Faculty of Engineering
SRINAKHARINWIROT UNIVERSITY

Applications of atmospheric plasma on water treatment and agricultural enhancement

Khanit MATRA

Department of Electrical Engineering, Faculty of Engineering

SRINAKHARINWIROT UNIVERSITY

Khanit@g.swu.ac.th, mr.khanit@gmail.com

The International Symposium 2022
on "Plasma Tech – Driving Sustainable Future"

https://www.foodsafetynews.com/2016/12/cold-plasma-proving-to-be-hottest-new-food-safety-treatment/

Presentation Outline

- Introduction
- Background knowledge
- Applications of Plasma on Agriculture
- [my] Current researches
- Summary
- Challenge of implementing plasma technologies in Thailand

Agriculture in Thailand

Regarding the data from the International Trade Administration,

"Agriculture accounts for only six percent of GDP in Thailand but the sector employs around one-third of the country's labor force."

Main sectors of the agriculture industry :

Livestock, Forestry, Fisheries, and Farming

https://www.nycfoodpolicy.org/food-policy-snapshot-thailand-urban-farm/
https://thairestaurantphuket.com/blog/top-five-thai-fruits-to-eat/
https://news.trueid.net/detail/5x1bJEqL2RrQ
http://www.painaidii.com/business/158825/photo/11/lang/th/
https://weanimalsmedia.org/2022/03/09/new-investigation-thai-fish-farms-and-markets/
https://www.kasikornresearch.com/en/analysis/k-econ/business/Pages/z3065.aspx
https://roboticsandautomationnews.com/2020/08/20/thai-agritech-startup-to-use-satellite-images-and-ai-for-farming/35399/

Plant Farming

A significant portion of the world's food is produced through agriculture, and seeds are essential to efficient farming and wholesome food production.

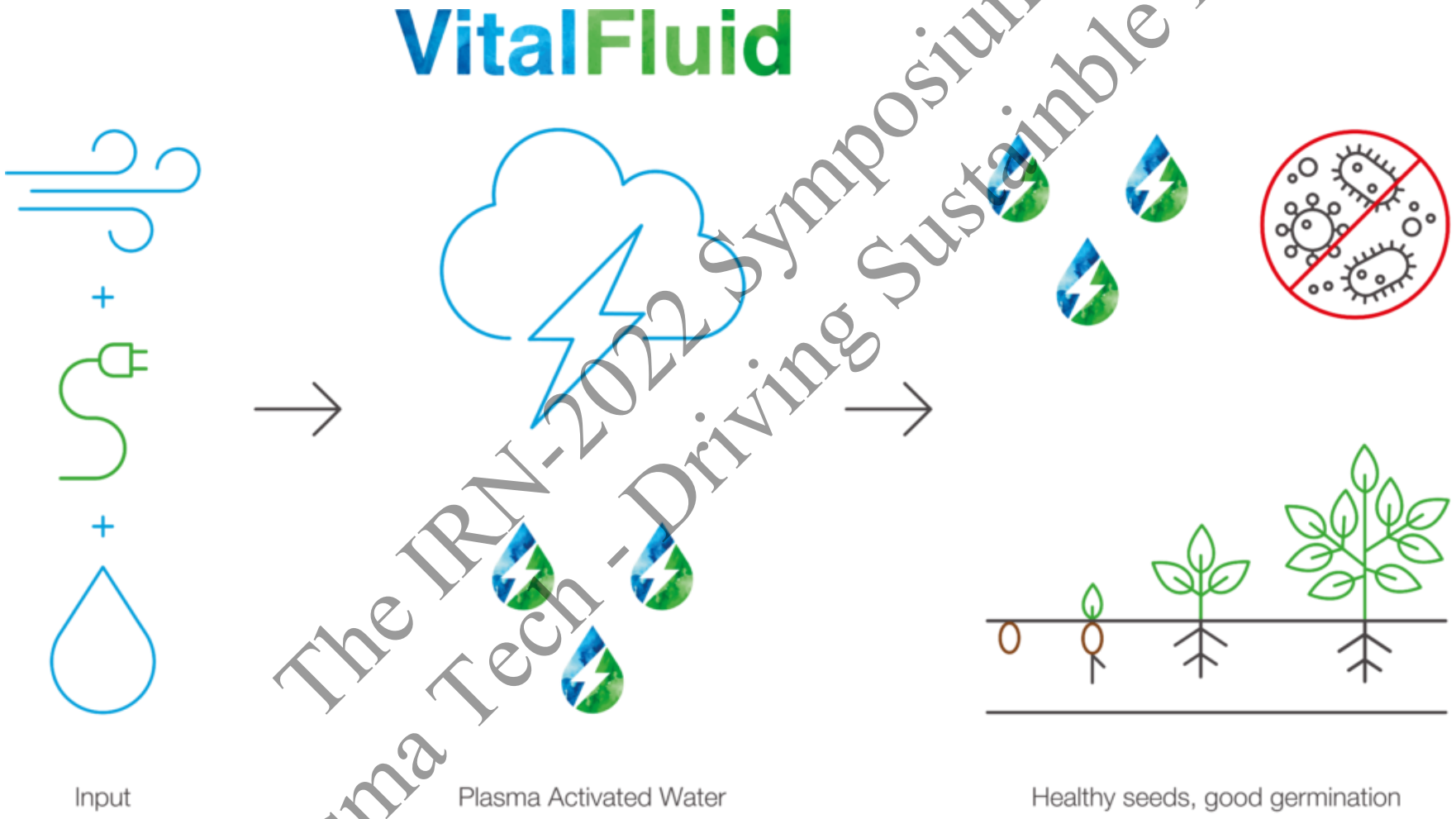
Conventional methods for farming enhancement

- **Chemical fertilizers**
- **Pesticides**

https://greyediting.com
https://www.thairath.co.th/lifestyle/food/1749128
https://www.lacademie.com/rice-flour-vs-glutinous-rice-flour/
https://campus.campus-star.com/variety/145288.html
https://www.kasetcenter.com/th/articles/126657
https://news.trueid.net/detail/5x1bJEqL2RrQ
https://www.kasikornresearch.com/en/analysis/k-econ/business/Pages/z3065.aspx
https://greendee.app/node-poi?nid=7954

Plasma Technology as a Key

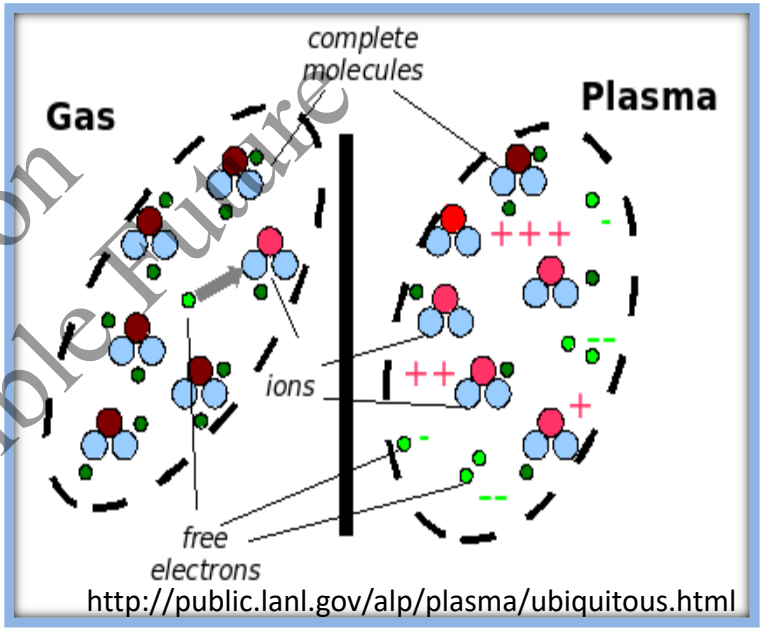
for Sustainable Agricultural Enhancement



https://vitalfluid.com/seed-treatment/

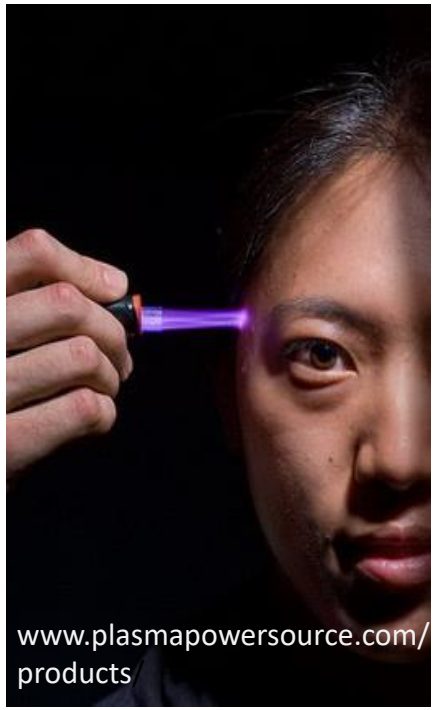
Plasma

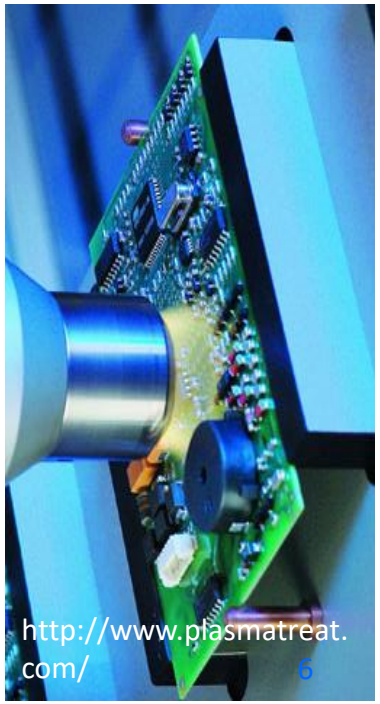
- Ionized gas
- Composed of quasi neutral charge
- Collective behavior due to long length force Coulomb and Lorentz forces)
- 4th state of matter
  [Solid, Liquid, gas and **PLASMA**]



Properties:

- Electrically conductive
- Contained many chemical reactions : medical treatments, pollution purification, electronic technology, chemistry analysis


www.plasmapowersource.com/products

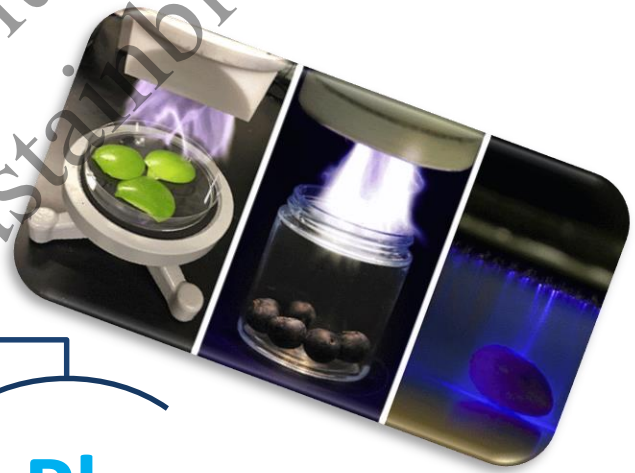

http://www.plasmatreat.com/

Background - Types of Plasma

Plasma

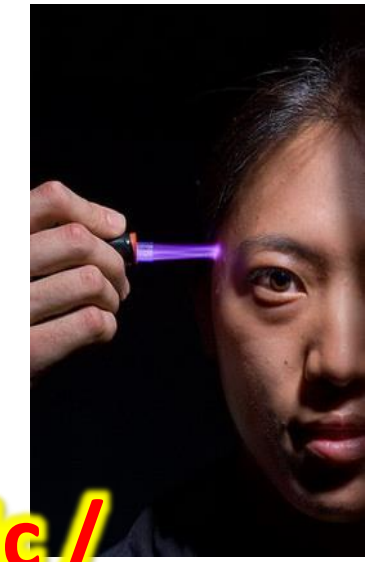
Nature

Man-made

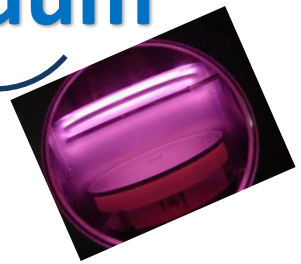


Hot Plasma

Cold Plasma



Vacuum



Atmospheric / High pressure

https://phys.org/news/2014-03-carbon-nanotubes-real-world-applications.html

https://blog.constructionmarketingassociation.org/what-you-need-to-know-about-plasma-cutting-and-welding-in-the-modern-era/

https://ghrc.nsstc.nasa.gov/home/micro-articles/lightning

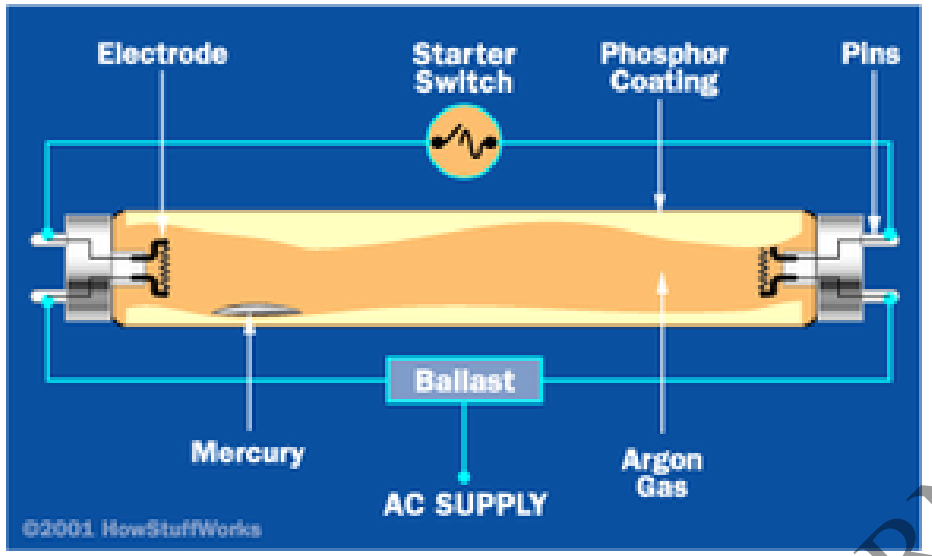
https://scitechdaily.com/scientists-shatter-record-for-the-amount-of-energy-produced-during-a-controlled-sustained-fusion-reaction/

