Controlled hydrodynamic cavitation as a tool to enhance the properties of biological sources

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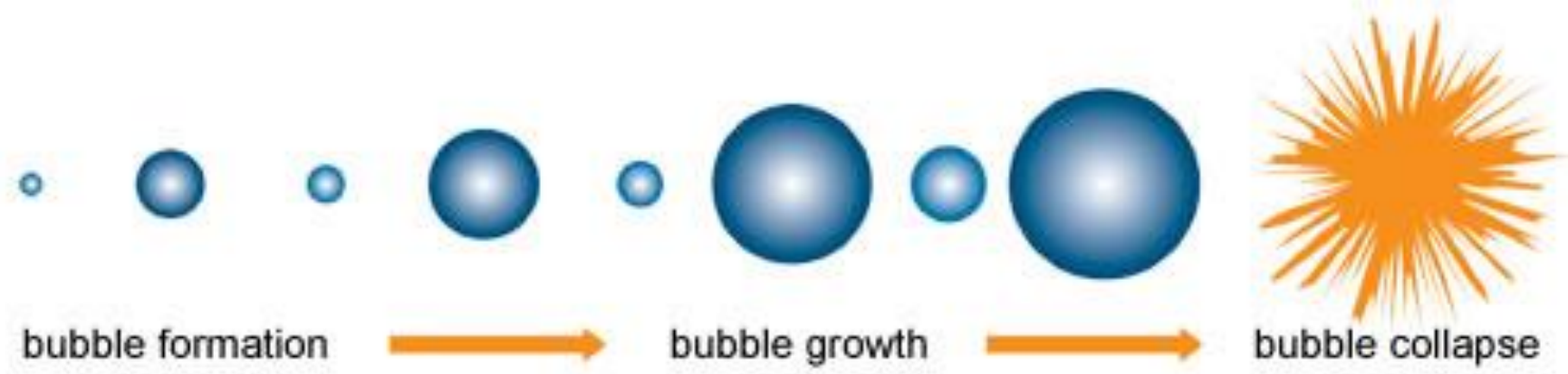
BioEconomy: biological sources for a sustainable world
CNR – Area della Ricerca di Roma 1, Montelibretti (RM) – 6 Marzo 2019

Cavitation in brief: bubbles in action



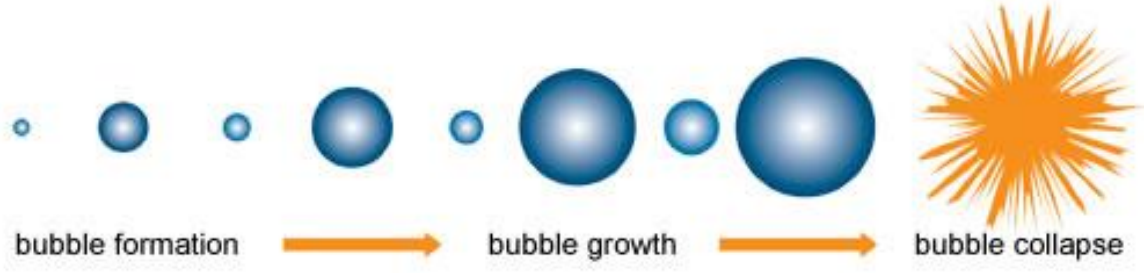
Effective and efficient way to **boost**

chemical and physical processes

also generating oxidizing species

Phenomenon of **formation, growth, and implosion** of vapor bubbles in a liquid medium occurring in a extremely small interval of time (milliseconds), able to release huge amounts of energy.

During the **adiabatic collapse phase**, temperature and pressure inside the cavity strongly increase concentrate the energy of the bulk liquid medium into a myriad of microscopic **“hot spots”** endowed with extremely high-energy density able to leads to the chemical and physical transformations operated by cavitation process.

