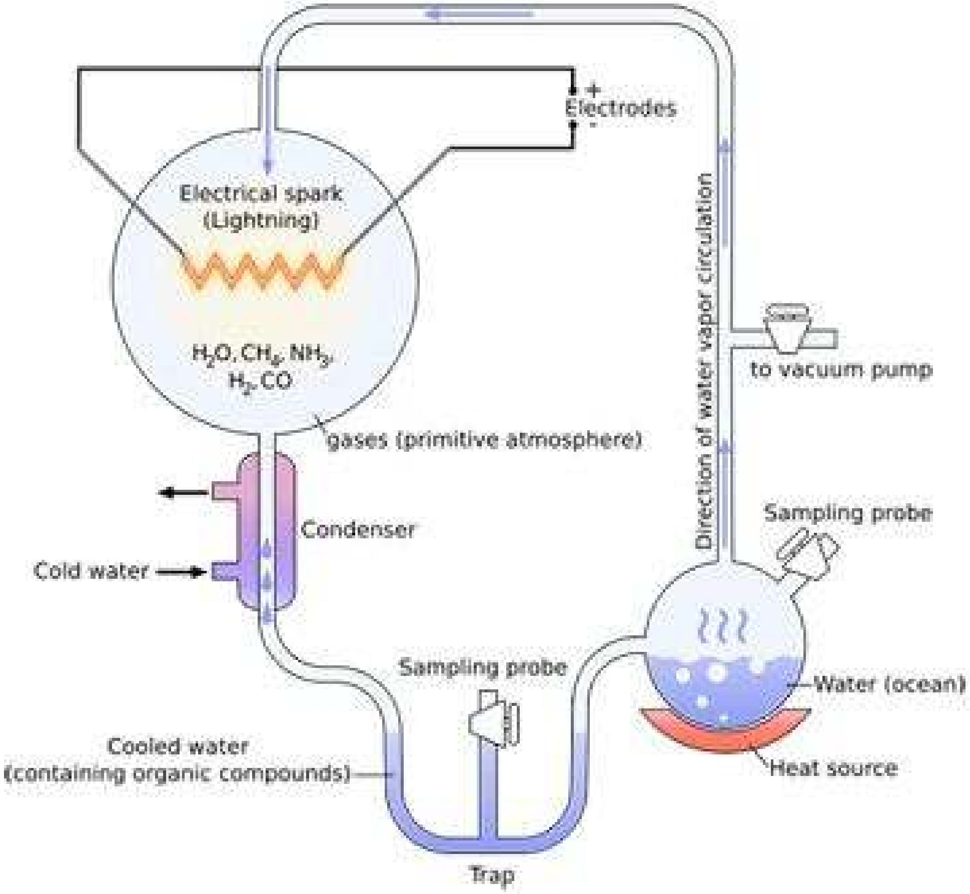
$T_i << T_e \leq 10^5$ K

e.g. low-pressure glow discharge

high-pressure cold plasma

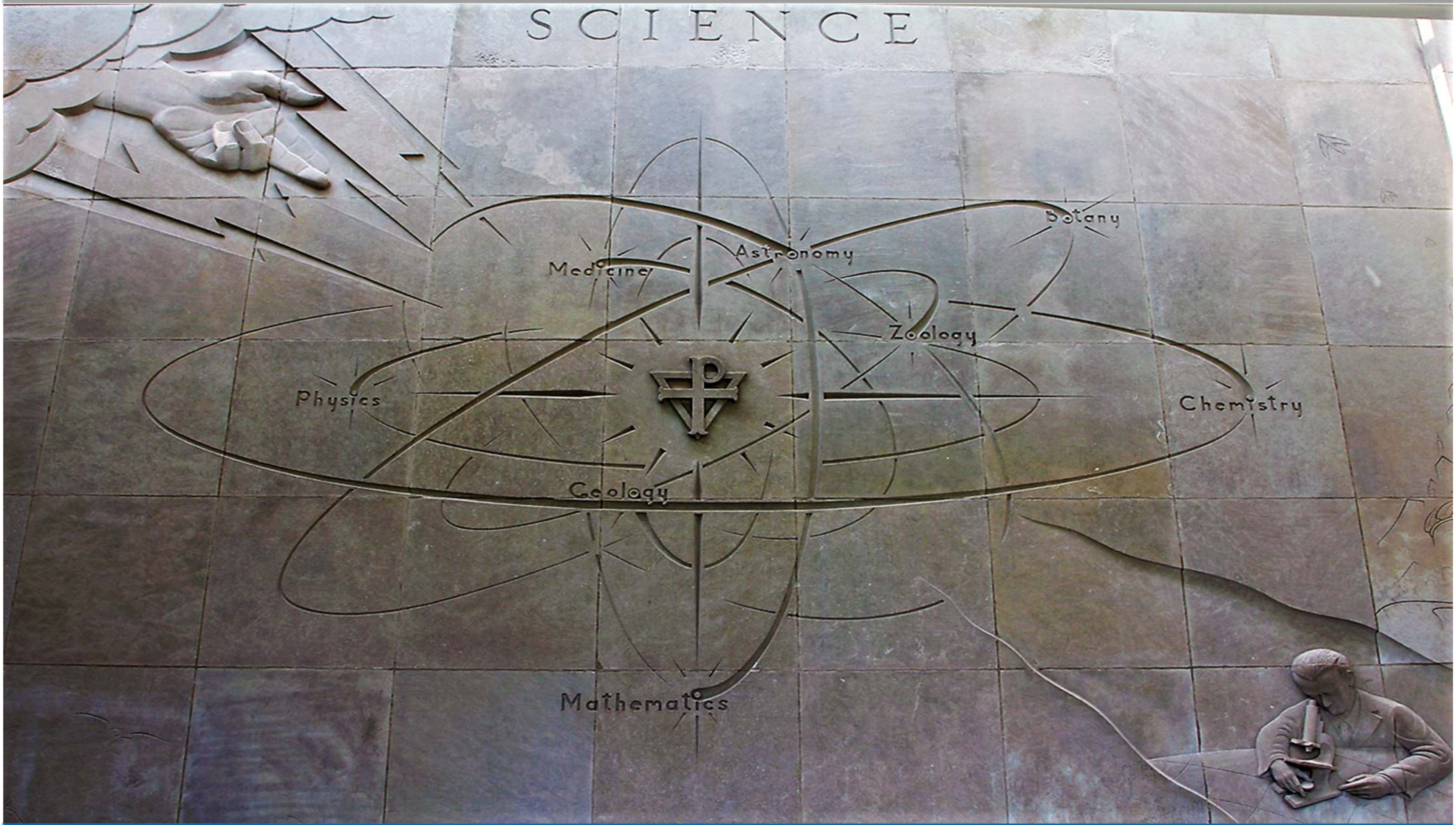
Plasma – Spark of Life?

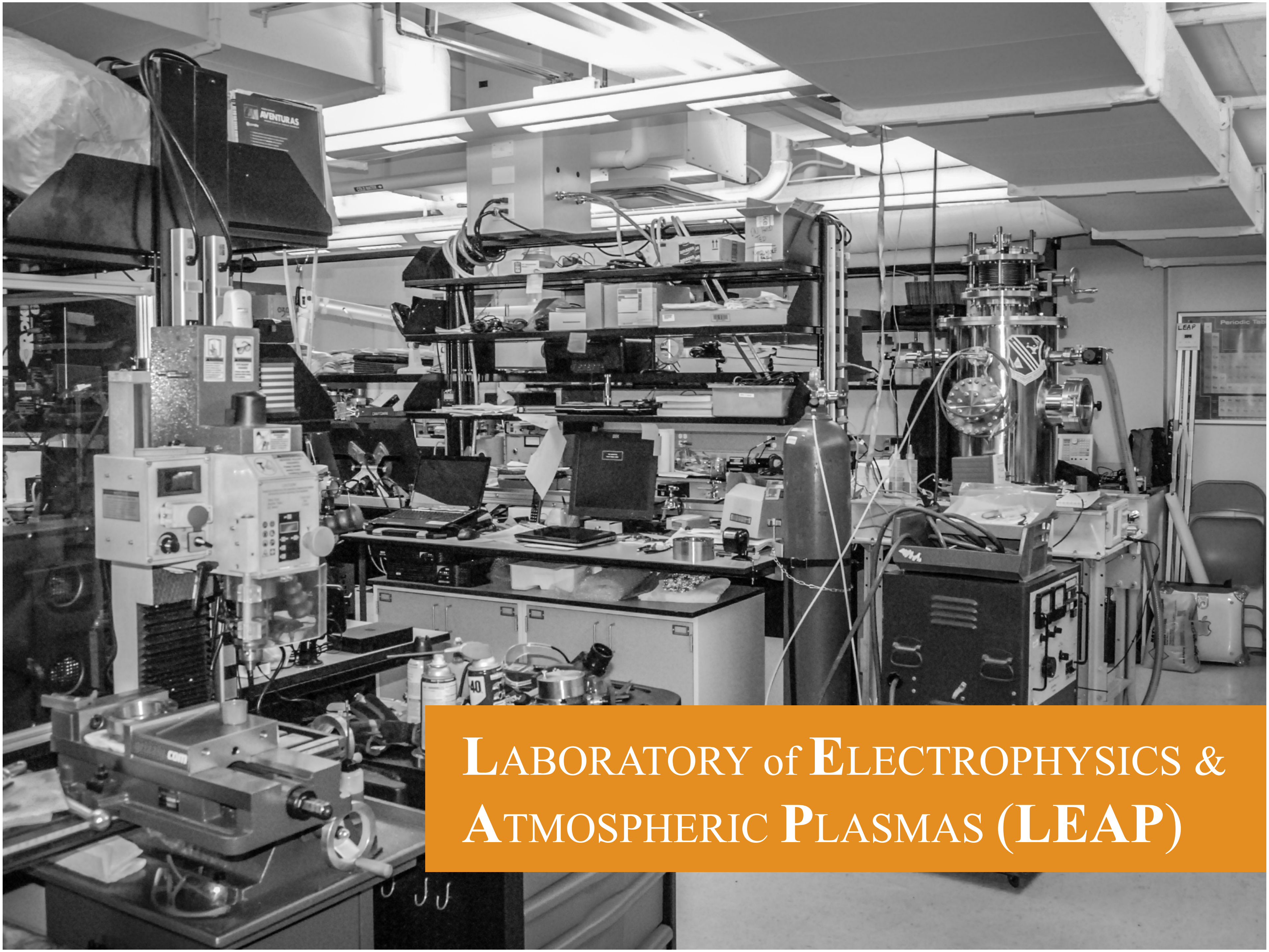




Urey-Miller Experiment – Origin of Life

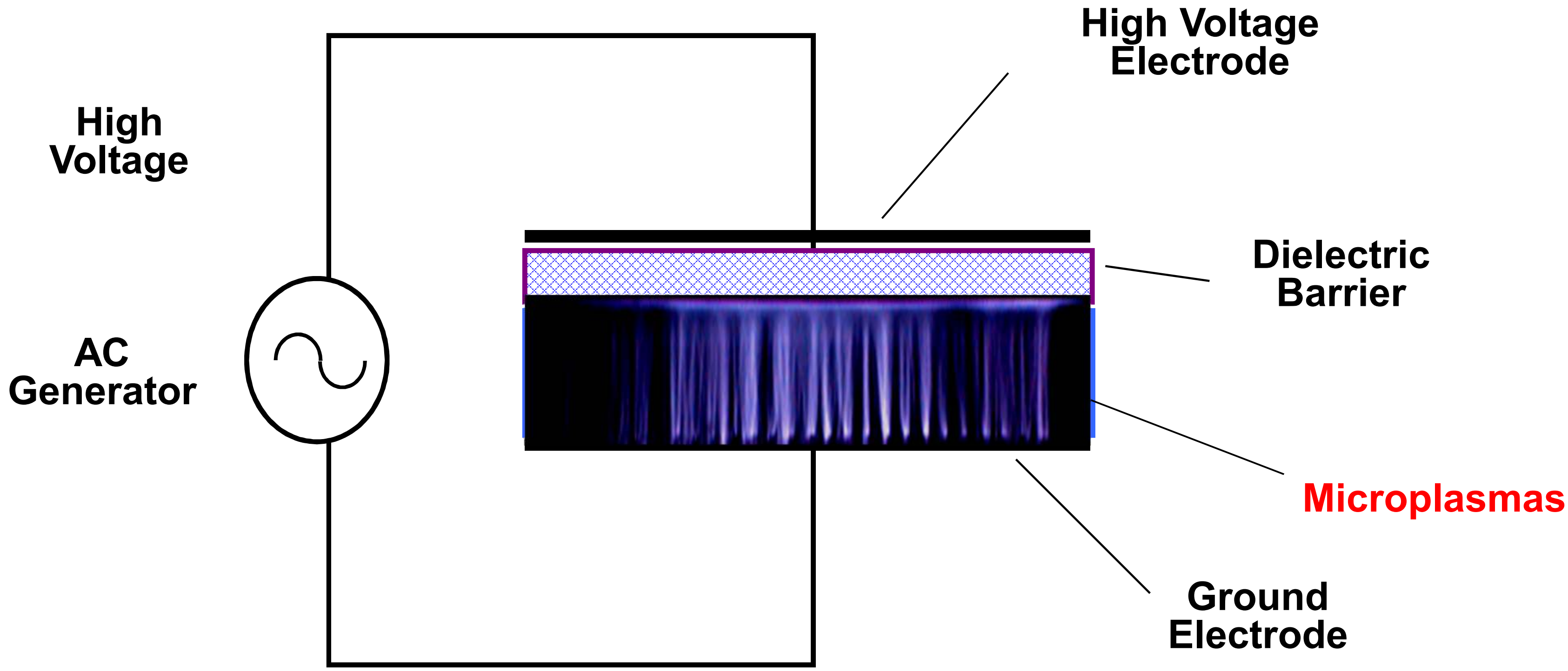
Plasma – Spark of all Existence!