https://www.medfoo.com/2020/05/applications-of-cold-plasma-technology.html

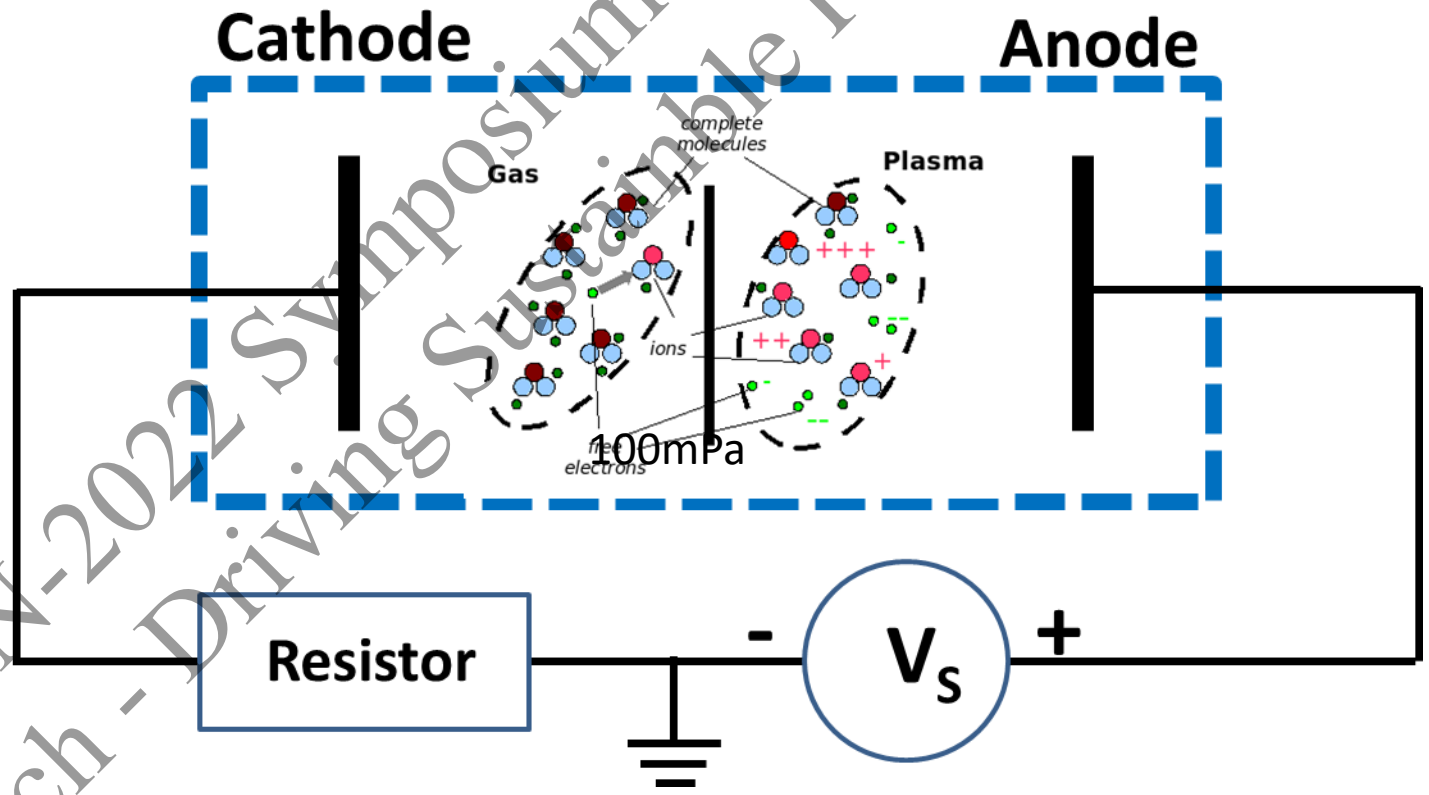
https://www.fastcompany.com/40402319/this-startups-plasma-reactors-create-conflict-free-diamonds-for-the-millennial-marke

Reference : https://sites.google.com/a/tkschool.ac.th/khi-prisna-darasastr-mystery-astronomy/home/rabb-suriya/dwng-xathity

Electrical discharge in Gases



Fluorescent lamp circuit



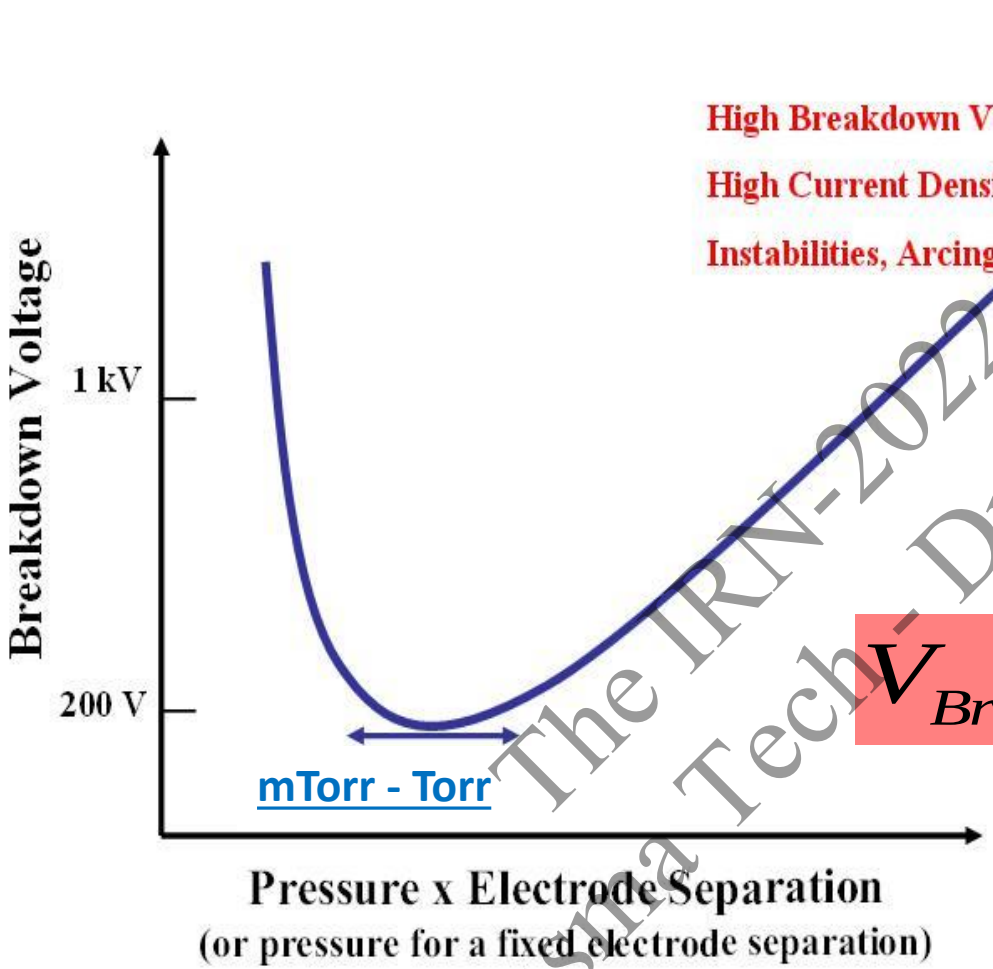
Electric breakdown is the process of conversion of A non conducting material (typically A gas) into A conductor by the application of A high enough electromagnetic field.

https://home.howstuffworks.com/fluorescent-lamp4.htm

http://public.lanl.gov/alp/plasma/ubiquitous.html

From vacuum to atmospheric environment

Paschen's curve



https://commons.wikimedia.org/wiki/File:PaschenCurve.jpg

1atm = 101kPa=760 Tor

Regarding the Similarity laws and Paschen's law, the first non-thermal atmospheric pressure plasma is possible

$$V_{Breakdown} = f(pd)$$

Tachibana, Kunihide. (2006). Current status of microplasma research. IEEJ Transactions on Electrical and Electronic Engineering. 1. 145 - 155. 10.1002/tee.20031.

Classification of Plasma Source

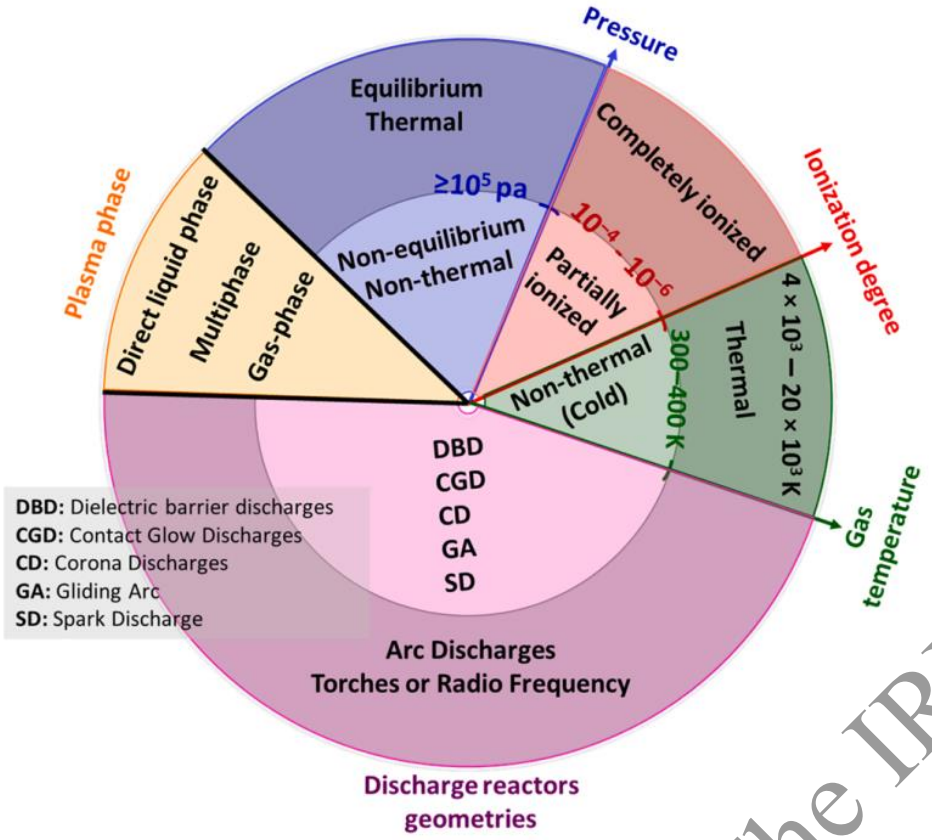


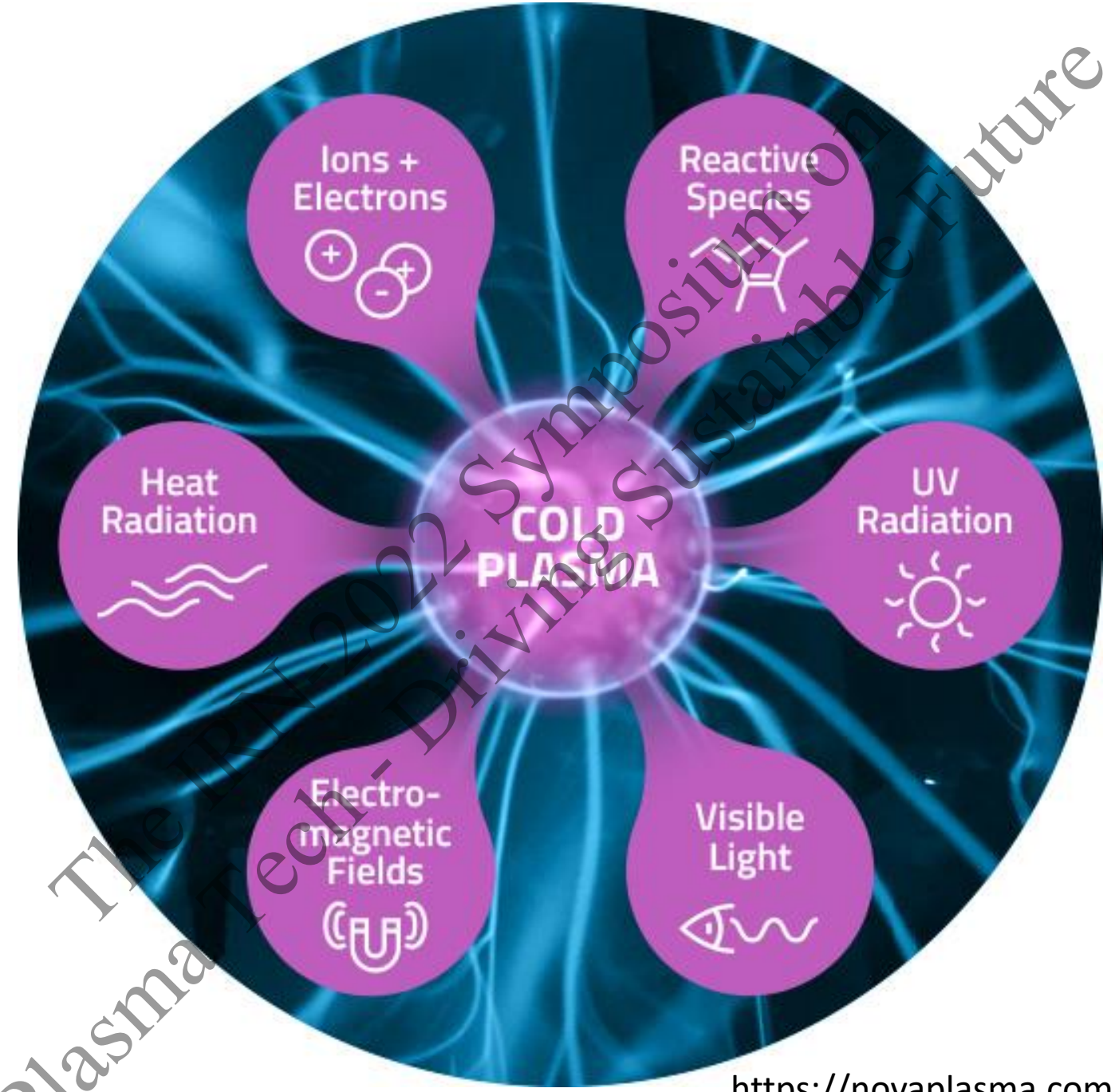
Fig. 5. Different classification of discharges plasma.