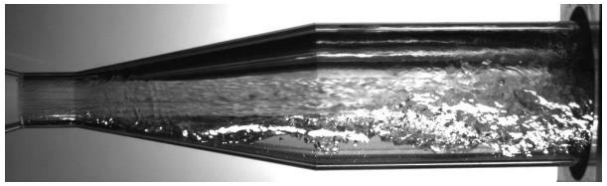


Cavitation in pills

- **INSIDE THE COLLAPSING BUBBLES** → **migration of the hydrophobic substances, micro-pyrolysis**
- **AT THE BUBBLE / BULK MEDIUM INTERFACE** → **oxidizing radicals without AOP additives**
- **AROUND THE COLLAPSING BUBBLES** → **mechanical effects, micro-porosity/grinding/disruption**
- **IN THE BULK MEDIUM** → **degassing, volumetric heating, enhanced mass and heat exchanges**

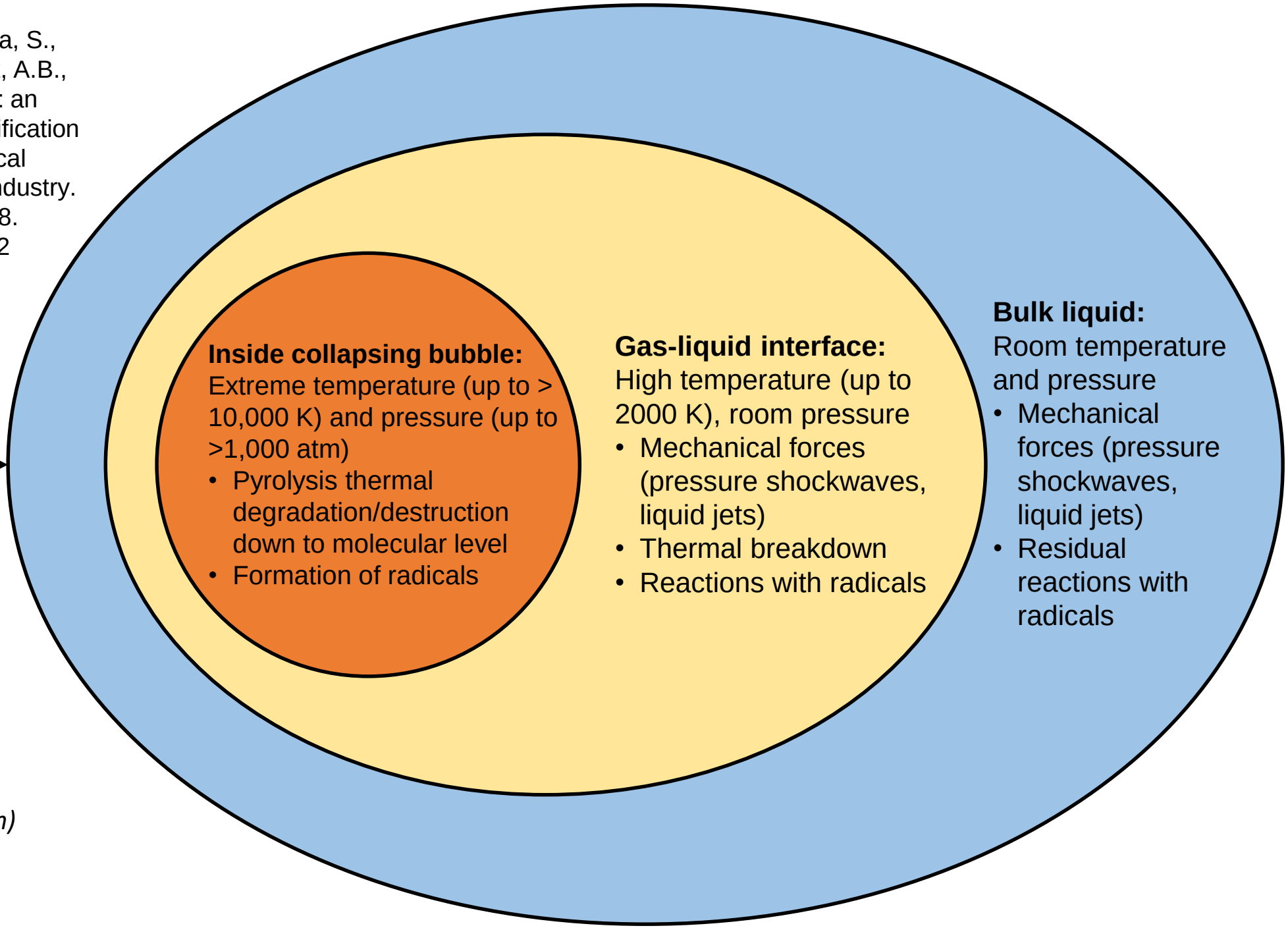
- **SUPERCAVITATION** → **formerly neglected regime, has proven outstanding ability to inactivate certain harmful bacteria** (*e.g.*, *Legionella pneumophila*, *Escherichia coli*, and *Bacillus subtilis*)