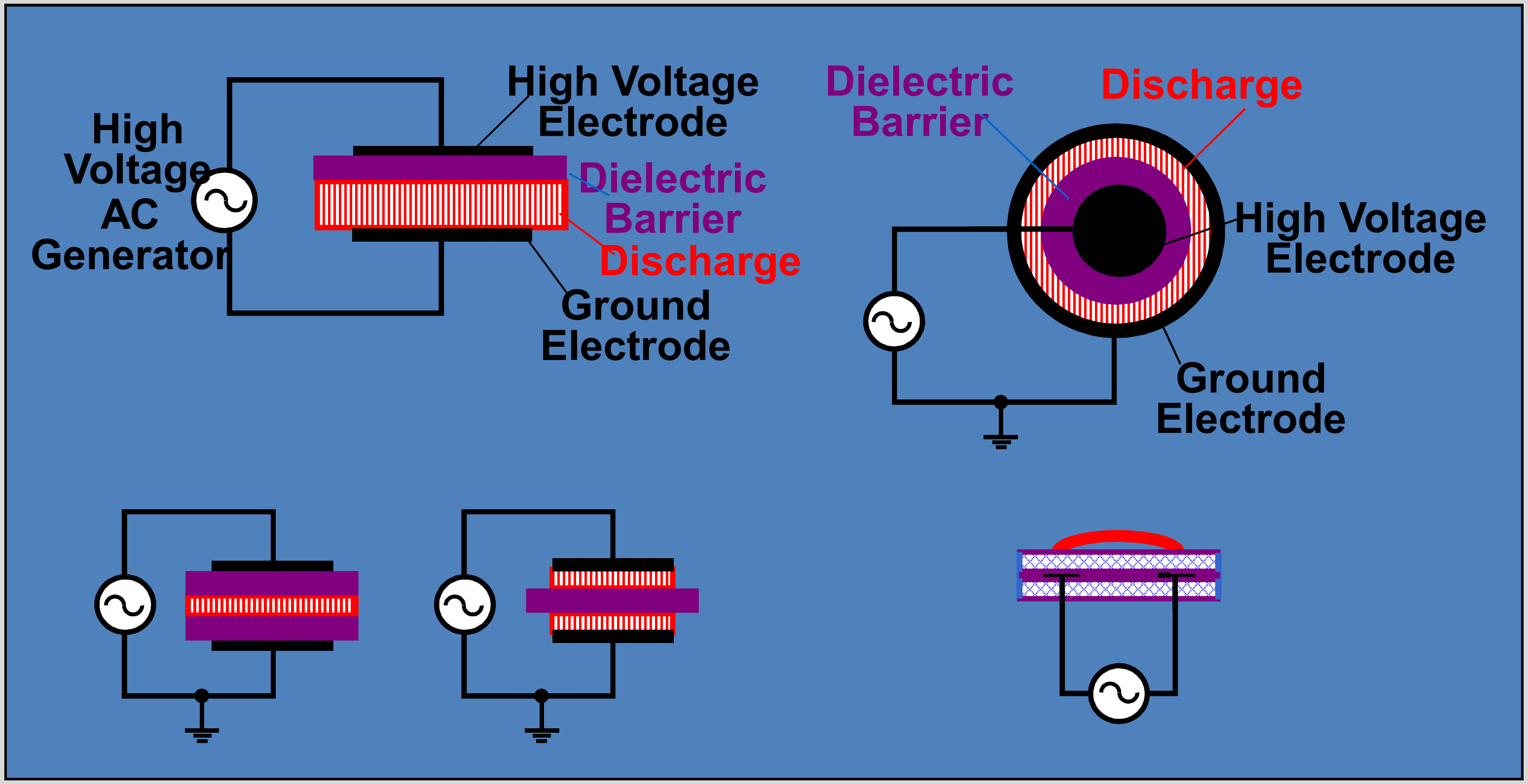


LABORATORY of ELECTROPHYSICS & ATMOSPHERIC PLASMAS (LEAP)

Atmospheric Pressure Cold Plasma



Dielectric Barrier Discharge

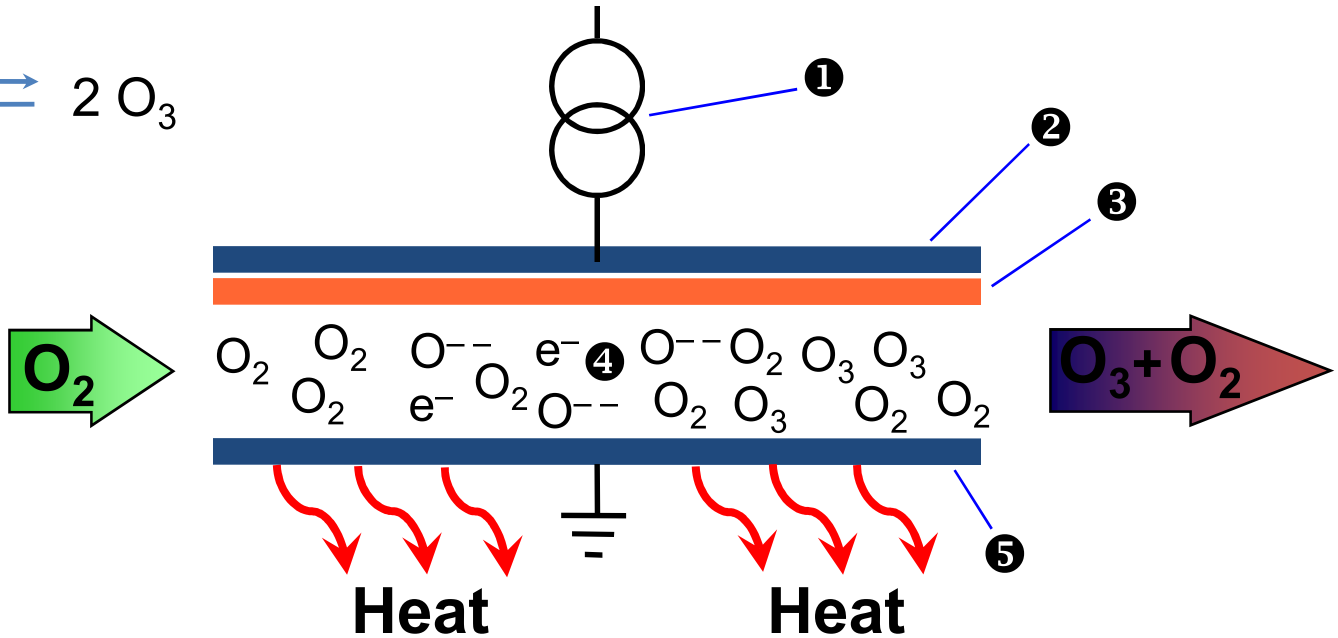


H.E. Wagner, R. Brandenburg, et. al. 'The barrier discharge: basic properties and applications to surface treatment'. *Vacuum.* 71 p417-436 (2003).

Ozone Generator

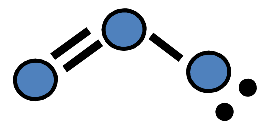
Dielectric Barrier Discharge

$$3\,O_2 \rightleftharpoons 2\,O_3$$



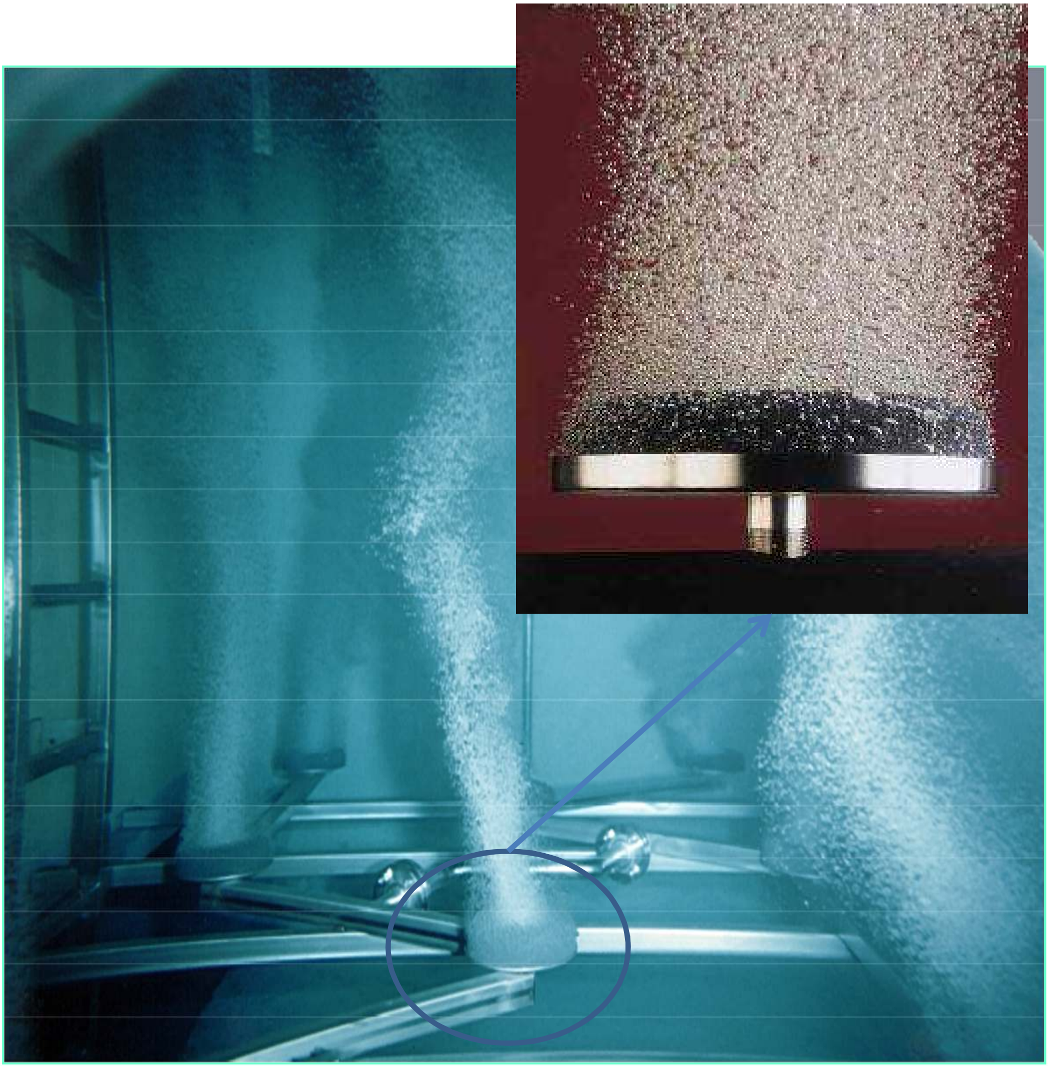
Properties of Ozone (O_3)

- Tri-atomic form of oxygen.



- Most powerful commercial oxidizing agent
- Unstable - must be generated and used onsite
- Limited solubility in water, but more so than oxygen
- Leaves a dissolved residual which ultimately converts back to oxygen

Ozone Water Treatment



Bubble Diffusion

- Easy to use
- Low energy usage
- Mass transfer efficiencies to > 90%

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Environmental and Water Remediation with Plasma Technologies

Guido Vezzu, Jose L Lopez, Alfred Freilich, Kurt H Becker. *Optimization of large-scale ozone generators.* IEEE Transactions on Plasma Science. Vol. 37, Issue 6, pp. 890-896 (2009).