Discharge type	P (mbar)	$N_e(cm^{-3})$	$T_e(eV)$	$T_{gas}(K)$
Dielectric barrier	Atm.	10^{12} - 10^{15}	2-10	300-500
Radiofrequency	10^{-3} – atm.	10^{12} - 10^{15}	1-5	300-500
Gliding arc	atm.	10^{11} - 10^{15}	0.5-3	600-3500
Microwave	10^{-5} – atm.	10^{10} - 10^{15}	1-3	300-6000
Glow	10^{-5} – atm.	10^{9} - 10^{12}	0.5-11	300-1000
Corona	atm.	10^{8} - 10^{14}	2-10	300-800

H. Zeghioud, P. Nguyen-Tri, L. Khezami, A. Amrane, and A. A. Assadi, "Review on discharge Plasma for water treatment: mechanism, reactor geometries, active species and combined processes," *J. Water Process Eng.*, vol. 38, 2020, doi: 10.1016/j.jwpe.2020.101664.

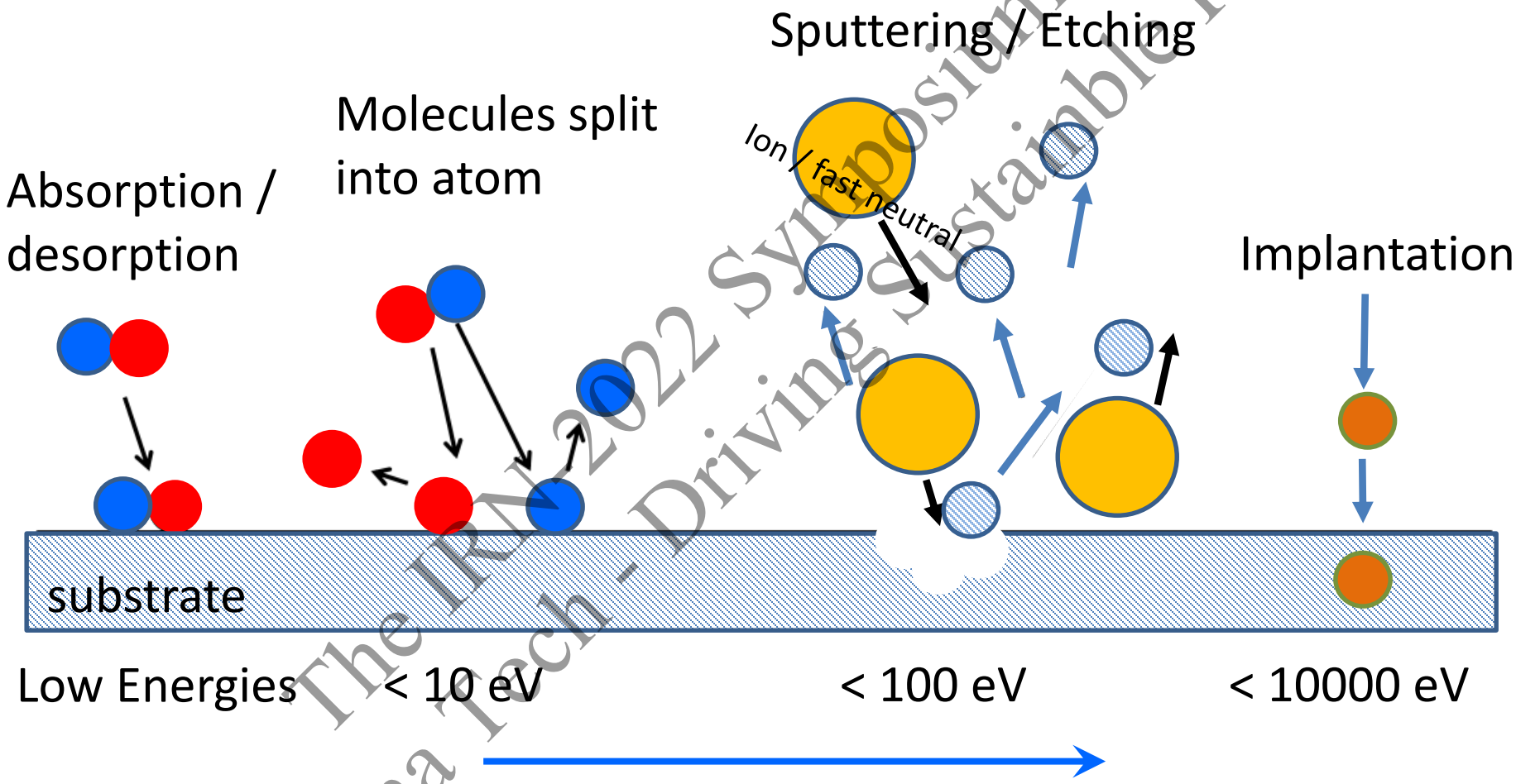
G. Chen, R. Snyders, and N. Britun, "CO2conversion using catalyst-free and catalyst-assisted plasma-processes: Recent progress and understanding," *J. CO2 Util.*, vol. 49, no. April, p. 101557, 2021, doi: 10.1016/j.jcou.2021.101557.

Utilization of cold plasma

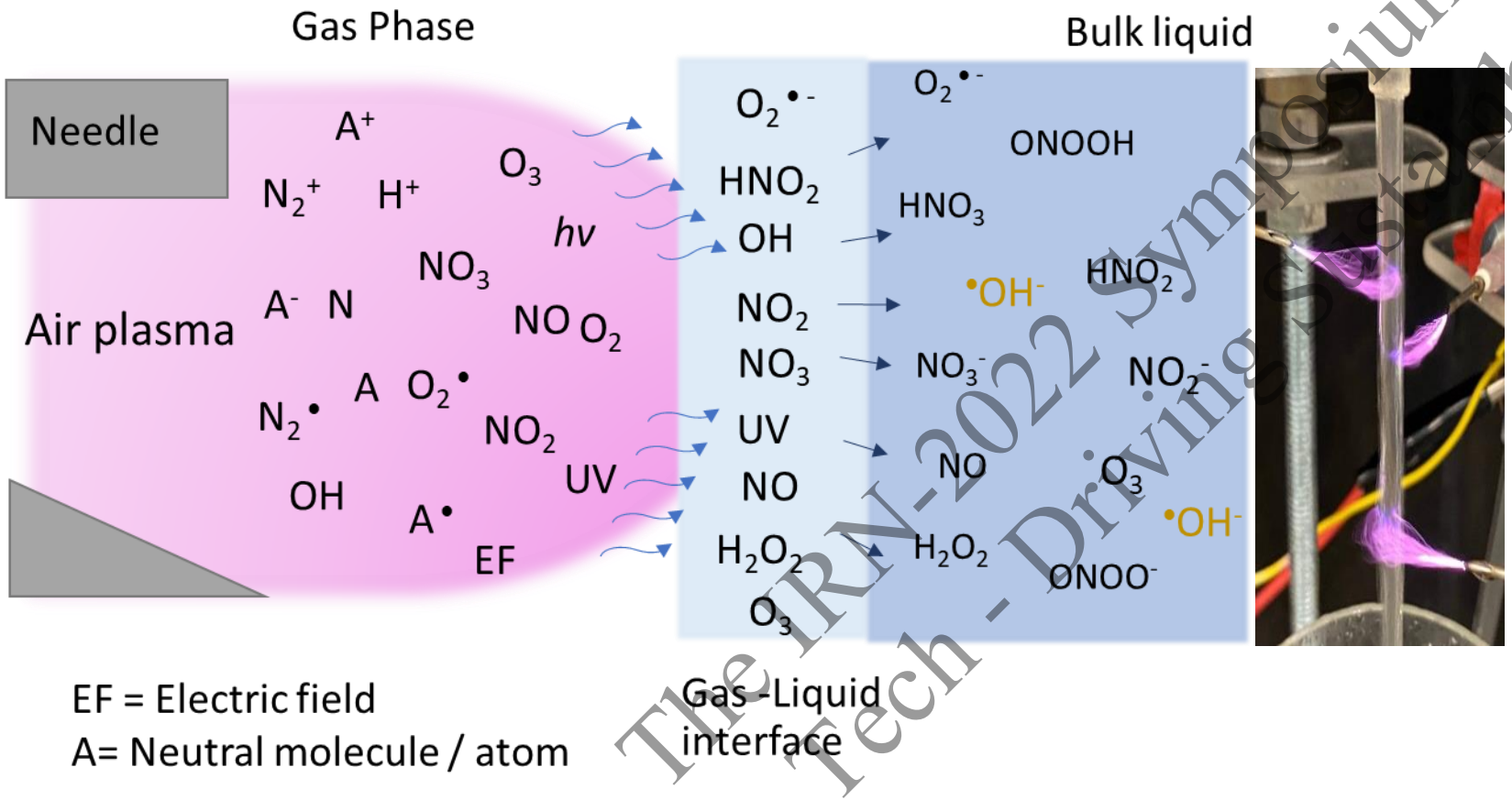


https://novaplasma.com/cold-plasma-technology/

Plasma – surface interaction



Plasma-Chemical reactions

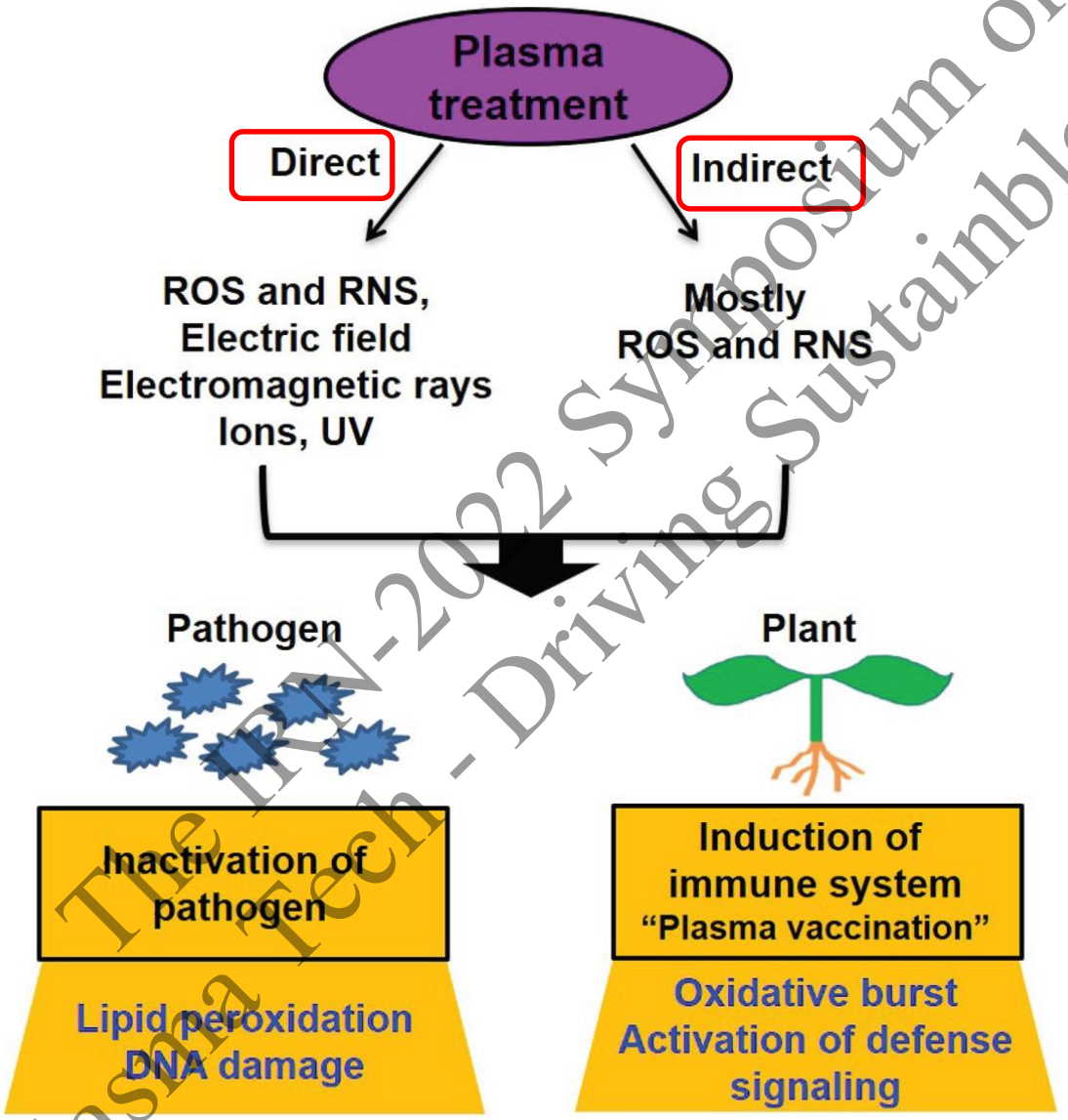


- **Primary RONS**, such as •OH, •NO, H_2O_2, O, O_3, are mainly created in the gas phase plasma
- **Secondary RONS**, such as, e.g., •OH and $•NO_2$ from HOONO, HNO_2, and HNO_3 from •NO and $•NO_2$, are the result of degradation or interaction of the primary RONS with each other or molecules in media
- **Long-lived molecular and ionic chemical species**, which remain in solution after plasma treatment, such as H_2O_2, NO_2^-, NO_3^-
- **Short-lived RONS** : O, •NO, •OH, O_2•-/•OOH , peroxynitrite (ONOO-), peroxynitrate (OONOO-)

Interactions of reactive species generated during air plasma generations with the treated liquid

Theepharaksapan, S., Lerkmahalikhit, Y., Suwannapech, P., Boonnong, P., Limawatchanakarn, M., & Matra, K. (2021). Impact of multi-air plasma jets on nitrogen concentration variance in effluent of membrane bioreactor pilot-plant. Engineering and Applied Science Research, 48(6), 732–739. https://doi.org/10.14456/easr.2021.75

Applications of cold plasma



- Medical treatment
- Food industry
- Environment
- Agriculture

Adhikari, B., Pangomm, K., Veerana, M., Mitra, S., & Park, G. (2020). Plant disease control by non-thermal atmospheric-pressure plasma. *Frontiers in plant science*, *11*, 77.