Developed cavitation
(frequent, fast bubbles implosion)



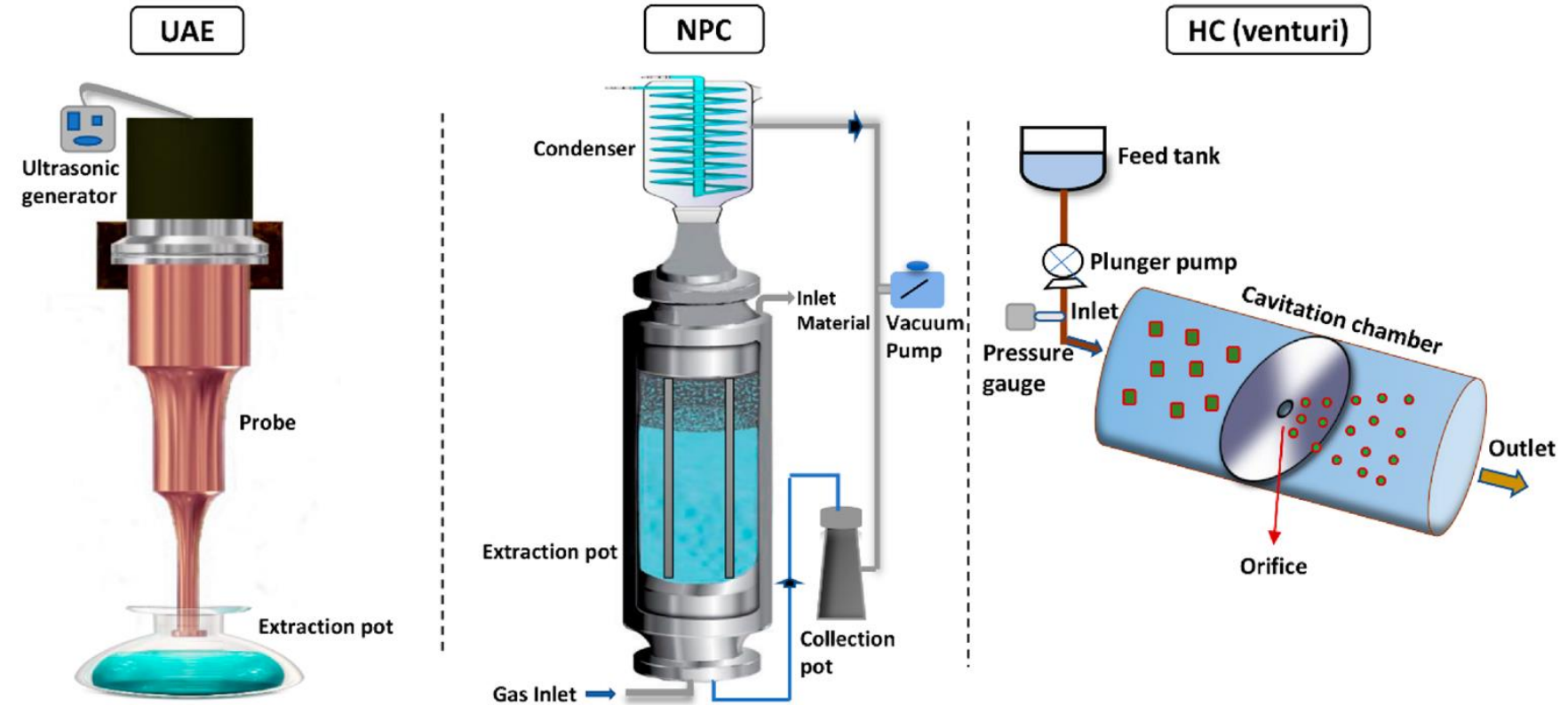
Supercavitation
(stable vapor mega-bubble)