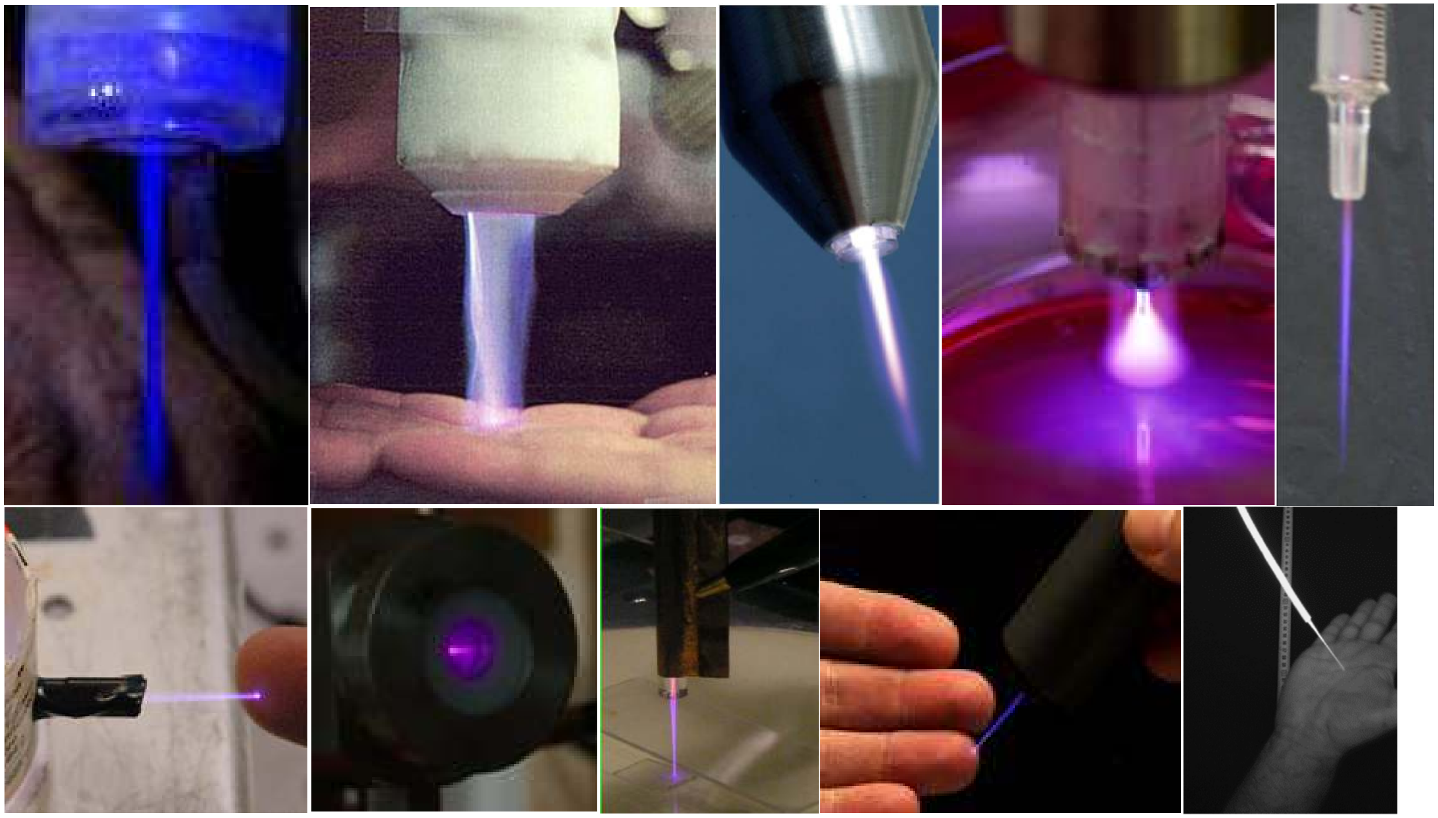
Intelligent Gap System

Degremont Technologies
SUEZ

5000 kg/day of ozone

Jose L Lopez. *Progress in Large-Scale Ozone Generation*. **Complex Plasmas: Scientific challenges and Technological Opportunities. Editors – Michael Bonitz, Jose Lopez, Kurt Becker, Hauke Thomsen.** Chp 13, pp. 427-453, Springer Publishing (2014).

A Brief Collection of Atmospheric Pressure Plasma Jets (APPJ)



Gases used: Helium, Argon… or mixed with reactive gases (O_2, CH_4…)

AC, pulsed DC, rf or microwave

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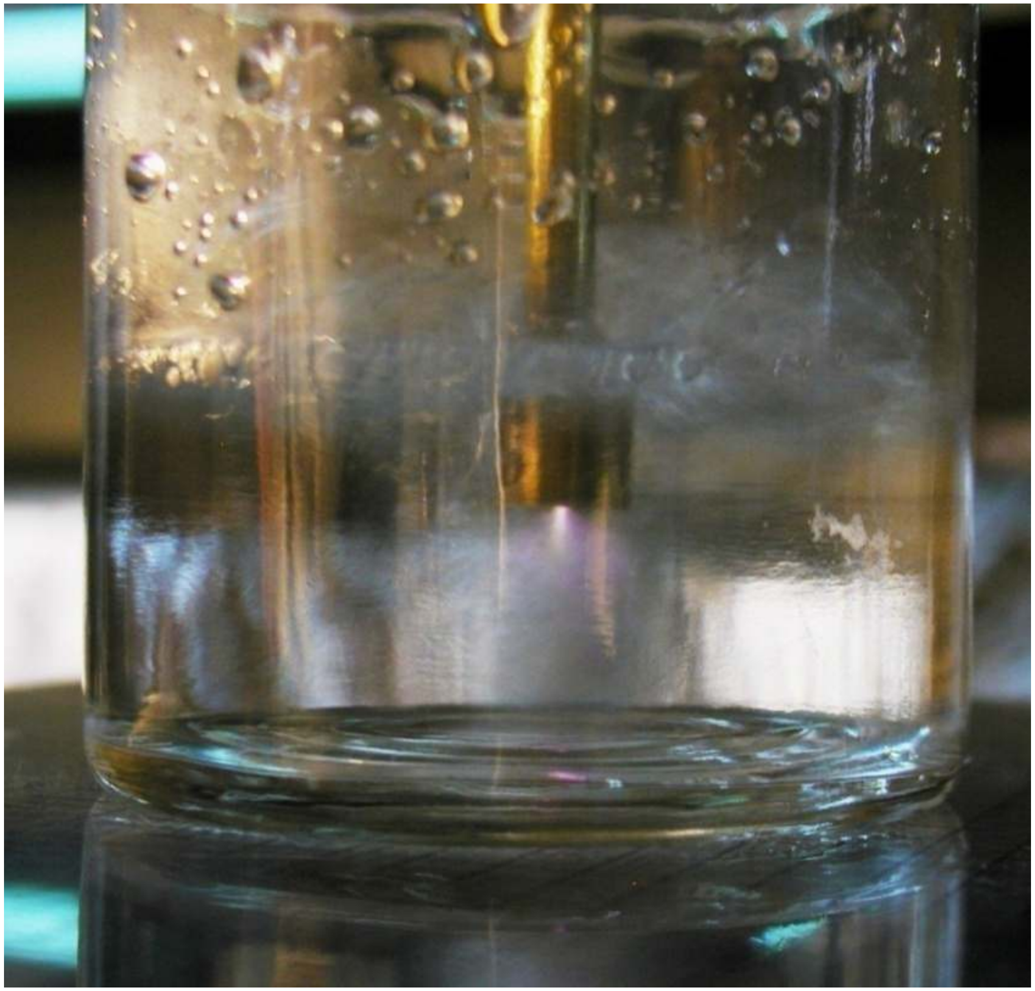
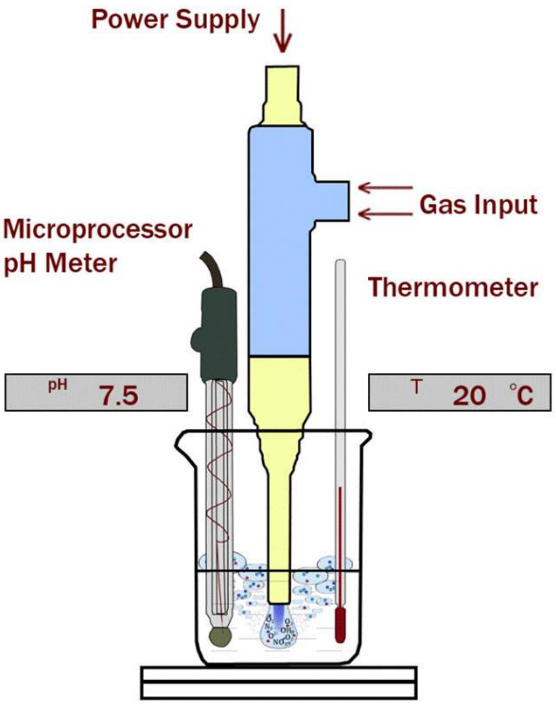
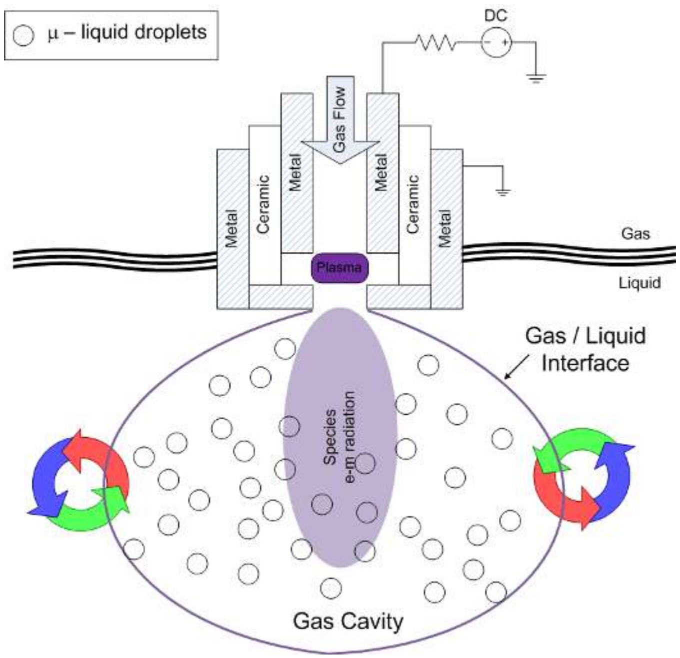
Plasma Micro Jet Inside Water



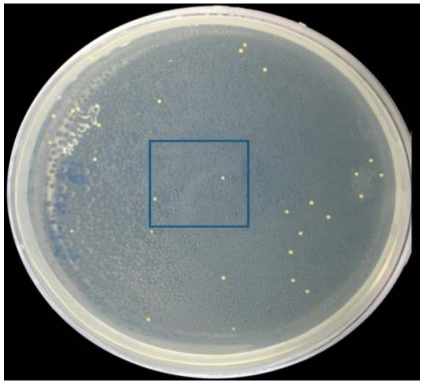


Plasma Micro Jet Inside Water

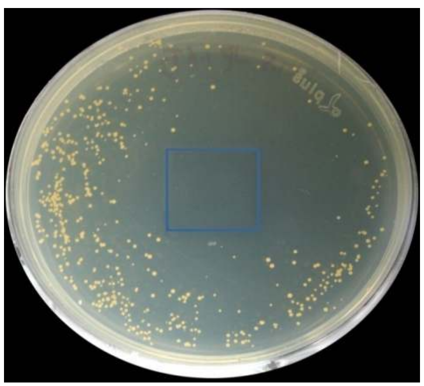


- Plasma Activated Species directly interact with Liquid Media
- Micro-liquid droplets in the gas bubbles from gas-liquid mixing increase the surface area for the chemical reactions → higher reaction efficiency

Different Inactivation Agents



M. Luteus



S. Aureus

Possible cause of different decreasing survival rate

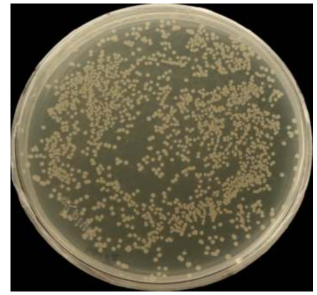
Presence of more than one inactivation agent with different efficacies
(UV & Reactive Radicals and also neg. ions)

- **UV – confined to treated area (because of rapid absorption)**
- **Reactive Radicals (O, OH, O_3) – these species have a long life time and can migrate into the untreated area (with radially decreasing concentration)**
- **Ions – measured ion current away from the nozzle suggests their presence in and near the treated area; their identity (O^-) and role needs to be explored**
- **Sequential/simultaneous action of UV, reactive radicals, and ions inactivates the different bacteria/spores with varying efficacy – experiments with control of the various inactivation agents are planned and/or under way**