Plasma in Agriculture

Physical Factors

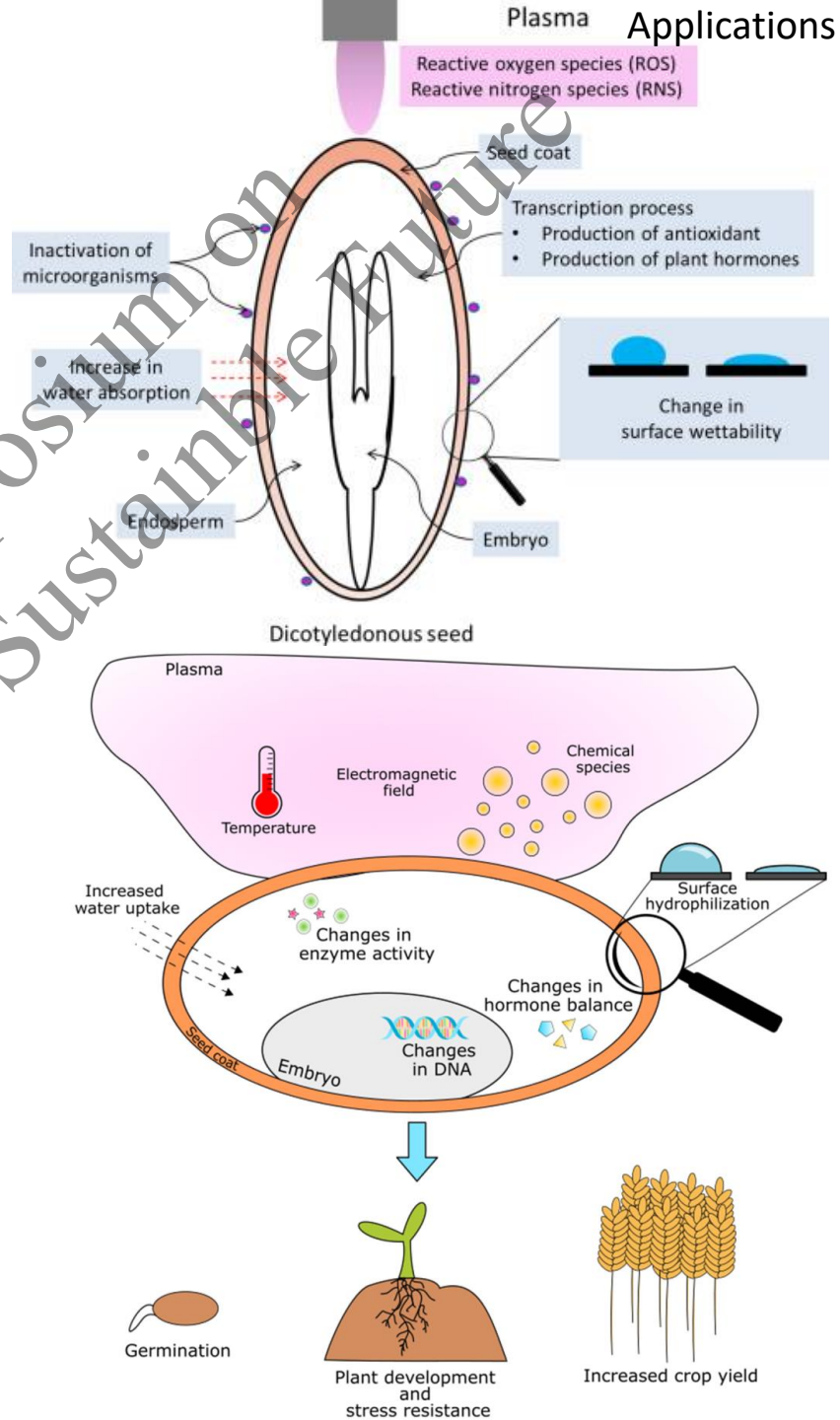
- Heat
- Ultraviolet ray (UV)
- Electromagnetic fields (EMF)
- Surface modification (sputtering)

Chemical Factors

- Nutrient Absorption
- Gas Exchange

Biochemical and Molecular Factors

- Chemical Species
- Hormones
- Metabolism
- Defense
- Gene Expression
- Epigenetics and Genetics



- Waskow, A.; Howling, A.; Furno, I. Mechanisms of Plasma-Seed Treatments as a Potential Seed Processing Technology. *Front. Phys.* **2021**, *9*, 1–23, doi:10.3389/fphy.2021.617345.
- Ohta, T. (2016). *Chapter 8 - Plasma in Agriculture* (N. N. Misra, O. Schlüter, & P. J. B. T.-C. P. in F. and A. Cullen, eds.). San Diego: Academic Press.
- Starič, P., Vogel-Mikuš, K., Mozetič, M., & Junkar, I. (2020). Effects of Nonthermal Plasma on Morphology, Genetics and Physiology of Seeds: A Review. Plants , Vol. 9. https://doi.org/10.3390/plants9121736

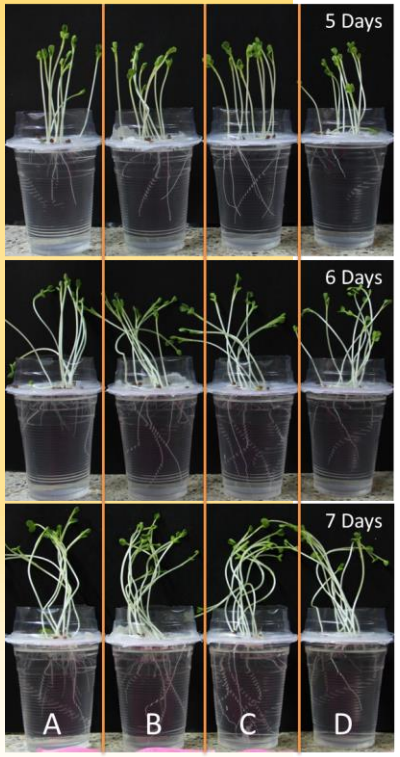
[my] Current Research Topics

- Agricultural Enhancement
  - Seed and plant growth enhancement
  - Nutrition enrichment
- Plasma activated water
  - Leachate water purification
  - Reused water enhancement
  - Micro algae farming
- Micro organism inactivation
  - Micro organism contaminated in food sterilization
  - Surface micro organism disinfection

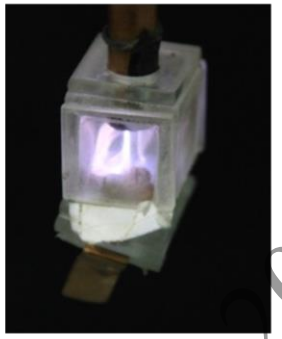
Agricultural Enhancement

Seed and plant growth enhancement

- Sunflowers, Radish, Jasmine rice, Mustard Green, and Microgreen Seed



Plasma Enhancement of Seed Germination



❖ *From the experimental results, it could be confirmed that plasma treatment could enhance the growth rate of sunflower seeds and radish seeds, increasing 10 percent of the dry weight radish*

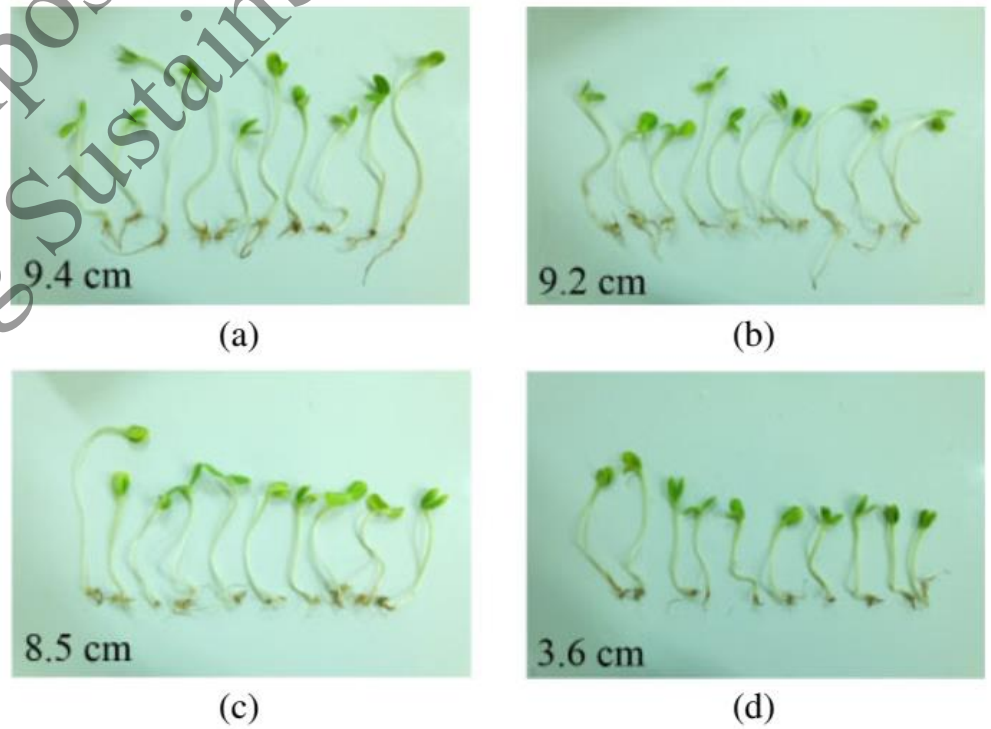


Fig. 7. (Color online) Images of sunflower sprouts treated with plasma for (a) 1, (b) 3, (c) 5, and (d) 0 (control group) min at a V_s of 8 kV and a 3 : 3 LPM of Ar : O_2 flow rate ratio, after 7 days of cultivation. The number depicted in each image is the average shoot length of sunflower sprouts under that experimental condition.

[1] K. Matra, "**Atmospheric non-thermal argon-oxygen plasma for sunflower seedling growth improvement**," *Jpn. J. Appl. Phys.*, vol. 57, no. 1, 2018, doi: 10.7567/JJAP.57.01AG03.

[2] K. Matra, "**Atmospheric non-thermal argon-oxygen plasma for sunflower seedling growth improvement**," *Jpn. J. Appl. Phys.*, vol. 57, no. 1, 2018, doi: 10.7567/JJAP.57.01AG03.