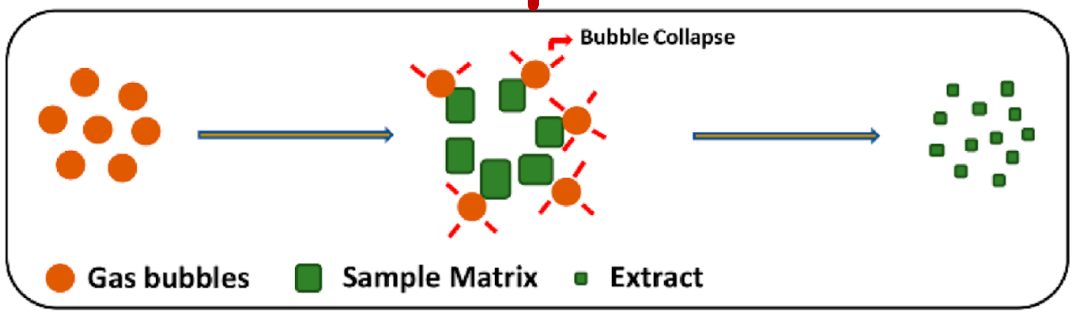
Originally adapted from:
Carpenter, J., Badve, M., Rajoriya, S., George, S., Saharan, V.K., Pandit, A.B., 2017. Hydrodynamic cavitation: an emerging technology for the intensification of various chemical and physical processes in a chemical process industry. *Rev. Chem. Eng.* 33, 433–468. doi:10.1515/revce-2016-0032



Developed cavitation
(frequent, fast bubbles implosion)

Panda, D., Manickam, S., 2019. Cavitation Technology—The Future of Greener Extraction Method: A Review on the Extraction of Natural Products and Process Intensification Mechanism and Perspectives. *Appl. Sci.* 9, 766. doi:10.3390/app9040766. Open access article (License CC BY 4.0).