Inactivation of *S. aureus* in Water

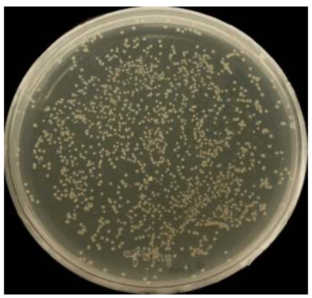
0min

2min



4min

6min

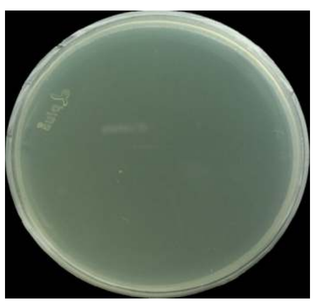


8min

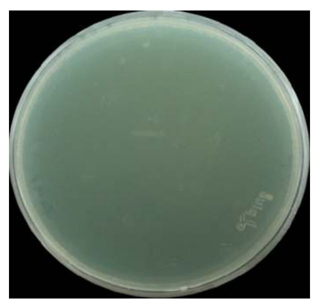
10min

12min

14min



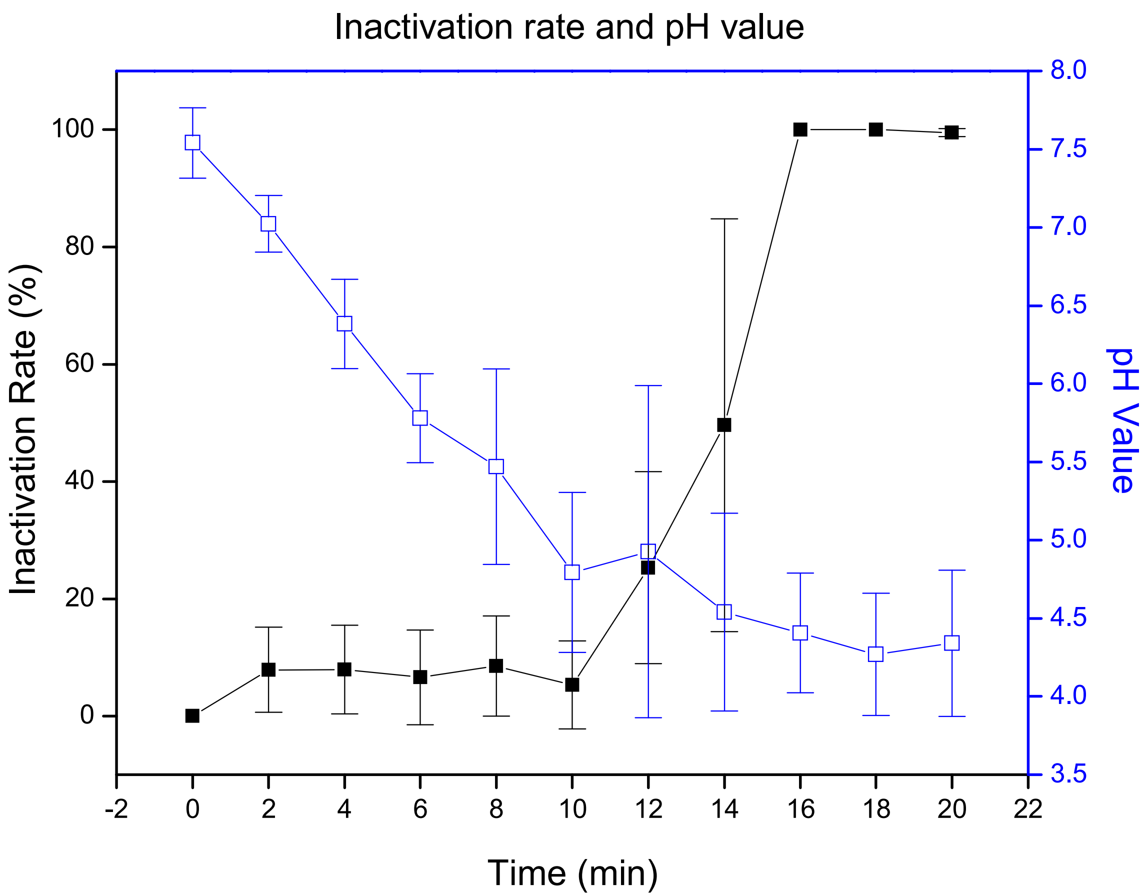
16min



18min

20min

Inactivation of *S. aureus* in Water

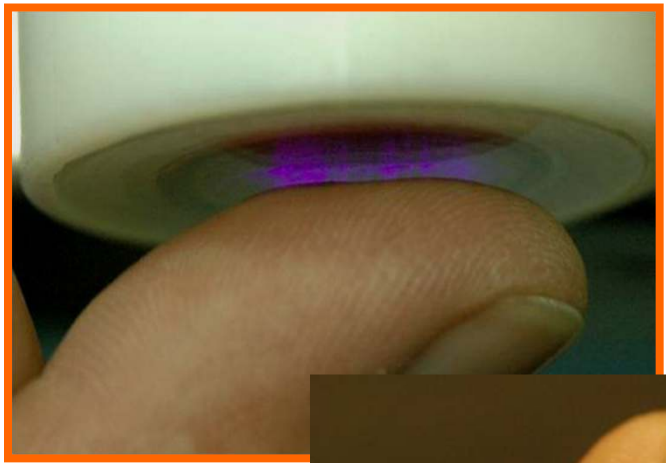


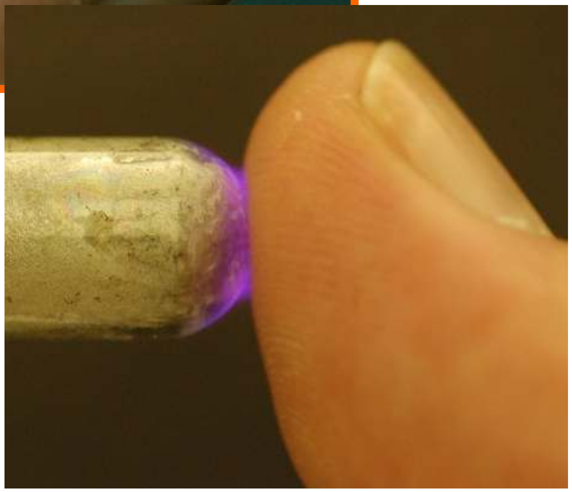
While the pH value deceased from 7.5 to 4.5 in the first 10 min, the inactivation rate of *S. aureus* stayed below 10%. After the pH value stabilized at 4.5, the inactivation rate started to increase rapidly, reaching 100% in the next 6 min.

Na Bai, Peng Sun, Haixia Zhou, Haiyan Wu, Ruixue Wang, Fuxiang Liu, WeiDong Zhu, Jose L Lopez, Jue Zhang, Jing Fang. *Inactivation of Staphylococcus aureus in water by a cold, He/O2 atmospheric pressure plasma microjet.* Plasma Processes and Polymers. Vol. 8, Issue 5, pp. 424-431 (2011)

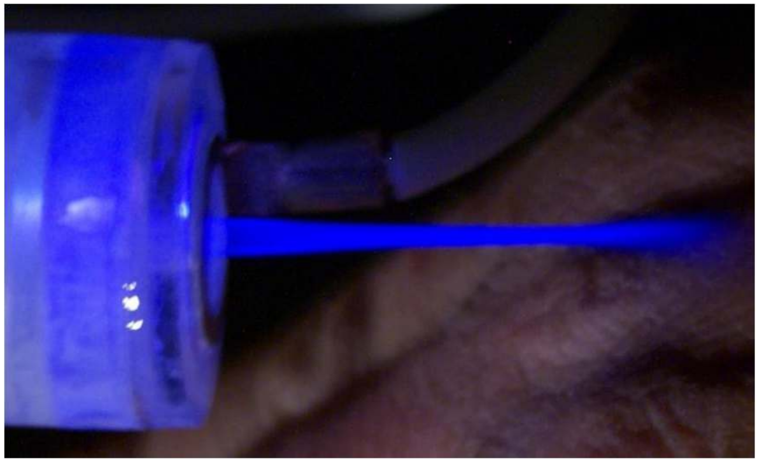
Plasma Applications in Medicine & Health