Agricultural Enhancement

Nutrition enrichment

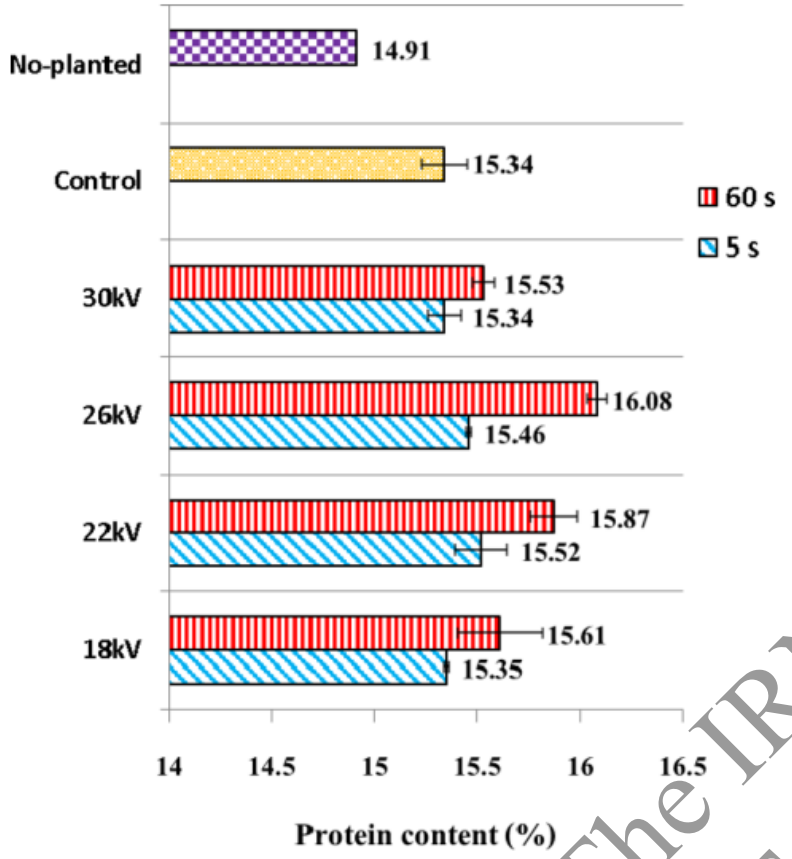
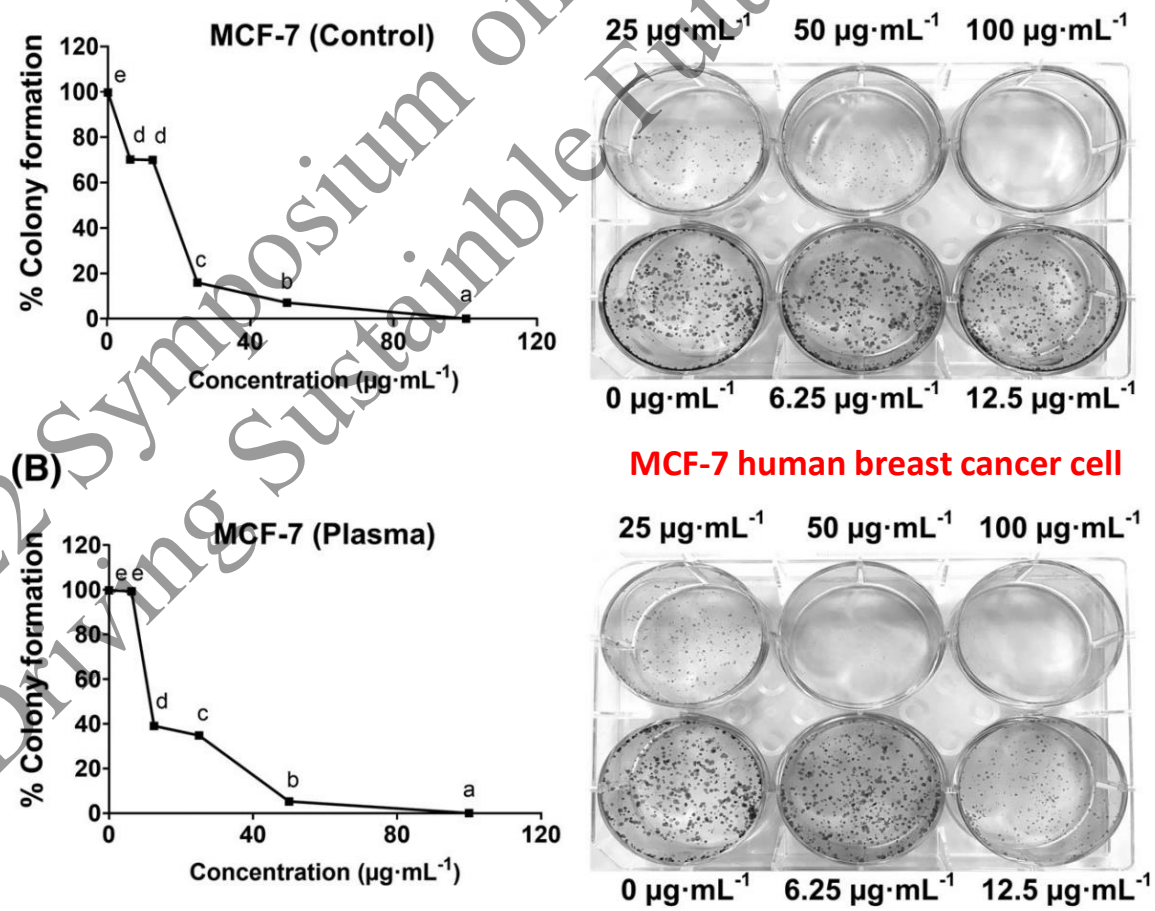


Fig. 8 The protein content of pre-germinated brown jasmine rice that has been treated with plasma under various V_S and treatment time, the control group, and no-planted group



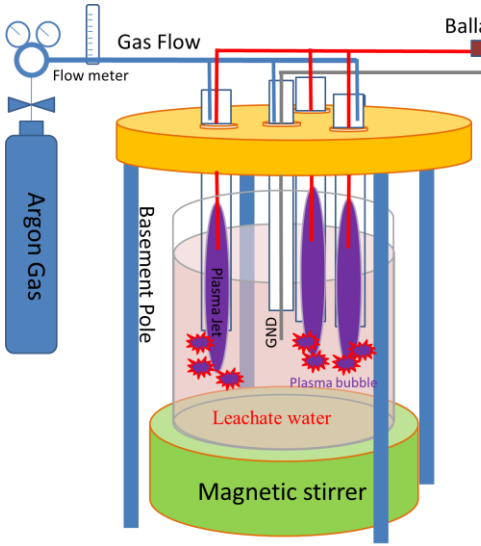
Antiproliferative effect. (A) MCF-7 cells treated with control. (B) MCF-7 cells treated with plasma. Control = RTR microgreen extract from control seeds. Plasma = RTR microgreen extract from plasma-treated seeds.

[1] Y. Tanakaran and K. Matra, "**The Influence of Atmospheric Non-thermal Plasma on Jasmine Rice Seed Enhancements**," *J. Plant Growth Regul.*, 2021, doi: 10.1007/s00344-020-10275-1.

[2] V. Luang-In *et al.*, "**Effect of cold plasma and elicitors on bioactive contents, antioxidant activity and cytotoxicity of Thai rat-tailed radish microgreens**," *J. Sci. Food Agric.*, vol. 101, no. 4, pp. 1685–1698, Mar. 2021, doi: 10.1002/jsfa.10985.

Plasma activated water

- Leachate water purification
- Reused water enhancement



- Stainless-steel needle anode was 0.5Ø mm
- Glass tube was 180 mm length with the inner and outer diameter of 4 and 6 mm, respectively.
- The tip of the needle anode was located above the tip of glass tube for 15 mm.
- To treat the stabilized landfill leachate, the tip of plasma jet generator was immersed in 250 ml beaker under the liquid level for 50 mm.
- Ground electrode was located at the center of 3 plasma jet generators, and also immersed under the leachate at the same level of tip of the glass tube's tip.
- The plasma jet was operated at the output power of 18.5 watt with the frequency of 93 kHz.

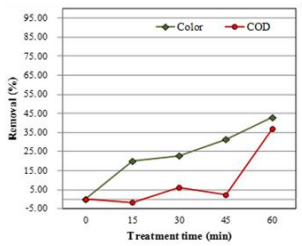


Fig. 3. Effect of plasma treating time on COD and color removal efficiency of the leachate water case 1.

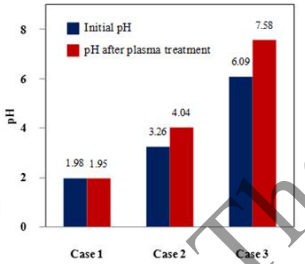
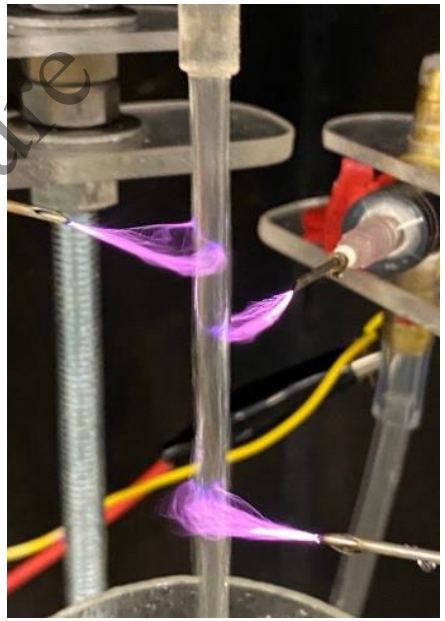


Fig. 2. pH of leachate at the different acidity before and after plasma treatment

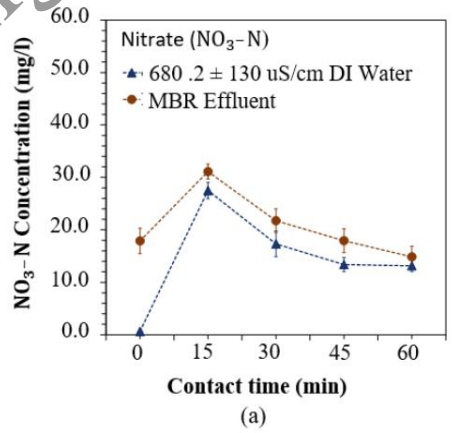
Fig. 1. Atmospheric non-thermal plasma generator for landfill leachate treatment.

[1] S. Theepharaksapan and K. Matra, "**Atmospheric Argon Plasma Jet for Post-Treatment of Biotreated Landfill Leachate**," in *IEECON 2018 - 6th International Electrical Engineering Congress*, 2018, doi: 10.1109/IEECON.2018.8712320.

MBR water stream being treated by multi-air plasma jets



Micro algae farming



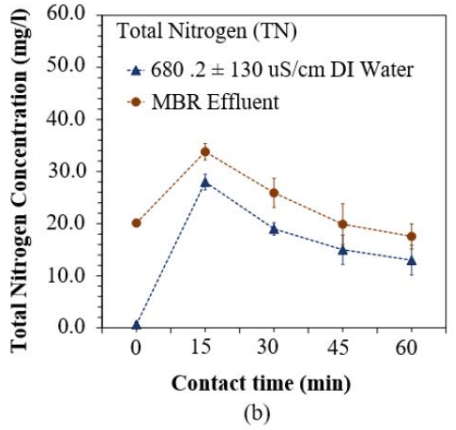
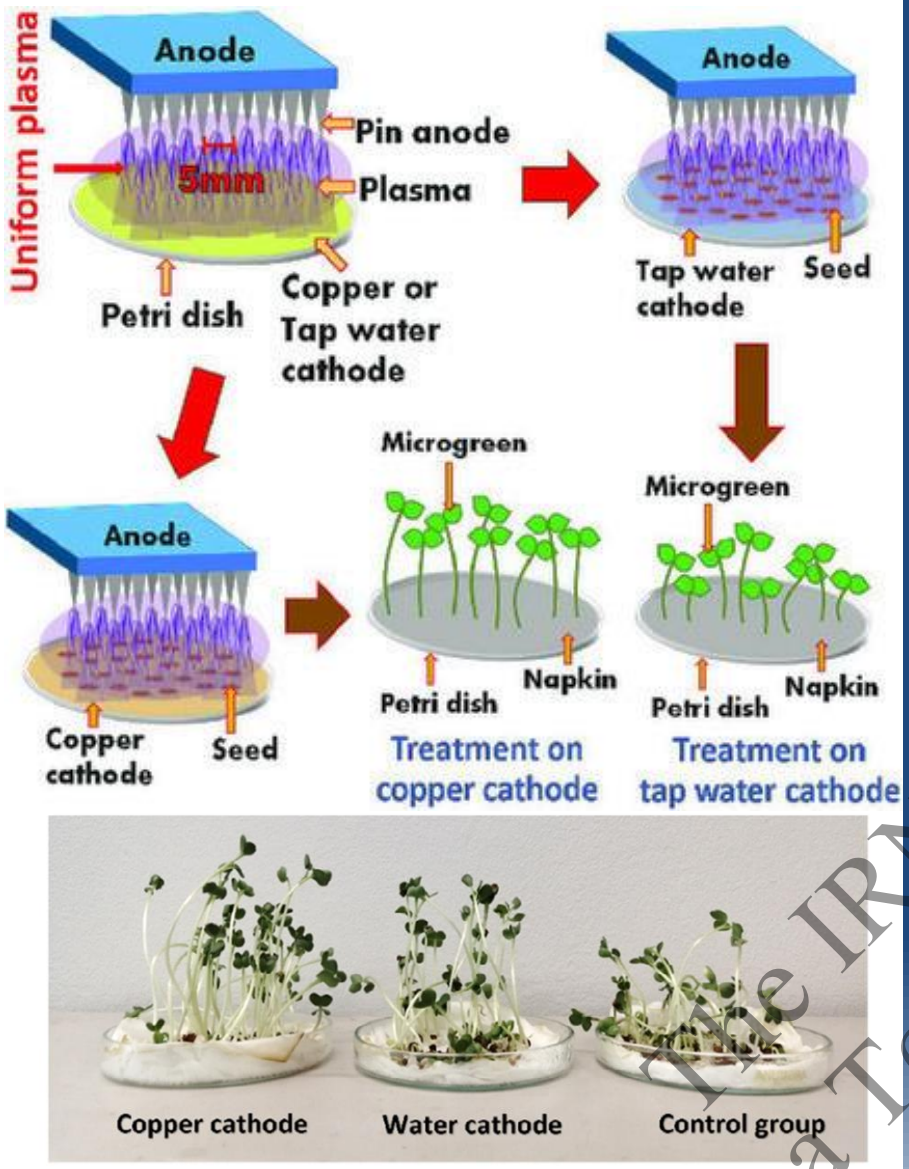


Figure 3 (a) Nitrate-nitrogen concentration, and (b) Total nitrogen concentration in MBR effluent and EC-adjusted DI water at various treatment times.

[2] S. Theepharaksapan, Y. Lerkmahalikhit, P. Suwannapech, P. Boonnong, M. Limawatchanakarn, and K. Matra, "**Impact of multi-air plasma jets on nitrogen concentration variance in effluent of membrane bioreactor pilot-plant**," Eng. Appl. Sci. Res., vol. 48, no. 6, pp. 732–739, 2021, doi: 10.14456/easr.2021.75.



. b) The microgreen sprouts after cultivation for 7 days.