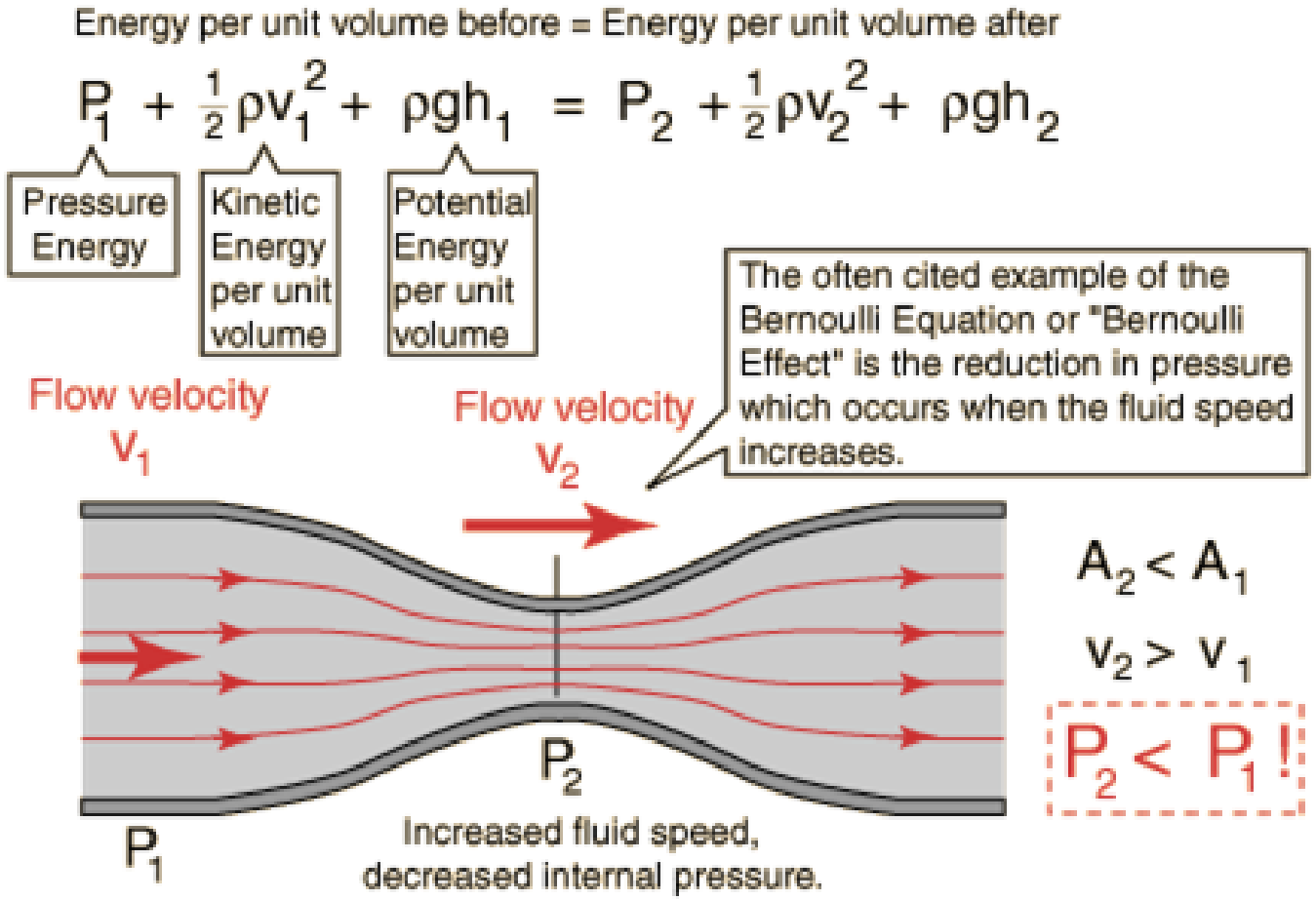


HC – Venturi

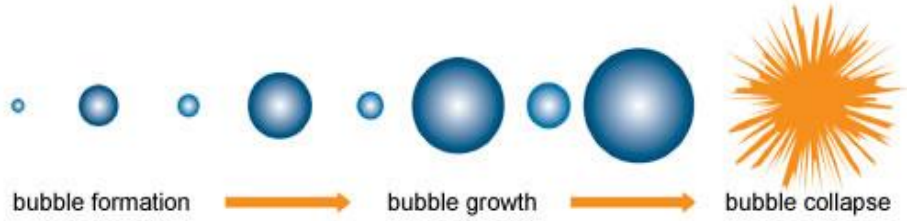
- **Reliable** (no moving parts)
- The *special one* for biological materials
- More effective with microbiological stability (inactivation of bacteria, spores, even viruses)
- Virtually indefinitely improvable

Controlled Hydrodynamic Cavitation (HC)