Direct Plasma – Charges on Tissue, Produced In Air or Oxygen

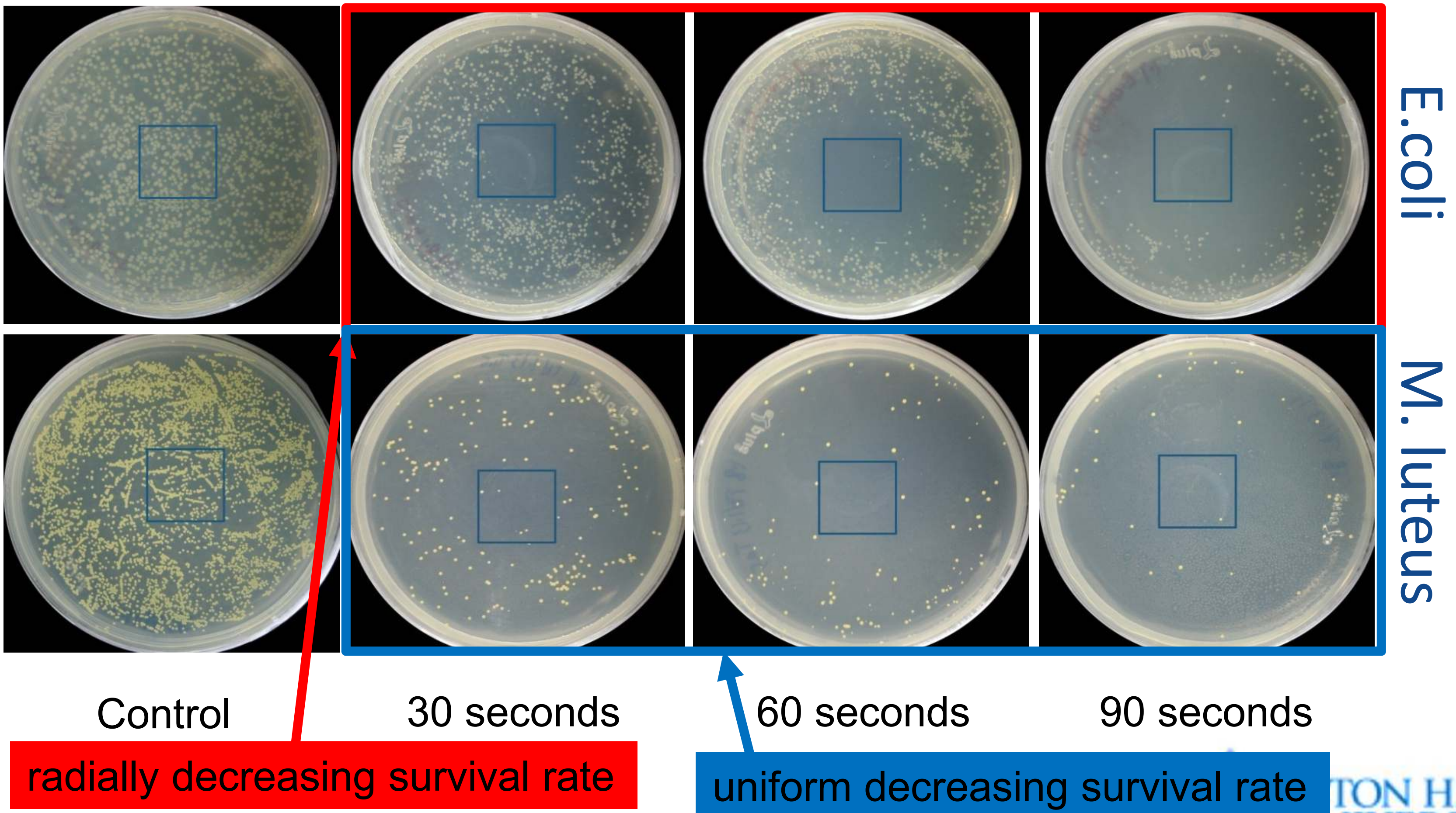




Indirect Plasma – Jet, Often NOT in OXYGEN

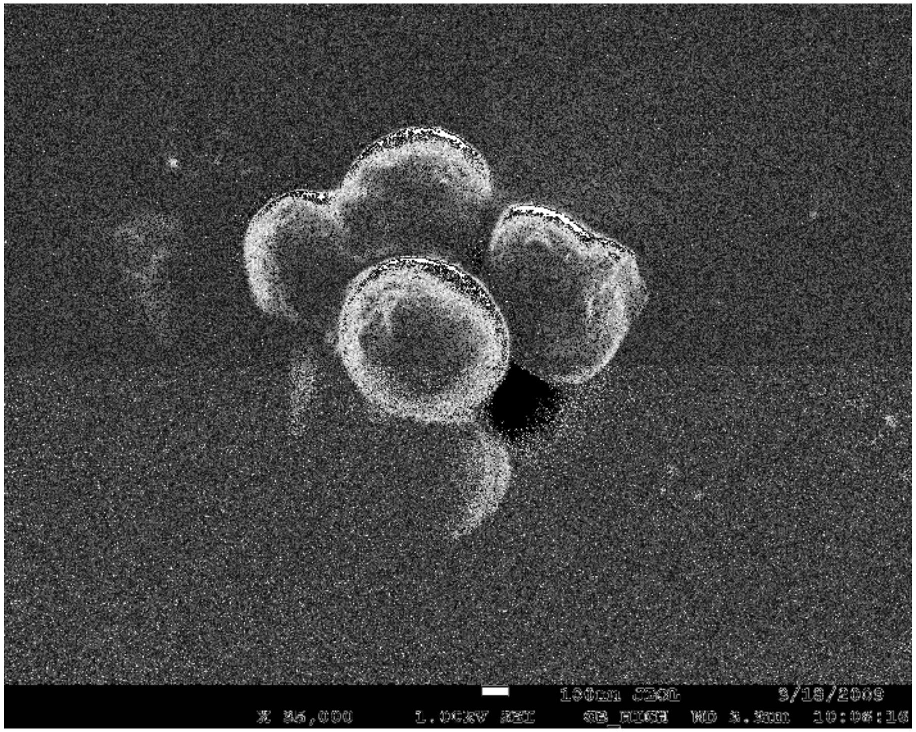


Plasma Dose Effect

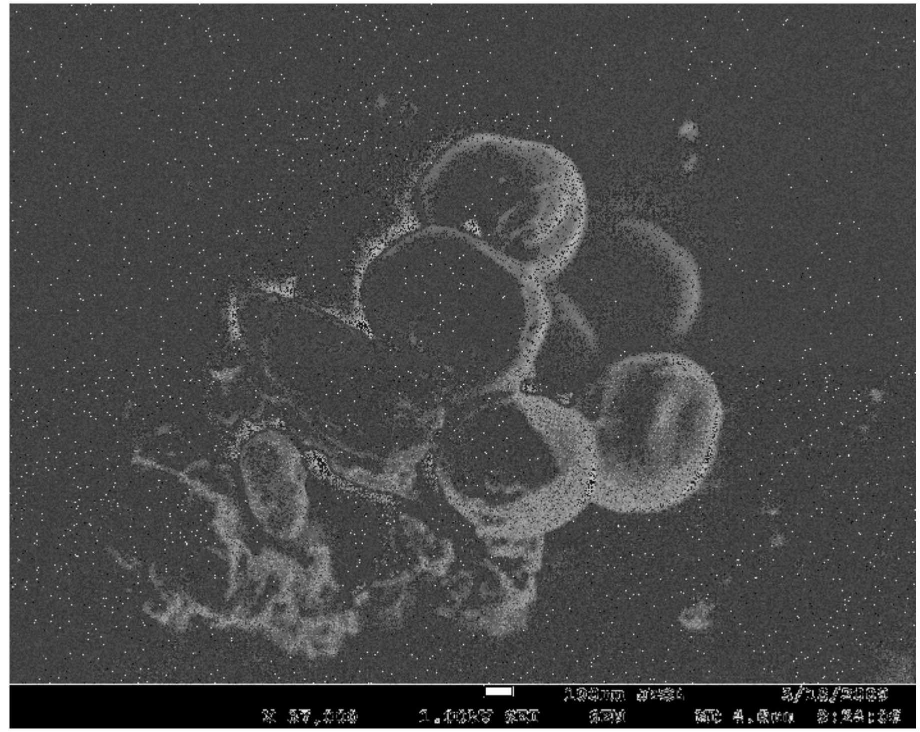


SEM Pictures

SEM pictures of S. aureus before and after PMJ treatment



Control



PMJ treatment

SEM of PMJ treated S. aureus show clear poration on cell membrane as well as the change of the cell morphology.

Living tissue sterilization without harm: Recent pig experiments

Courtesy: Drexel Plasma Institute

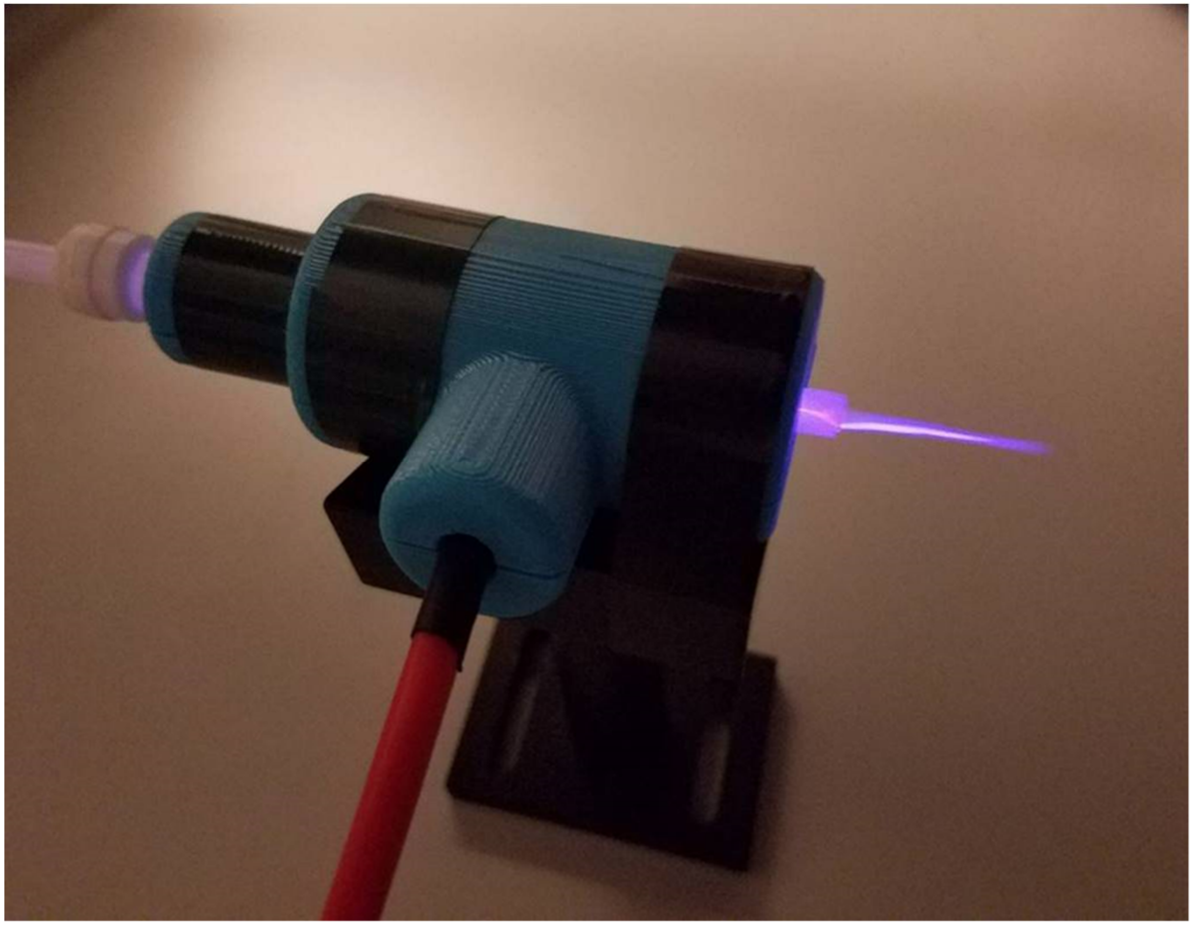
Hemostasis and coagulation in Hairless mice, not immunocompromised (SKH_1)

Saphenous vein cut: without plasma animal continues to bleed for 10-20 minutes.

15 seconds of FE-DBD clots the blood and seals the vessel <u>without damaging tissue</u>, preventing additional bleeding.

Courtesy: Drexel Plasma Institute

Our Version of the Atmospheric Pressure Plasma Jet



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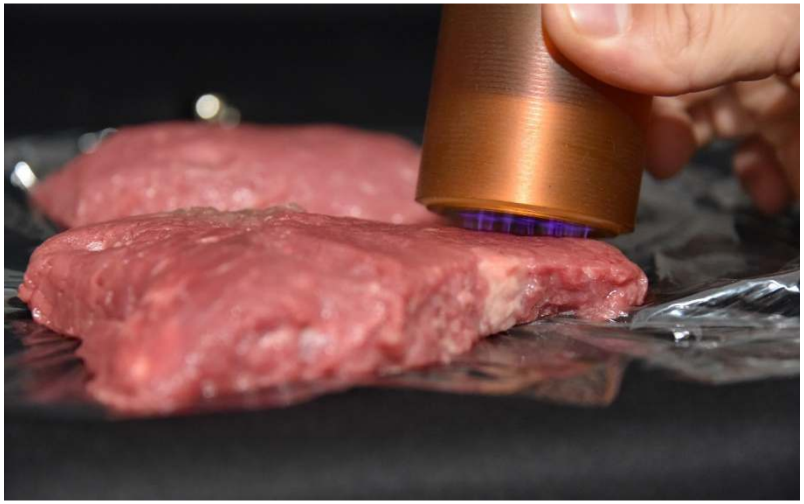
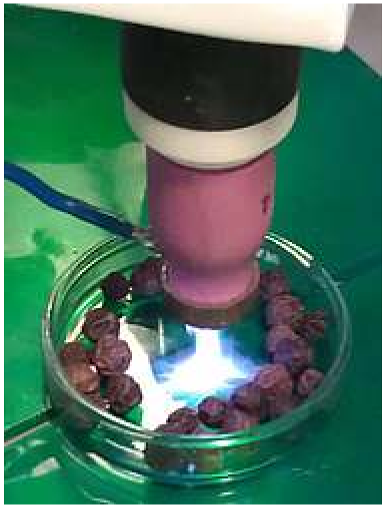
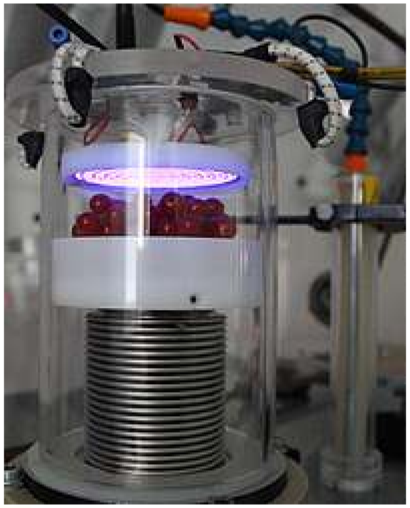
Plasma Enhanced Agriculture & Food Safety

Cold plasma proving to be hottest new food safety treatment

BY **NEWS DESK** | DECEMBER 7, 2016

Described as a "purple blow torch" by food safety scientists, cold plasma treatment can kill 99.9 percent of norovirus on blueberries without damaging the delicate fruit, giving a food safety boost to the so-called superfood.

Brendan Niemira, a microbiologist at the U.S. Department of Agriculture's Eastern Regional Research Center in Wyndmoor, PA, and a team of scientists already demonstrated that cold plasma (CP) can kill pathogens such as Salmonella and E. coli on blueberries.

The researchers, led by Alison Lacombe, focused on blueberries with their latest project because of the increasing popularity of the fruit in recent years, attributed to its antioxidants and other nutritional benefits. They also considered the manner in which the blue fruit is grown, packed, shipped and consumed.

Natural Antioxidants

- Green tea in Far East (catechin, a principal polyphenolic compound, has been shown to be an effective free radical scavenger and inhibitor of lipid oxidation)
- Black tea (theaflavins: polyphenolics and major red pigments are effective free radical scavengers)
- Red and purple fruits (anthocyanin pigments)
- Spices: Carnosol in rosemary; rosmarinic acid in oregano
- Essential Oils

Essential Oils – Biological / Chemical Activity

- **Antioxidant** – biological and chemical processes prevent lipid oxidation in food systems (spontaneous oxidation / autoxidation).

- **Antimicrobial** – protect against pathogenic and spoilage microorganisms (e.g., carvacrol in oregano is effective against *E. coli*, *S. aureus*).