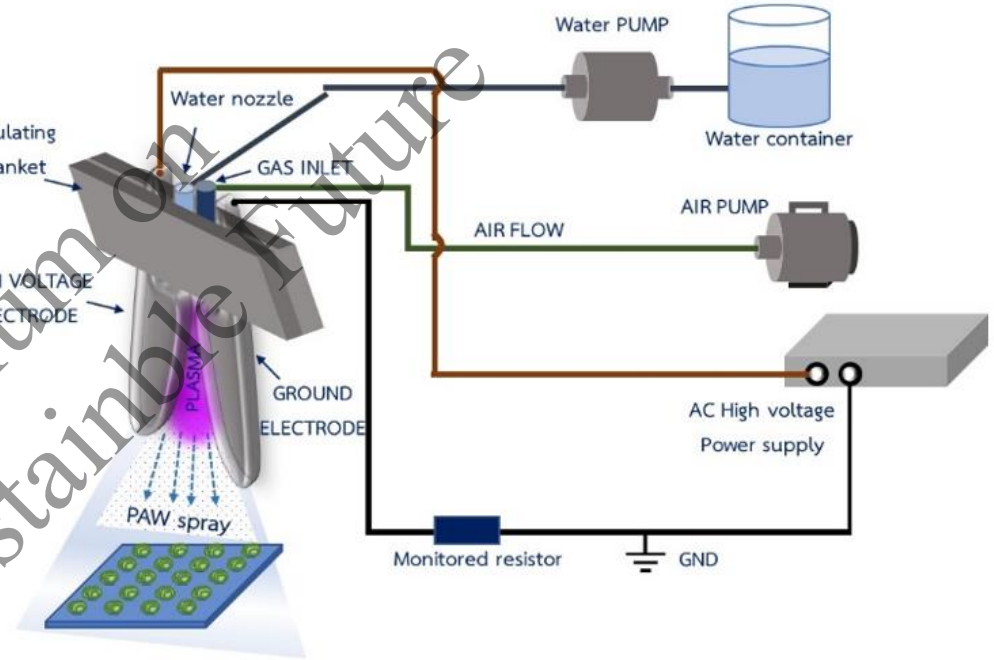


Fig. 1. The schematic drawing of PAW spray gliding arc plasma generator and the experimental setup

TABLE IV
STATISTICAL ANALYSIS RESULTS OF AVERAGE GROWTH PARAMETERS AFTER 9 CULTIVATION DAYS

Conditions	Control	8 kV	10 kV	12 kV
Number of leaves	7.11 ± 0.036^{b}	7.67 ± 0.04^{a}	7.29 ± 0.04^{ab}	7.24 ± 0.03^{b}
Sprout width (cm)	8.9 ± 0.11^{bc}	10.09 ± 0.08^{a}	9.12 ± 0.07^{b}	8.46 ± 0.10^{c}
Leaf width (cm)	2.19 ± 0.05^{c}	3.11 ± 0.07^{a}	2.53 ± 0.06^{b}	2.44 ± 0.06^{b}
Stem length (cm)	8.54 ± 0.27^{bc}	10.88 ± 0.33^{a}	8.9 ± 0.19^{b}	8.12 ± 0.34^{c}
Fresh weight (g)	20.16 ± 0.69^{c}	29.24 ± 1.05^{a}	25.51 ± 0.75^{b}	21.22 ± 0.65^{c}
Dry weight (g)	1.86 ± 0.68^{bc}	3.14 ± 0.48^{a}	2.46 ± 0.49^{ab}	2.2 ± 0.61^{abc}

*Data are shown as a mean data ± SD of triplicated experiment. Data with different upper-case letters (a, b, c) within the same row are significantly different ($p< 0.05$).

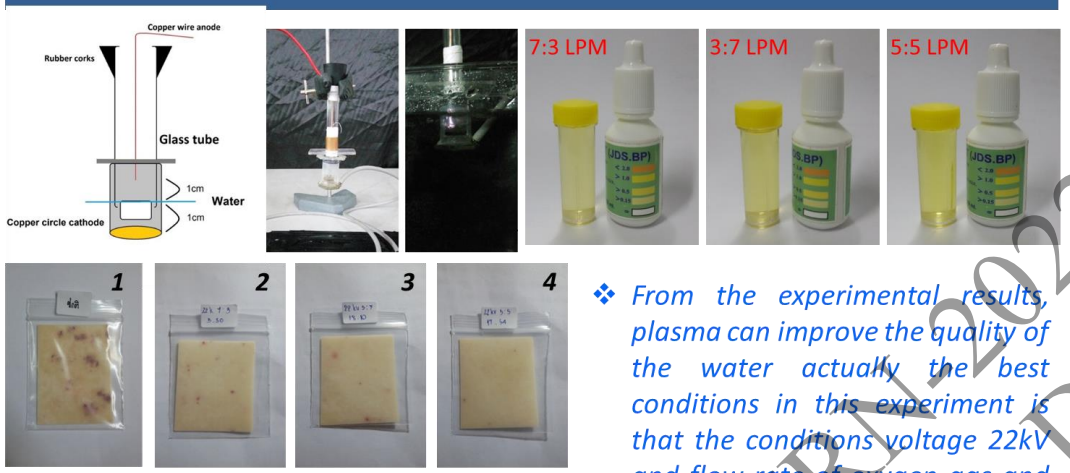
[1] Y. Tanakaran and K. Matra, "**Influence of Multi-Pin Anode Arrangement on Electric Field Distribution Characteristics and Its Application on Microgreen Seed Treatment**," *Phys. Status Solidi Appl. Mater. Sci.*, vol. 218, no. 1, p. 2000240, Nov. 2021, doi: 10.1002/pssa.202000240.

[2] K. Matra, Y. Tanakaran, V. Luang-In, and S. Theepharaksapan, "**Enhancement of Lettuce Growth by PAW Spray Gliding Arc Plasma Generator**," IEEE Trans. Plasma Sci., pp. 1–10, 2021, doi: 10.1109/TPS.2021.3105733.

Micro organism inactivation

- Micro organism contaminated in food sterilization
- Surface Micro organism disinfection
- PAW sanitizer

Non-Thermal Plasma for Bio Decontamination of Wastewater



Bacteria in wastewater

1. No plasma treatment
2. Oxygen per Argon 7:3
3. Oxygen per Argon 3:7
4. Oxygen per Argon 5:5

❖ *From the experimental results, plasma can improve the quality of the water actually the best conditions in this experiment is that the conditions voltage 22kV and flow rate of oxygen gas and argon gas at 5: 5 LPM.*

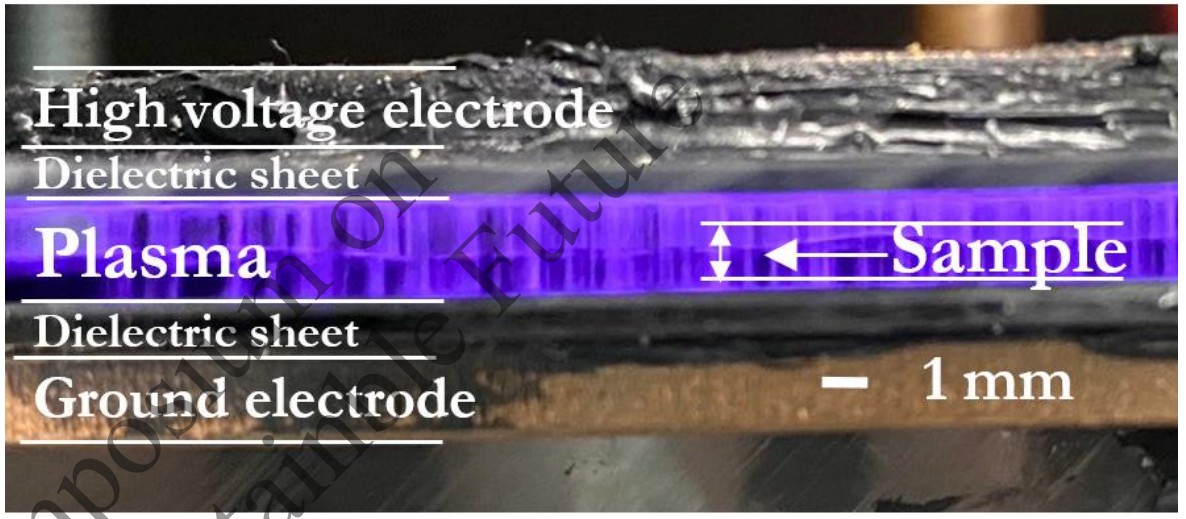
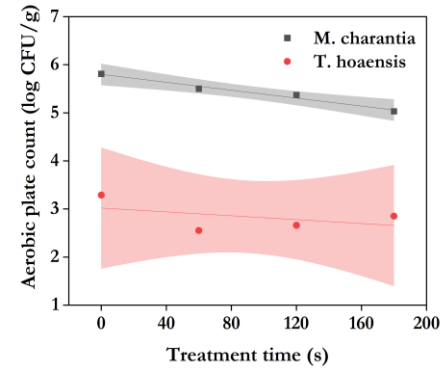


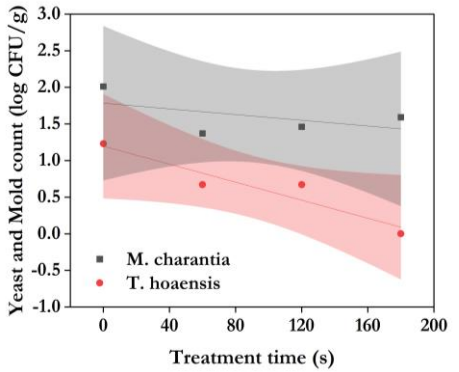
Table 1. Microbial inactivation of herb powders by DBD plasma at various treatment times (s).

	Microbe/treatment time (s)*			
	0	60	120	180
Bitter Melon (*M. charantia*)				
TPC	5.81±0.16^{a}	5.50±0.09^{ab}	5.37±0.01^{ab}	5.03±0.32^{c}
YM	2.01±0.17^{a}	1.37±0.41^{a}	1.46±0.45^{a}	1.59±0.11^{a}
BC	< 10	< 10	< 10	< 10
CL	< 3.0	< 3.0	< 3.0	< 3.0
EC	< 3.0	< 3.0	< 3.0	< 3.0
SA	< 3.0	< 3.0	< 3.0	< 3.0
Chan Khao (*T. hoaensis*)				
TPC	3.29±0.36^{a}	2.55±0.15^{b}	2.66±0.10^{b}	2.85±0.15^{b}
YM	1.23±0.4^{a}	0.67±0.57^{ab}	0.67±0.57^{ab}	0.00^{b}
BC	< 10	< 10	< 10	< 10
CL	< 3.0	< 3.0	< 3.0	< 3.0
EC	< 3.0	< 3.0	< 3.0	< 3.0
SA	< 3.0	< 3.0	< 3.0	< 3.0

TPC:Total aerobic plate count (mean±SD log CFU/g); YM:Total yeast and mold count (mean±SD log CFU/g). Values with difference letters (a, b, c) within the row differ significantly (p< 0.05). BC: *B. cereus* (CFU/g). CL: Coliform bacteria (MPN/g). EC: *E. coli* (MPN/g). SA: *S. aureus* (MPN/g).



a)

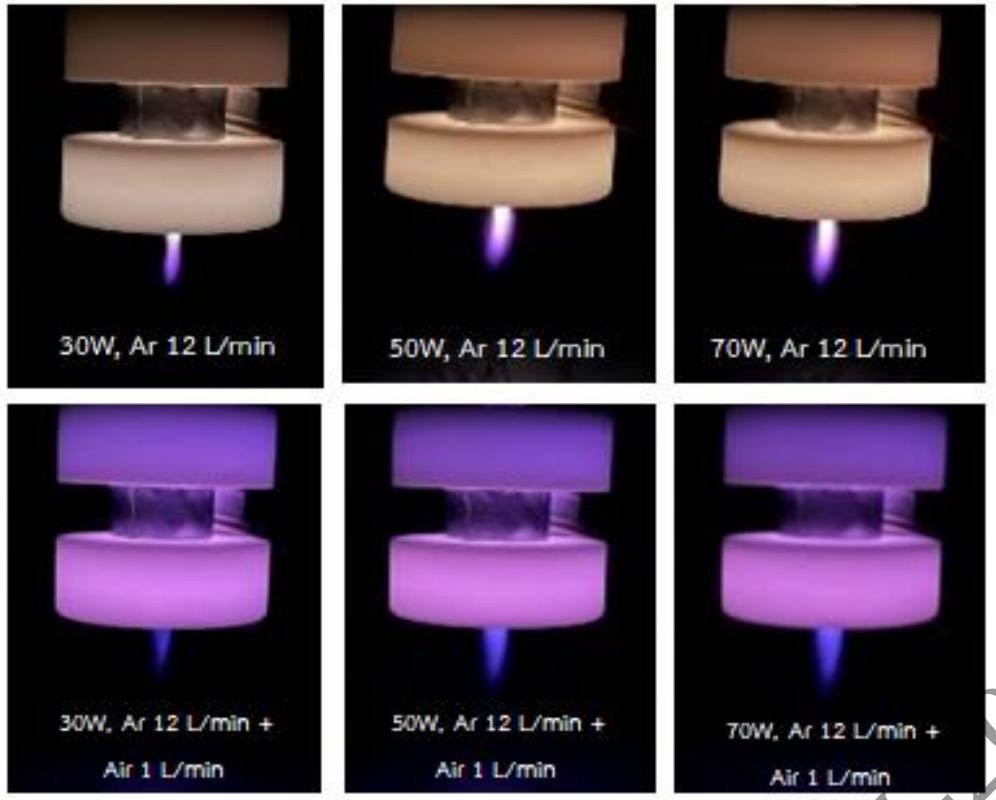


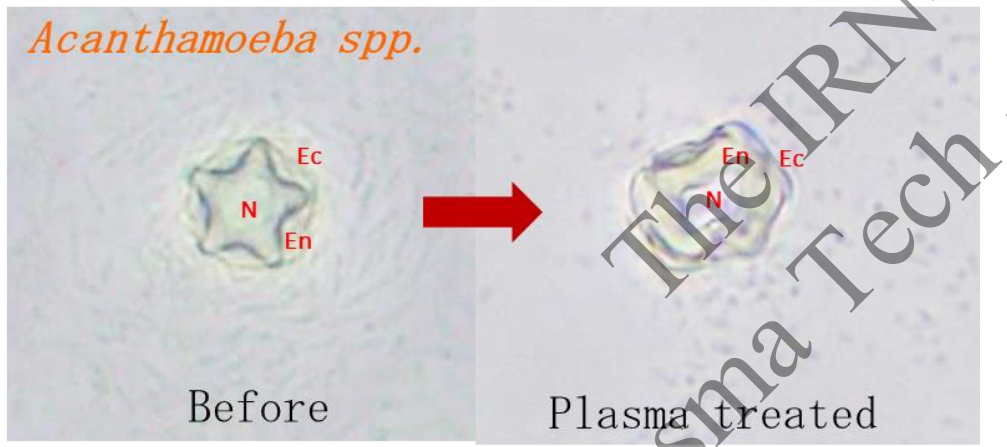
b)

Fig. 4. Reduction of a) total aerobic plate count, and b) total yeast and mold count at various treatment times.