HC is generated by affecting pressure variations in a flowing liquid by forcing the fluid to pass through a constriction channel in a conduit (Venturi)

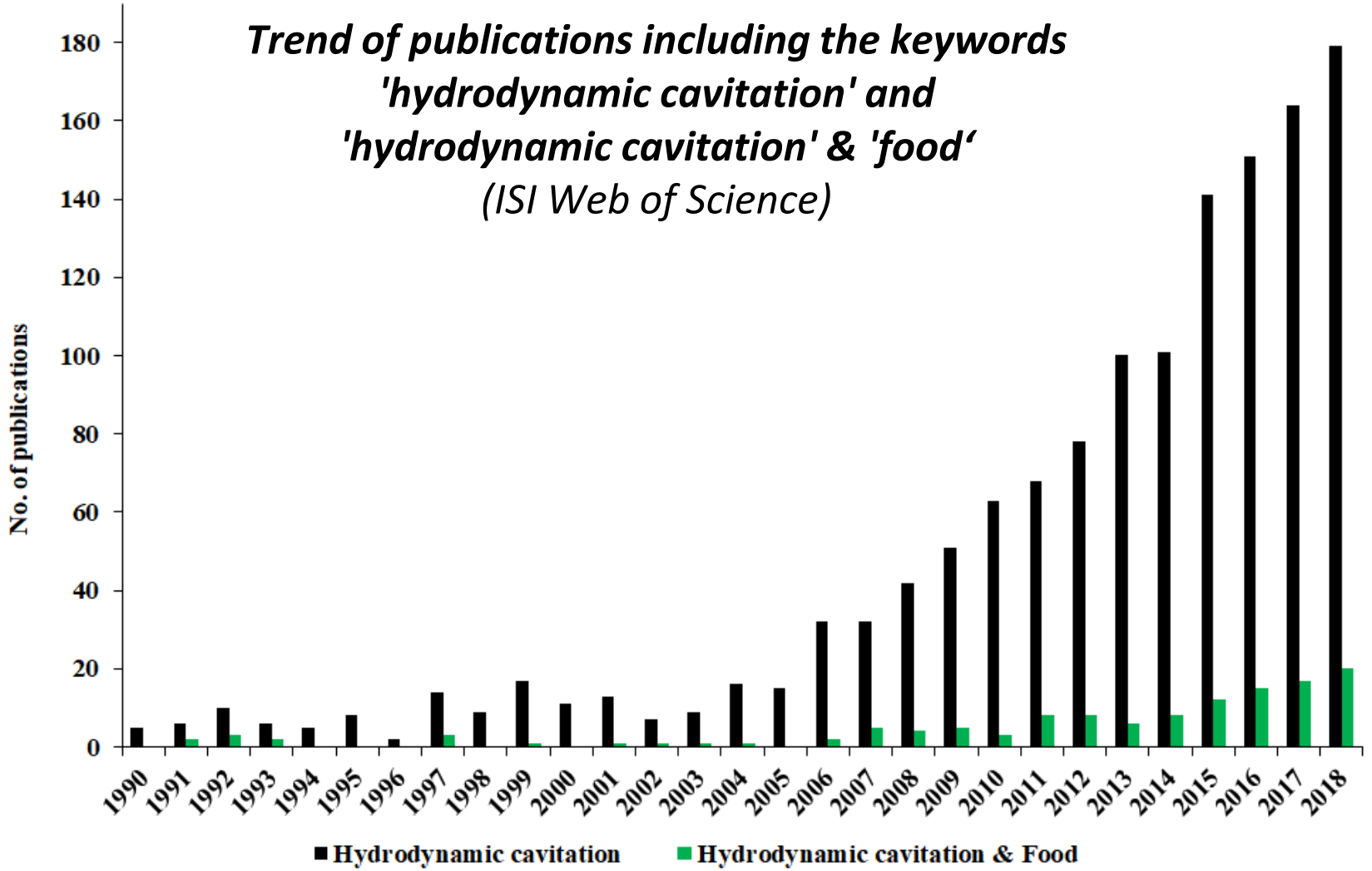


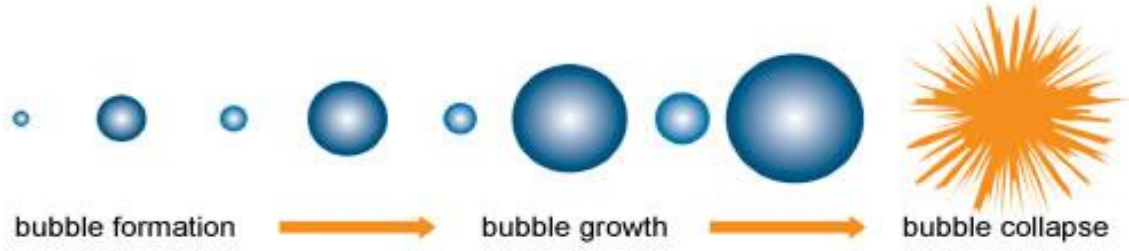
- Temperature and pressure increase up to 5000–10,000 K and 300 atm.
- Extreme local (nano-scale) energy releases, as heat (2,500 - 20,000 °C), pressure shockwaves (up to 2,000 atm), and micro-jets (more than 150 m/s).
- “Hot spot” regions are created generating high-intensity local turbulence, with very strong shear forces, micro-jets and pressure shockwaves.



Hydrodynamic cavitation
Increasing interest

Trend of publications including the keywords 'hydrodynamic cavitation' and 'hydrodynamic cavitation' & 'food'
(ISI Web of Science)





Hydrodynamic cavitation

Increasing reputation

ICEMS 2016

Hydrodynamic Cavitation: A Novel Treatment Approach

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Abstract

Wastewater treatment with hybrid technologies is need of an hour to meet strict regulations and putting a forward step in fulfilling the dream of zero liquid discharge. One such hybrid treatment method – Hydrodynamic Cavitation, a blessing in disguise, an effective treatment