Essential Oils and Major Bioactive Components

- **Basil** – eugenol, estragole, β-pinene, β-limonene
- Clove – eugenol
- Garlic – menthatriene, propenyldisulfide
- Lemon - α-pinene, β-pinene
- Mandarin - α-pinene, di-limonene, farnesene
- Orange – myrcene, farnesene
- Oregano – carvacrol, γ-terpinene, thymol
- Rosemary – α-pinene, camphene, eucalyptol
- Sage – α-pinene, camphene, eucalyptol
- Thyme – camphene, β-pinene, eucalyptol, thymol

Seton Hall Research

- The increase of agricultural food production and the subsequent preservation of yielded food are matters of grave importance to all of humanity.

- Cold plasma processing has been shown to increase the yield of botanicals known to be key producers of essential oils and to demonstrate the possibility of methods for solving the global issues of both food production shortage and food product preservation without creating any further detrimental environmental problems.

- Cold plasma treated plants were compared with control (non-treated) plants and commercially available essential oils.

Our Version of the Atmospheric Pressure Plasma Jet

Gerald J. Buonopane, Cosimo Antonacci, & Jose L. Lopez. *Effect of cold plasma processing on botanicals and their essential oils*. Plasma Medicine. Vol 6, Issue 3-4 (2016).

Plasma Processing: Experimental Plan

G.J. Buonopane, C. Antonacci, J.L. Lopez. *Effect of Cold Plasma Processing on Botanicals and Their Essential Oils*. Plasma Medicine Vol. 6, Issue 3-4 (2016).

→  → Plasma Treatment → Measure Plants

Harvest → Distillation → Antioxidant Testing

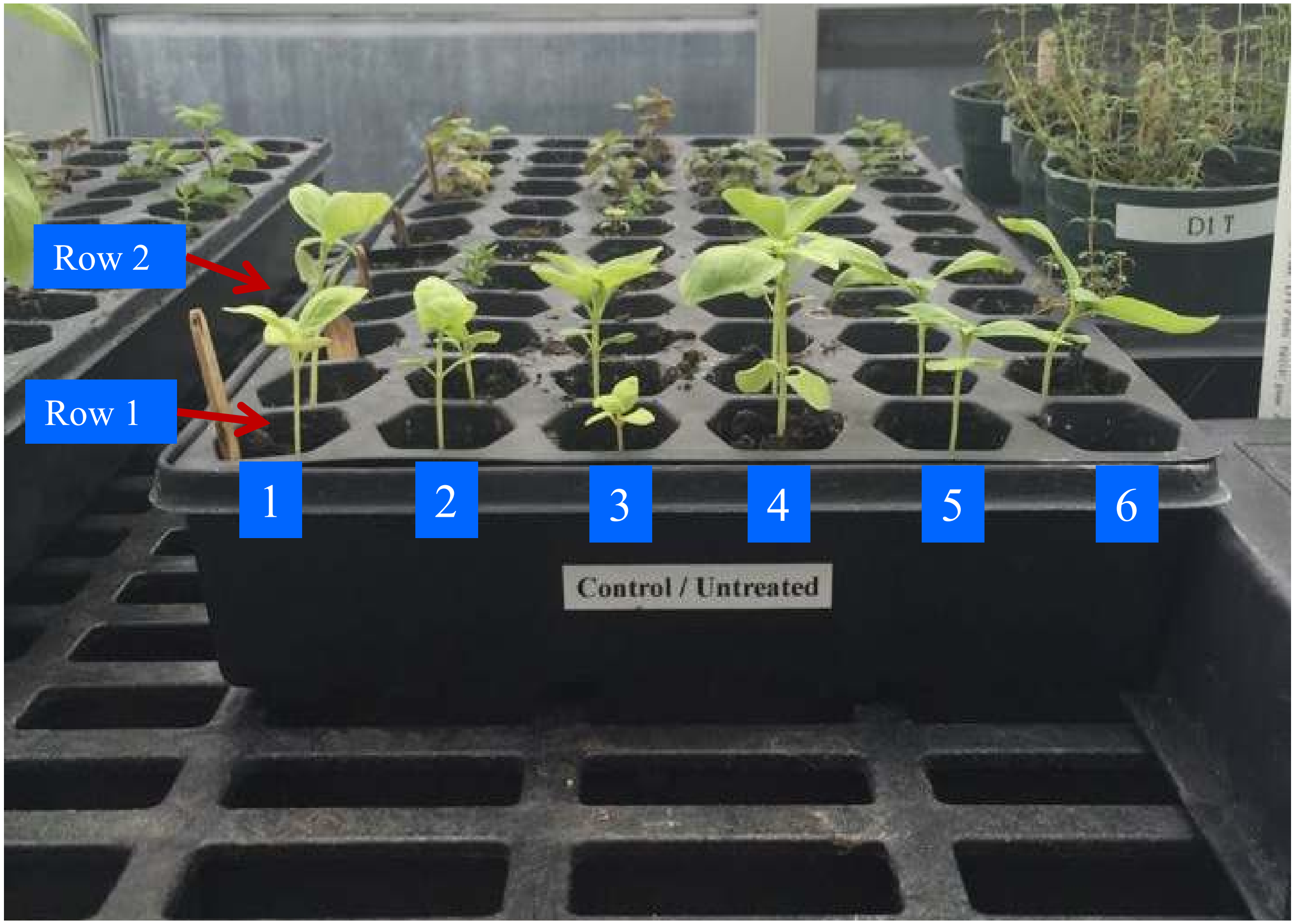
Distillation

GC-MS

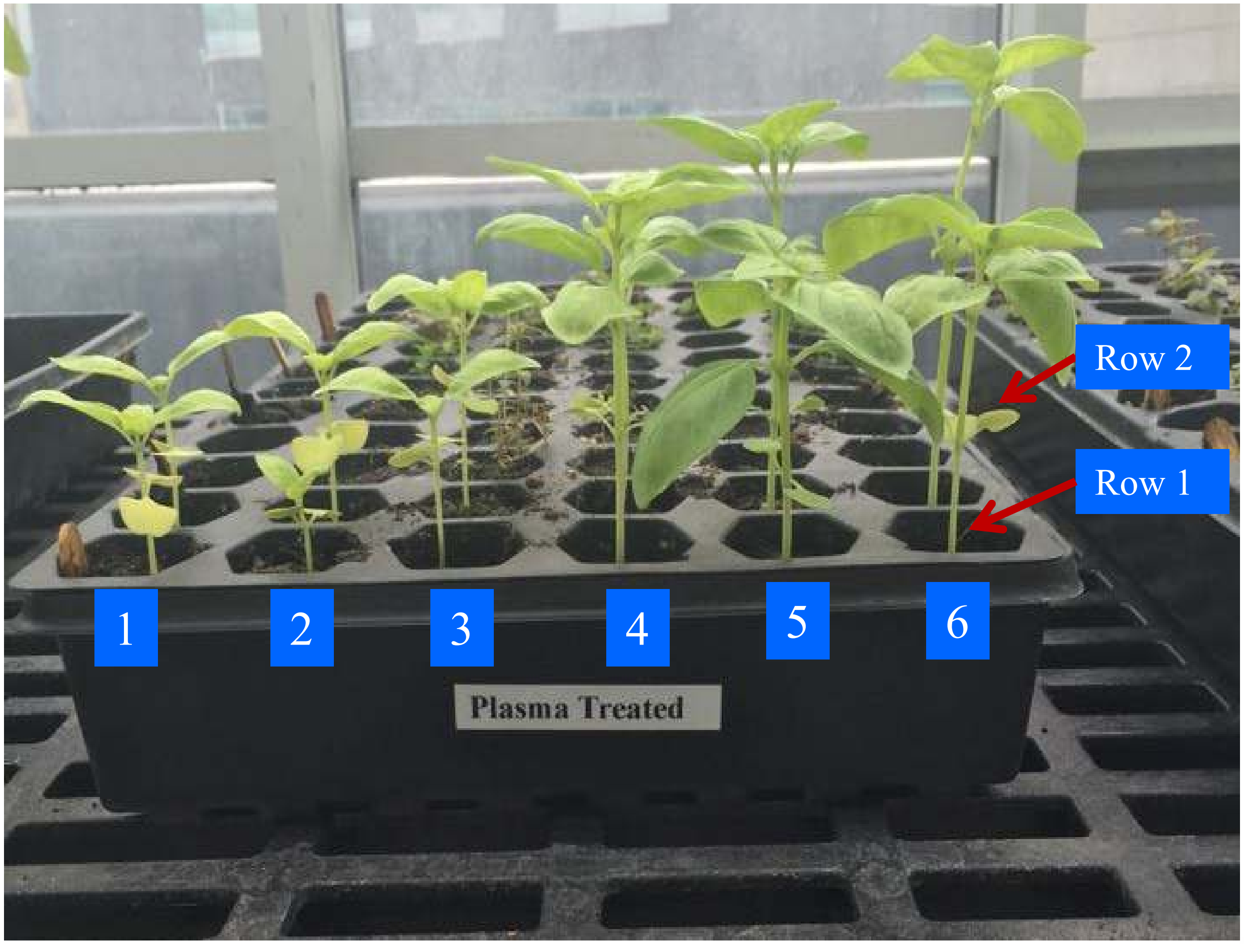
Plasma Seed Treatments

(a) Side-view of basil seedlings grown from plasma treated seeds (left) and untreated seeds (right). (b) Top-view of basil seedlings grown from plasma treated seeds (left) and untreated seeds (right).

Untreated (Control) Basil



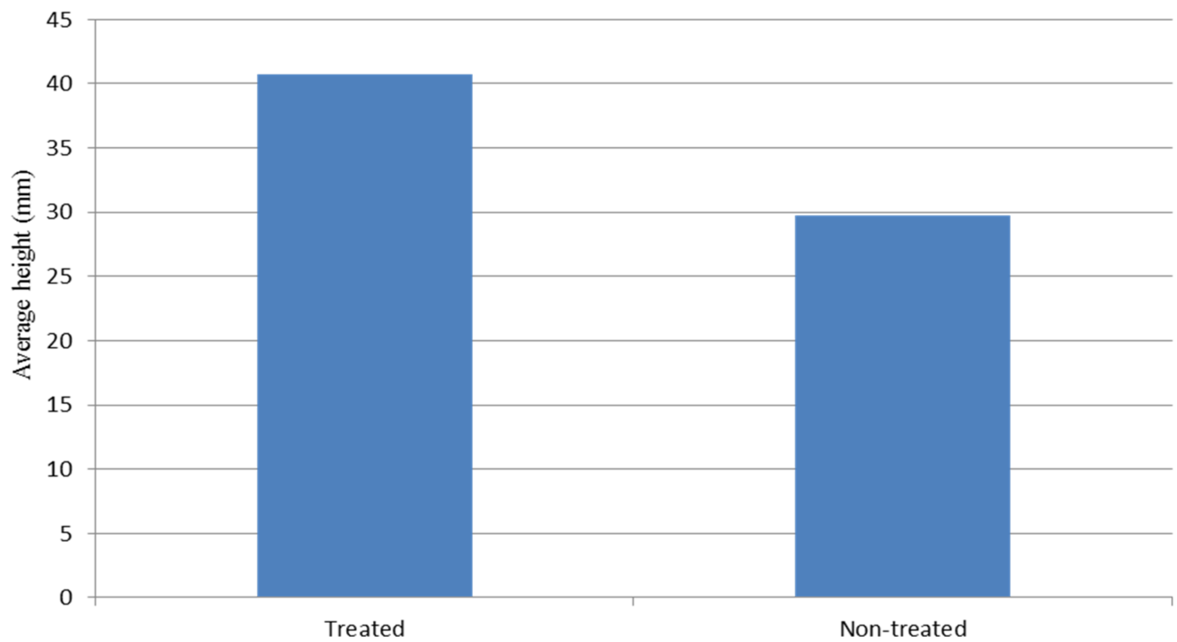
Plasma Treated Basil



Basil: Plasma Treated vs. Untreated

Basil: Plasma Treated vs. Untreated

25% increase in growth with plasma treatment!