K. Matra, (2016). **Atmospheric Non-thermal Plasma for Improving Wastewater**. In Electrical Engineering Conference (EECON39), Petchburi, Thailand

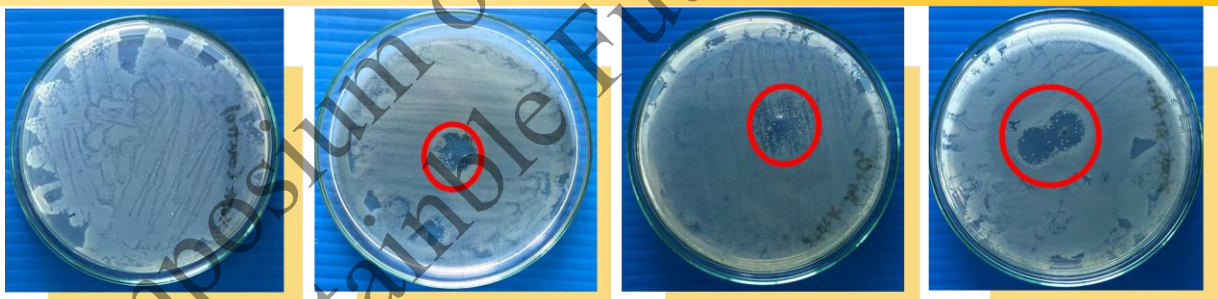
K. Matra, K. Narinram, S. Ploysap, P. Prakongsil, and P. Jiraporn, "**Microbial Reduction of Bitter Melon (*Momordica charantia L .*) and Chan Khao (*Tarenna hoaensis Pitard*) Herb Powder by Dielectric Barrier Discharge Plasma for Food Sanitary**," vol. 2021, no. May 2021, 2021, doi: 10.4186/ej.2021.25.10.87.



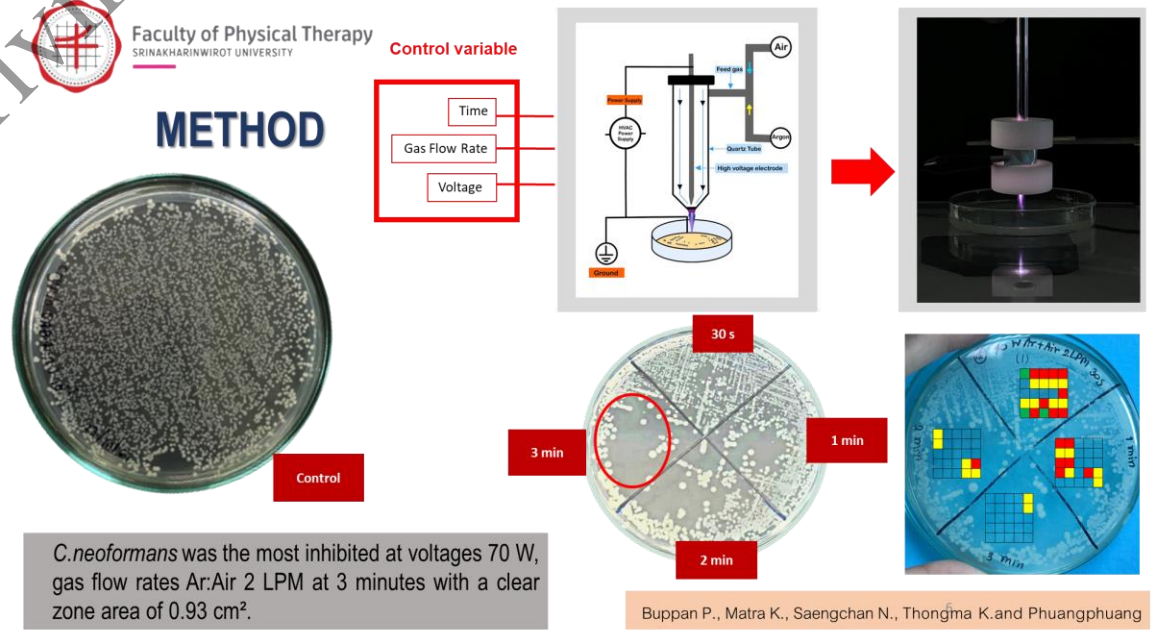


INACTIVATION OF ACANTHAMOEBA BY ATMOSPHERIC PRESSURE COLD PLASMA JET, *In progress*

Clearance zones of *E.coli* strains after plasma treatment by various conditions.

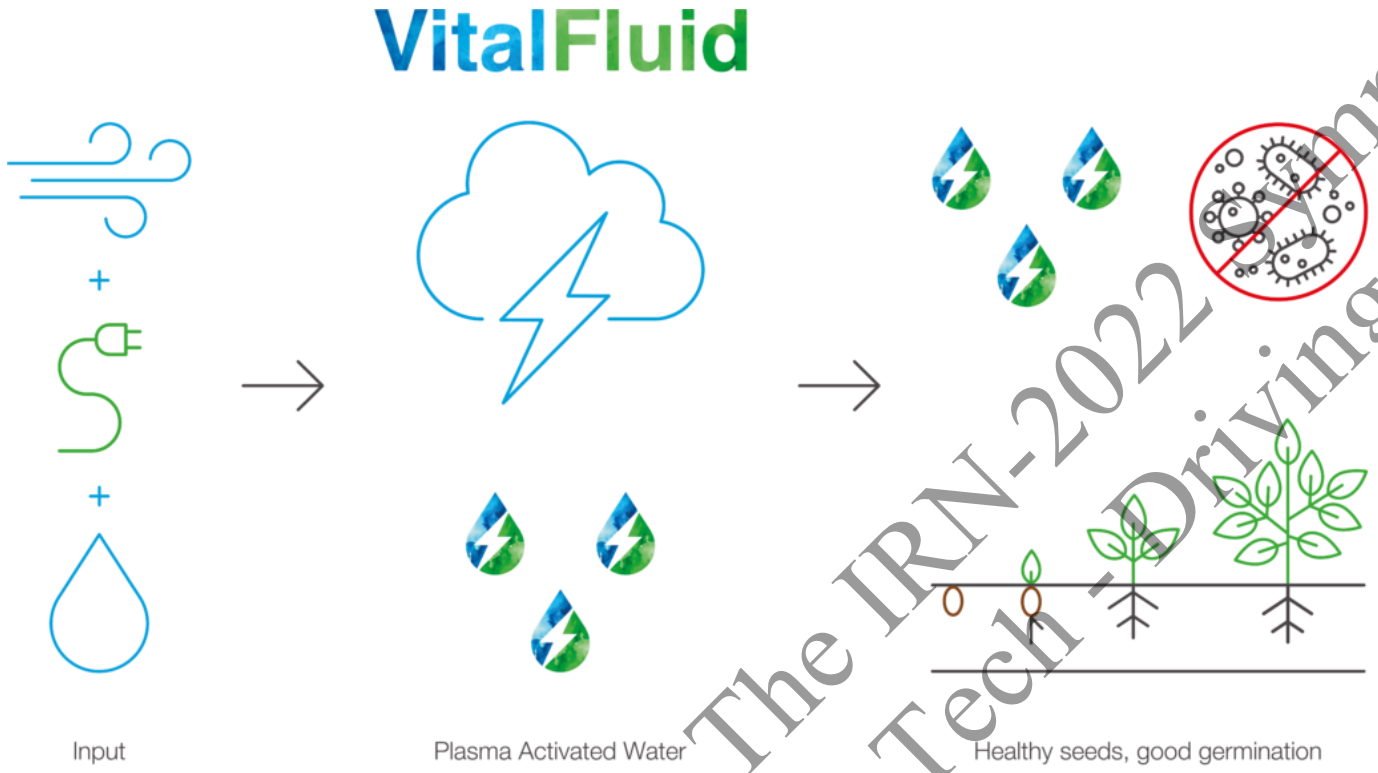


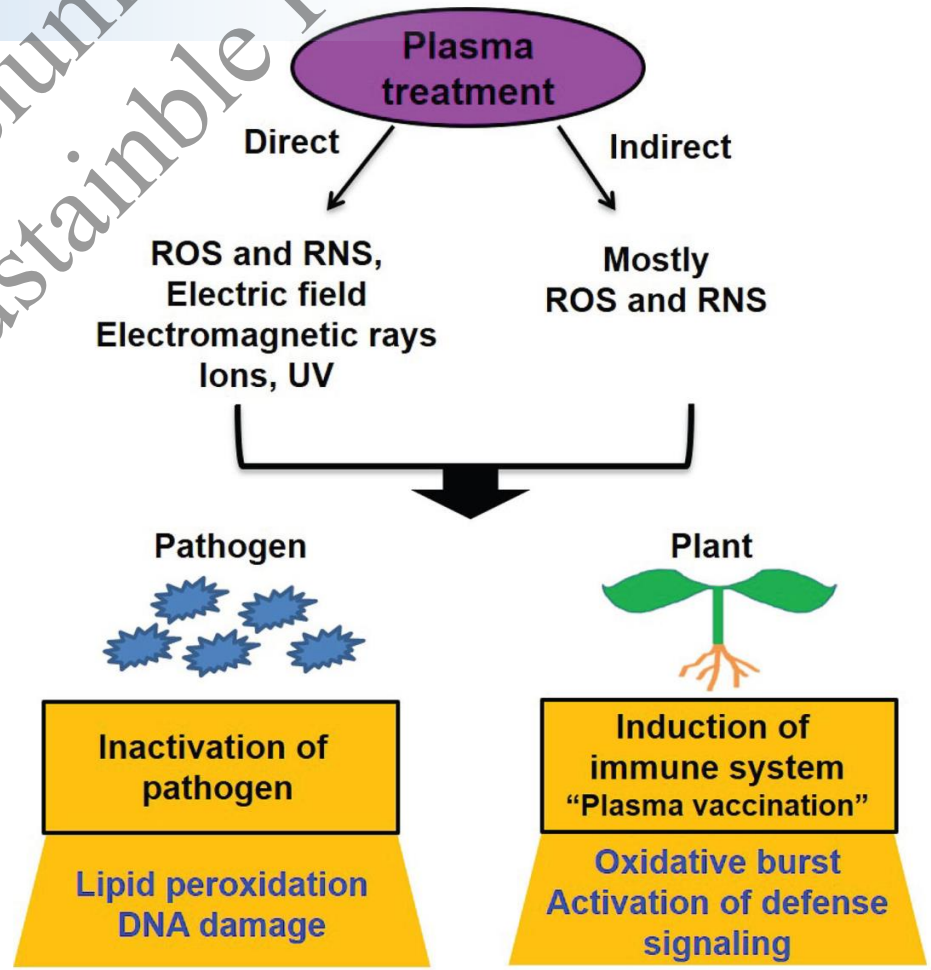
S. Nimbua, C. Pluksa, T. Temponsub, P. Thabin, P. Buppan, and K. Matra, "**The influence of Argon, Oxygen, and Air plasma jet on *Escherichia coli* inactivation**," in 2020 8th International Electrical Engineering Congress (iEECON), Mar. 2020, pp. 1–4, doi: 10.1109/iEECON48109.2020.229566.



Summary : Plasma Technology as a Key

for Sustainable Agricultural Enhancement



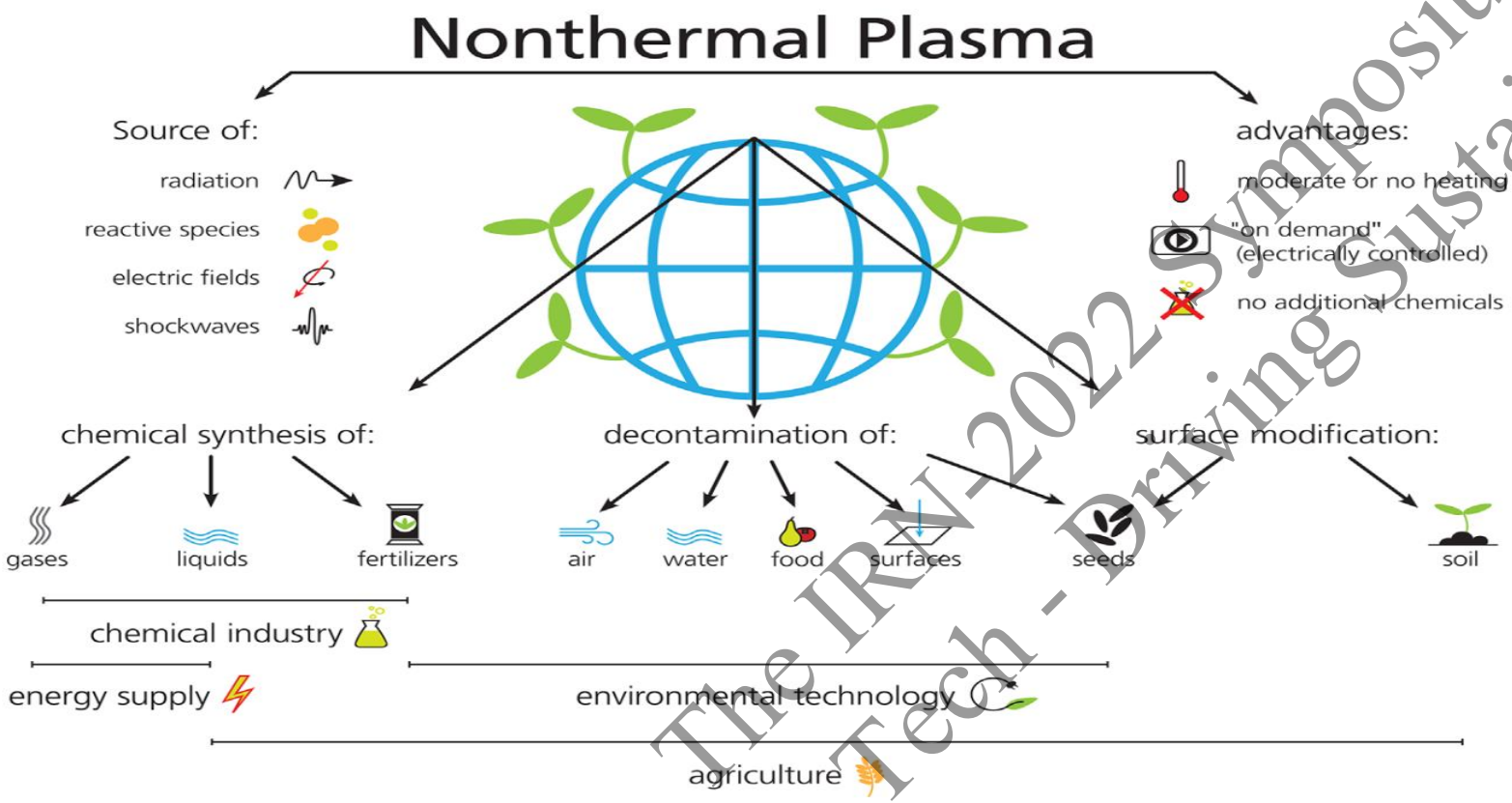


https://vitalfluid.com/seed-treatment/

Adhikari, B., Pangomm, K., Veerana, M., Mitra, S., & Park, G. (2020). Plant disease control by non-thermal atmospheric-pressure plasma. *Frontiers in plant science*, *11*, 77.

Summary : Plasma Technology as a Key

for Sustainable Agricultural Enhancement



Brandenburg, R., Bogaerts, A., Bongers, W., Fridman, A., Fridman, G., Locke, B. R., … Ostrikov, K. (Ken). (2019). White paper on the future of plasma science in environment, for gas conversion and agriculture. *Plasma Processes and Polymers*, *16*(1), 1700238. https://doi.org/https://doi.org/10.1002/ppap.201700238

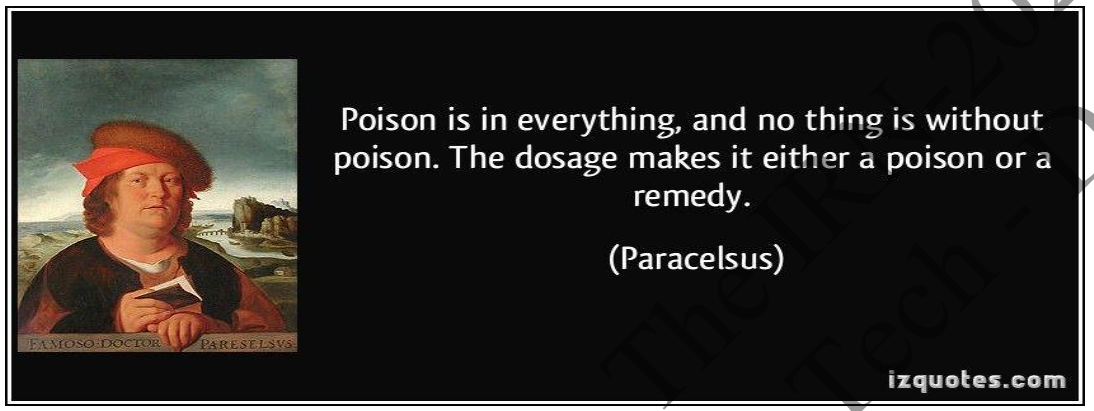
M. Domonkos, P. Tichá, J. Trejbal, and P. Demo, "Applications of Cold Atmospheric Pressure Plasma Technology in Medicine, Agriculture and Food Industry," Applied Sciences, vol. 11, no. 11, p. 4809, May 2021, doi: 10.3390/app11114809.

Challenges of implementing plasma technologies in Thailand

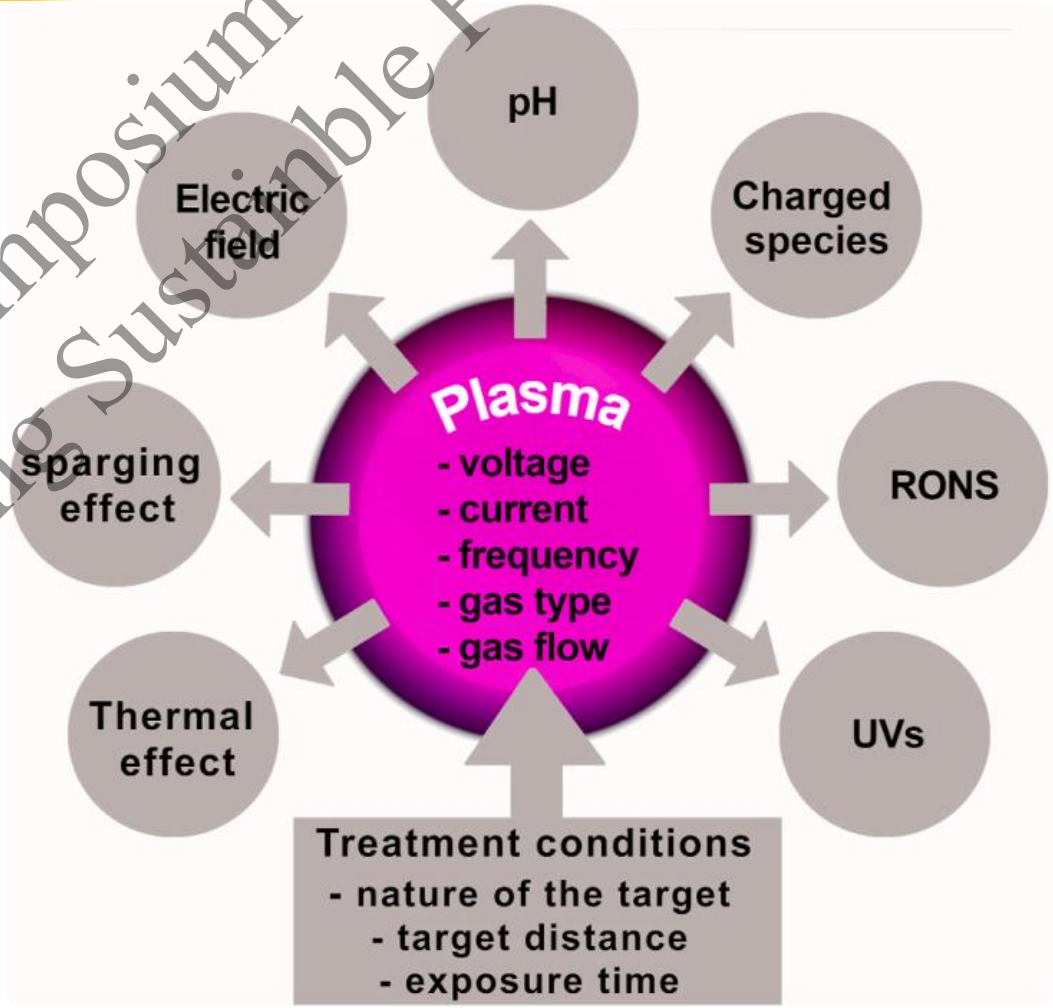
"Plasma has demonstrated a broad spectrum of effects (from inactivation to activation) on the biological target samples, depending on the dose and the reactive species generated from the plasma"

Ji, S.H.; Kim, J.S.; Lee, C.H.; Seo, H.S.; Chun, S.C.; Oh, J.; Choi, E.H.; Park, G. Enhancement of vitality and activity of a plant growth-promoting bacteria (PGPB) by atmospheric pressure non-thermal plasma. Sci. Rep. 2019, 9, 1–16, doi:10.1038/s41598-018-38026-z.

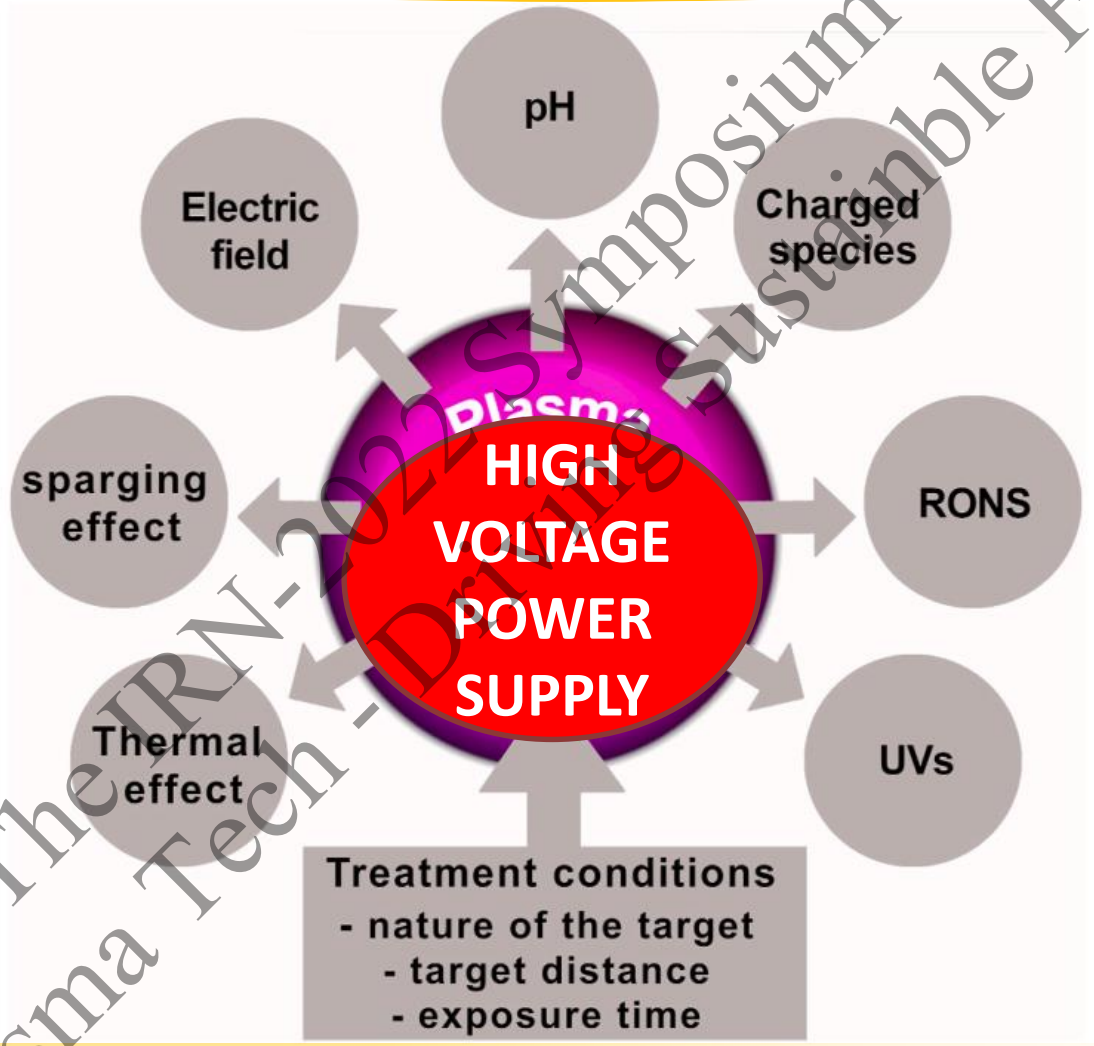
https://pin.it/6ggtCiu



Busco, G., Robert, E., Chettouh-Hammas, N., Pouvesle, J.-M., & Grillon, C. (2020). The emerging potential of cold atmospheric plasma in skin biology. *Free Radical Biology and Medicine*, *161*, 290–304. https://doi.org/https://doi.org/10.1016/j.freeradbiomed.2020.10.004



Challenges of implementing plasma technologies in Thailand



Busco, G., Robert, E., Chettouh-Hammas, N., Pouvesle, J.-M., & Grillon, C. (2020). The emerging potential of cold atmospheric plasma in skin biology. *Free Radical Biology and Medicine*, *161*, 290–304. https://doi.org/https://doi.org/10.1016/j.freeradbiomed.2020.10.004

Thank You Very Much For Your Kind Attention

Sincerely, Thanks to all HAP LAB students, including those not in the picture, for their contribution to the HAP LAB researches.