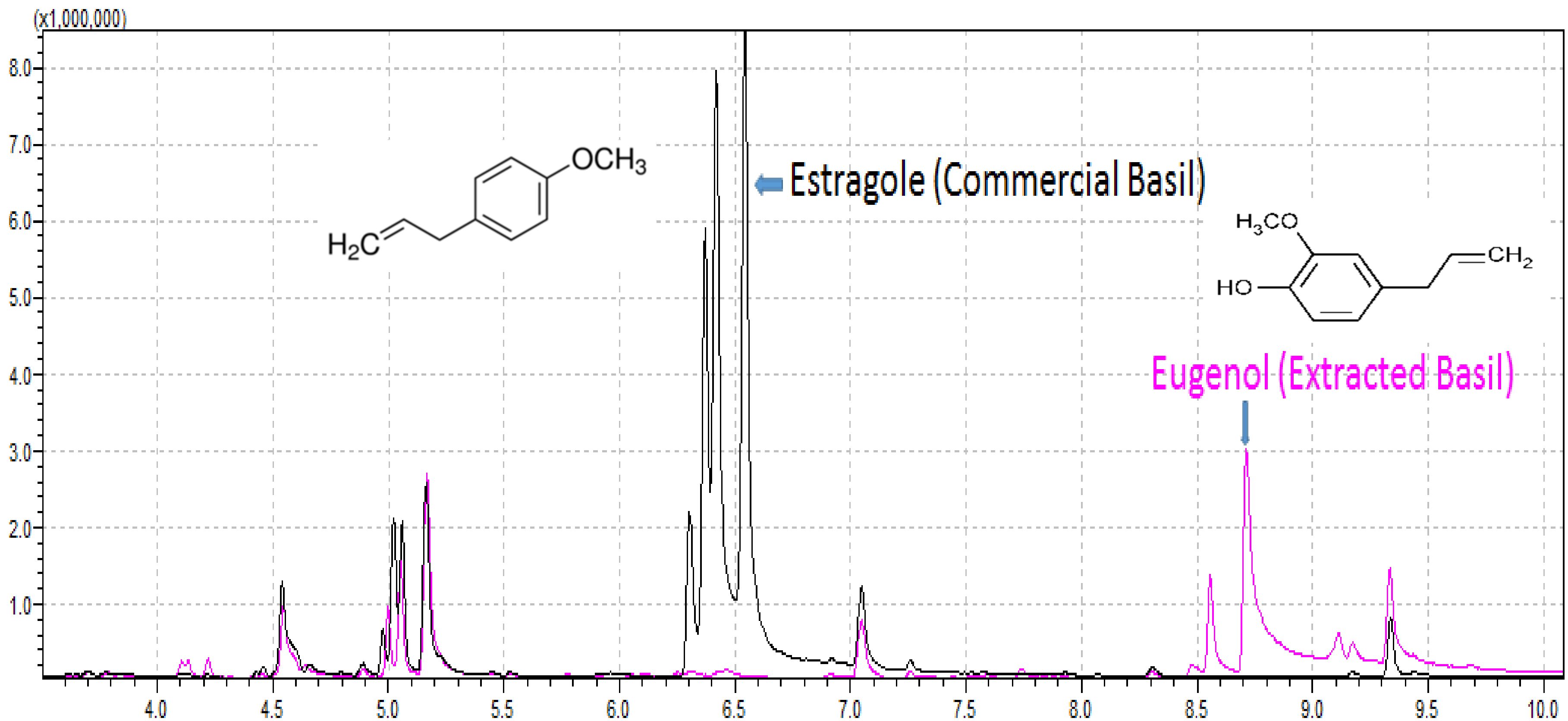
Graph demonstrating average final height of twelve treated and non-treated sweet basil plants after a month of growth from seeds.

Percent Antioxidant Activity – Home-Grown Basil (seed treated)

Antioxidant / Concentration	15 µg/mL	25 µg/mL	50 µg/mL	125 µg/mL	250 µg/mL
Plasma-Treated Basil	48.00%	62.55%	81.55%	90.55%	94.82%
Non-Treated Basil	19.55%	26.91%	46.36%	78.27%	90.64%

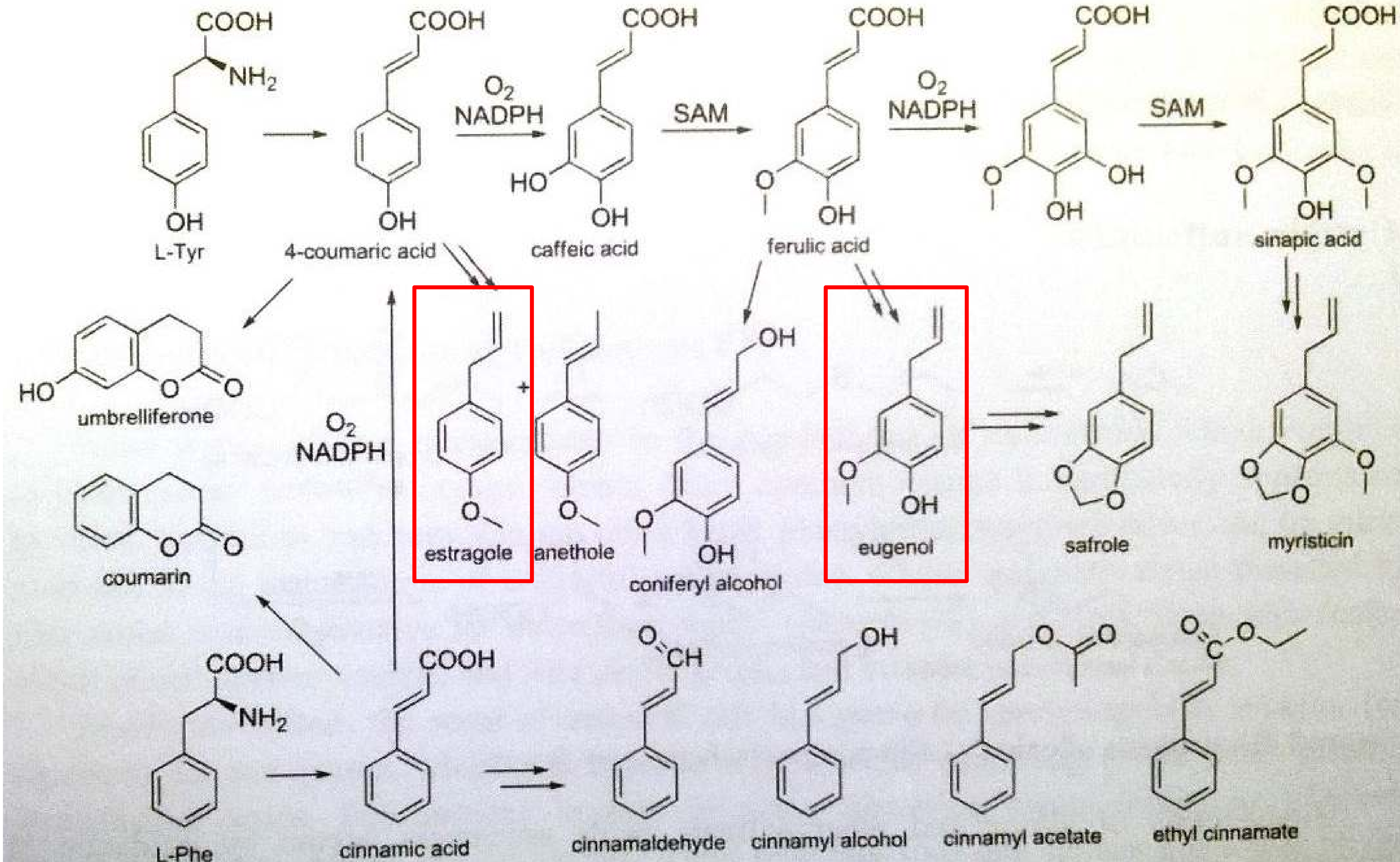
Gas Chromatogram: Overlay of Commercial Oil and Extracted (T + NT)

Shimadzu GC-MS; Column: RTX-5 MS: 15m X 0.25mm X 0.25µm

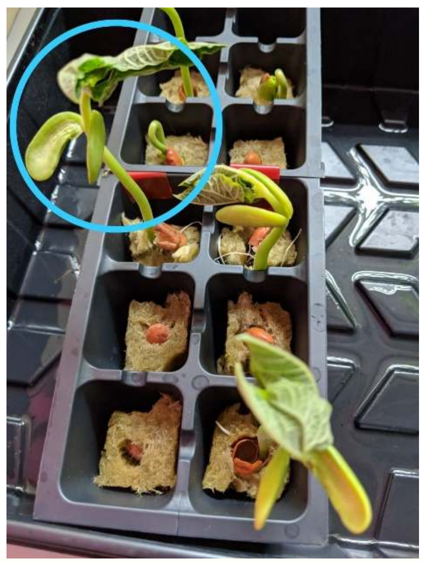


Biosynthesis of Phenylpropanoids and Phenolic Compounds

(Valgimigli, 2012)

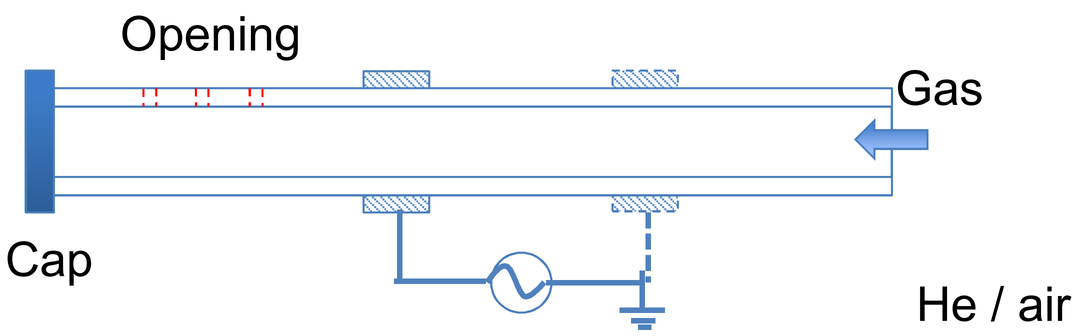


Aeroponic & Aquaponic Investigations

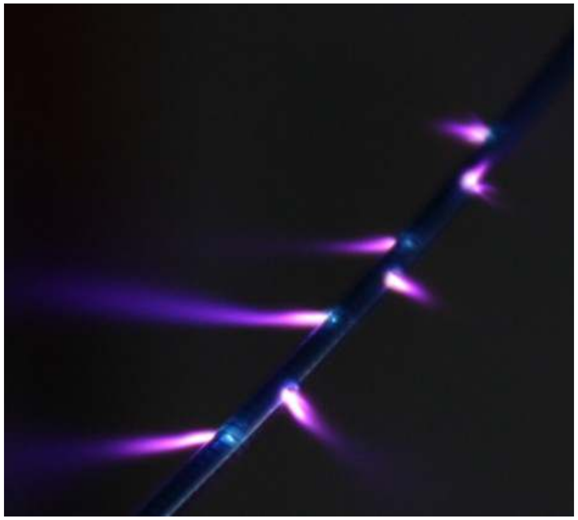


Kidney Bean Research

Create plasma jets in multiple directions



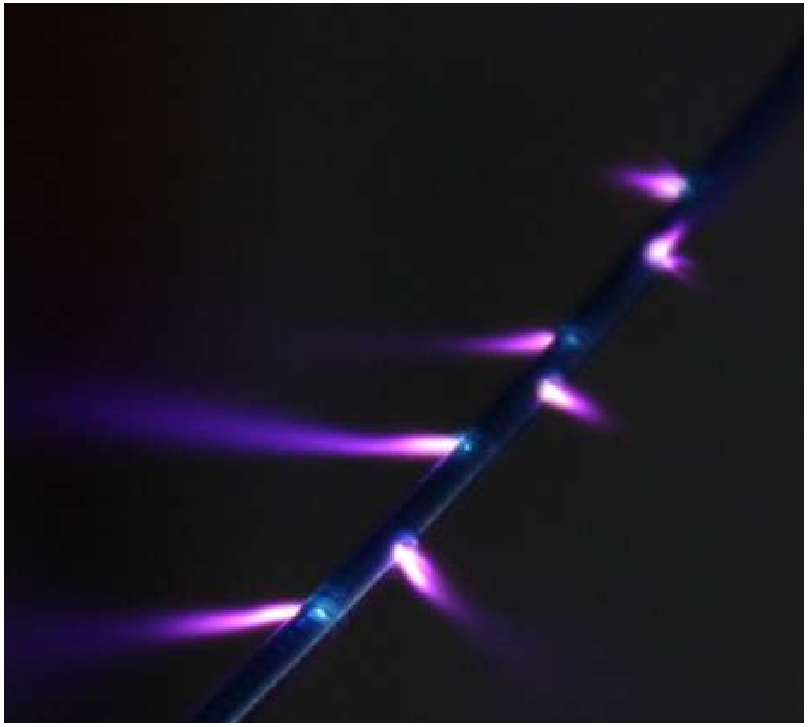
3-D Arrays!



Plasma Jet Array

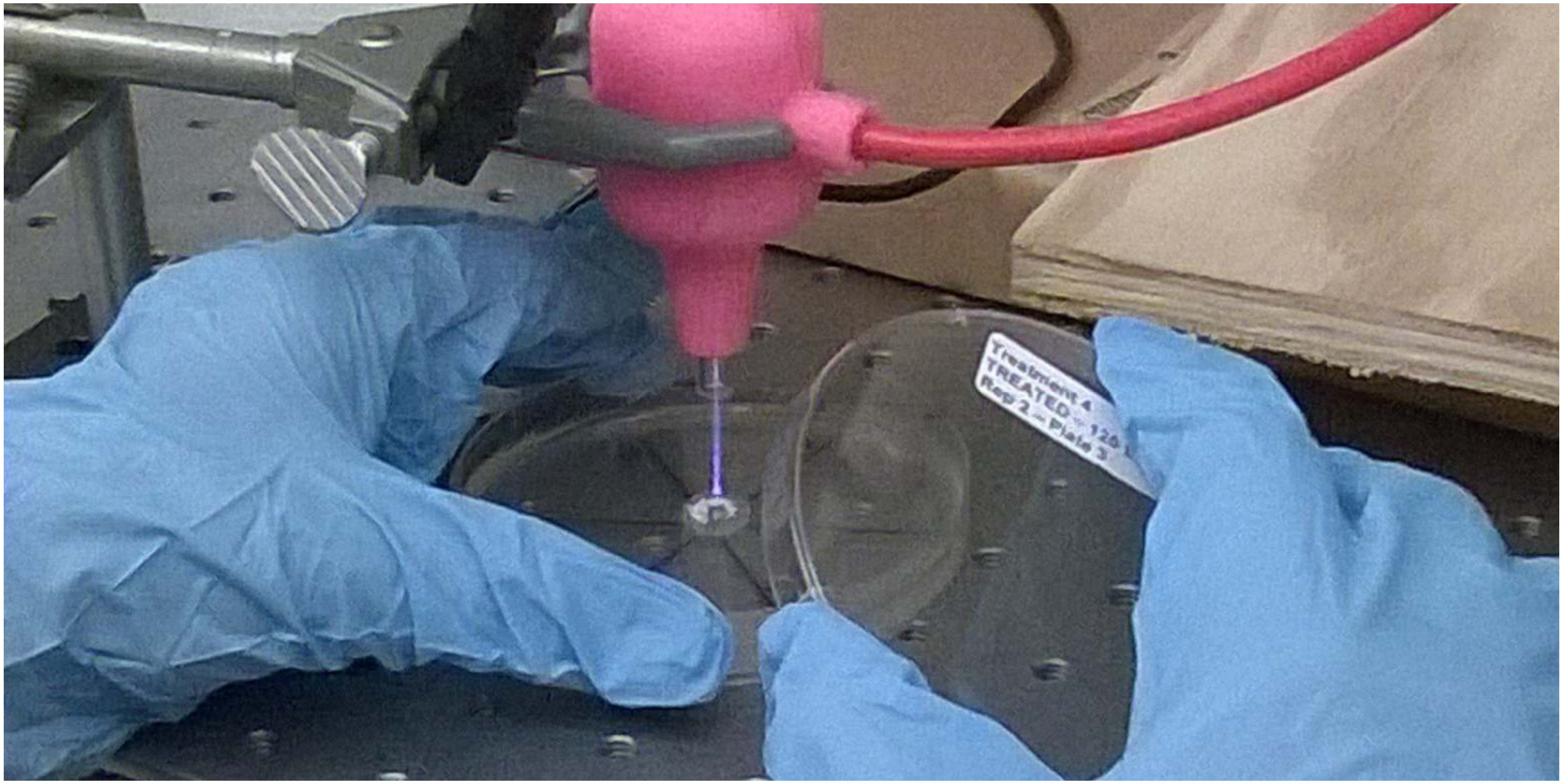
Irrigation: Water & Plasma

Water irrigation in fields and greenhouses



Plasma irrigation for agriculture

Plasma Treatment of Fungi



Peng Sun, Yi Sun, Haiyan Wu, Weidong Zhu, Jose L Lopez, Wei Liu, Jue Zhang, Ruoyu Li, Jing Fang. *Atmospheric pressure cold plasma as an antifungal therapy*. Applied Physics Letters. Vol. 98, Issue 2 (2011).

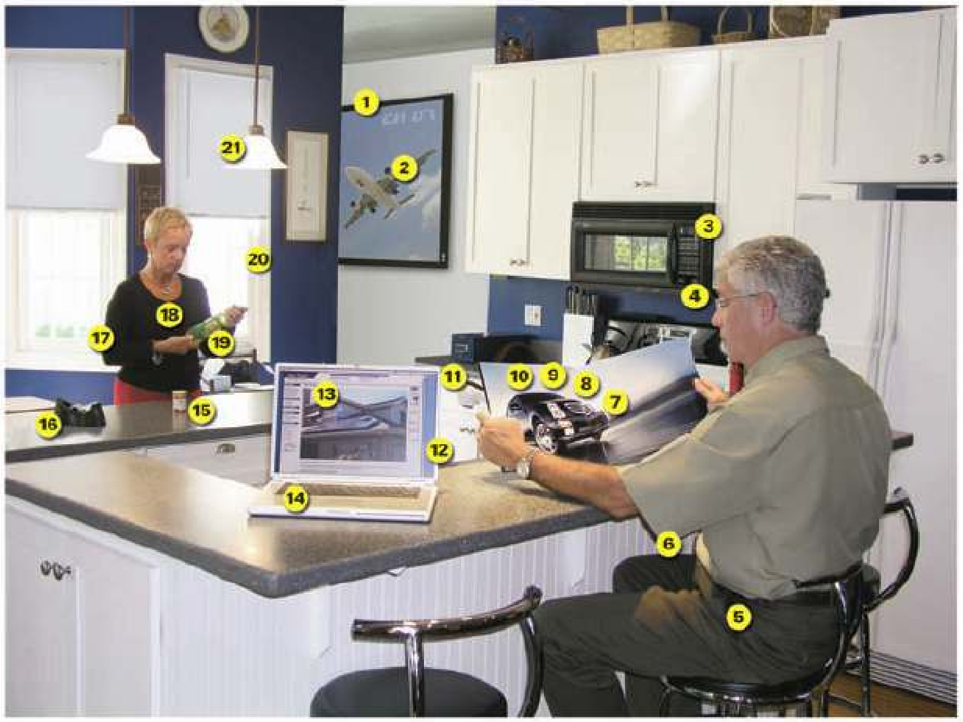
SETON HALL UNIVERSITY

The Future of Agriculture

‘Food’ for Thought

- Urban areas are a direct result of the tremendous historical success of agriculture.
  - Global food security has essentially eliminated famine.
  - This has created more time to discover, invent, innovate & disrupt.
- Urban populations as they grow will more and more determine what they want to ‘Eat’.
- The human capital + physical infrastructure found in cities will create many Smart-Sectors
  - SmartAg is ripenning for disrupt Agro-Food systems

Plasma enabled technology



01—Plasma TV
02—Plasma-coated jet turbine blades
03—Plasma-manufactured LEDs in panel
04—Diamondlike plasma CVD eyeglass coating
05—Plasma ion-implanted artificial hip
06—Plasma laser-cut cloth
07—Plasma HID headlamps
08—Plasma-produced H_2 in fuel cell
09—Plasma-aided combustion
10—Plasma muffler
11—Plasma ozone water purification
12—Plasma-deposited LCD screen
13—Plasma-deposited silicon for solar cells
14—Plasma-processed microelectronics
15—Plasma-sterilization in pharmaceutical production
16—Plasma-treated polymers
17—Plasma-treated textiles
18—Plasma-treated heart stent
19—Plasma-deposited diffusion barriers for containers
20—Plasma-sputtered window glazing
21—Compact fluorescent plasma lamp

Plasmas in the kitchen. Plasmas and the technologies they enable are pervasive in our everyday life. Each one of us touches or is touched by plasma-enabled technologies every day.

Plasma Science: Advancing Knowledge in the National Interest. Plasma 2010 Committee, Plasma Science Committee, National Research Council. ISBN: 0-309-10944-2, 280 pages, (2007)

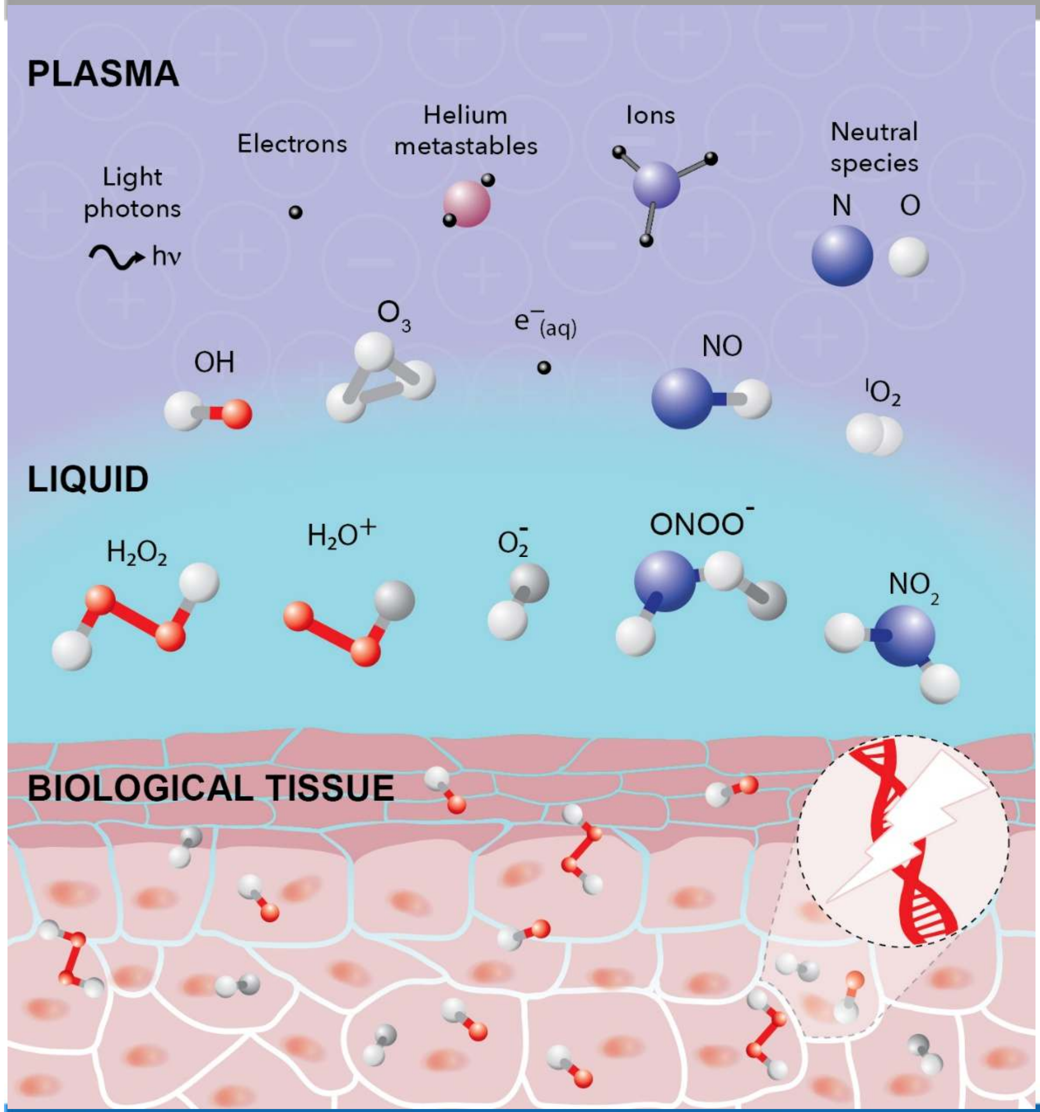
Major Global Challenges

National Academies of Sciences, Engineering, and Medicine have identified major global challenges in the 21st century that science and technology must help solve:

1. Energy
2. Environment
3. Water Resources
4. Agriculture and Food Security
5. Global Health / Population / Human Rights International Security

Plasmas provide some potential solutions to many of these global challenges.

What is plasma interaction doing to the biological material?



Many unanswered questions as to the role of plasma in the biological interactions with biological materials.

- What are the plasmas doing to the live biological materials?
- Can plasma sources be tailored to better control interactions with biological materials?

IEEE TRANSACTIONS ON PLASMA SCIENCE

Jose L. Lopez – Seton Hall University

Senior Editor of Industrial, Commercial, and Medical Applications of Plasmas

Masters of Science (M.S.) in Physics

Two M.S. in Physics Degree Tracks:

1. Course track (33 credits) for educators / doctoral degree (Ed.D.) and business tracks (M.B.A)
2. Master’s Thesis (30 credits) for R&D research or scientific research doctoral degree (Ph.D.)

Research Areas:

1. Plasma Physics - Science & Technology
2. Condensed Matter / Complex Matter Physics
3. Biophysics & Environmental Physics
4. Environmental Systems & Technologies

COLLEGE OF ARTS AND SCIENCES
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DEPARTMENT OF PHYSICS

Questions???