process, with its wide range of application and different factors is discussed in this paper. Study suggests that Hydrodynamic Cavitation can manage process economics in terms of money and space if proper optimization is done for any particular wastewater and can be effectively coupled with any other AOP's for enhancing efficiency of treatment with less polluting as no byproducts are formed.

Selection and Peer-review under responsibility of International Conference on Recent Trends in Engineering and Material Sciences (ICEMS-2016).

"A blessing in disguise"

2019

ARTICLE IN PRESS

Ultrasonics - Sonochemistry xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ultrasonics - Sonochemistry

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

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Harnessing cavitational effects for green process intensification

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2019

applied sciences

MDPI

Review

Cavitation Technology—The Future of Greener Extraction Method: A Review on the Extraction of Natural Products and Process Intensification Mechanism and Perspectives

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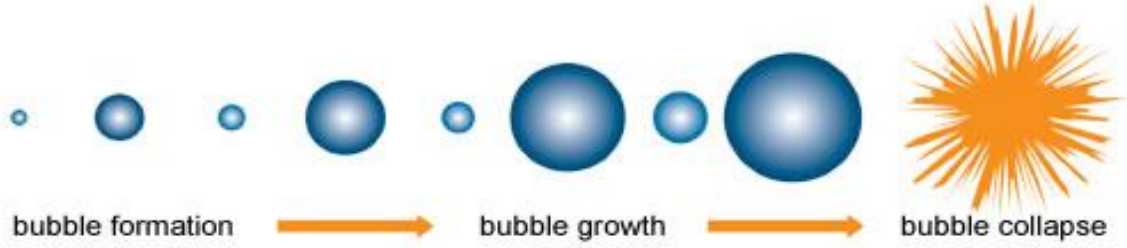
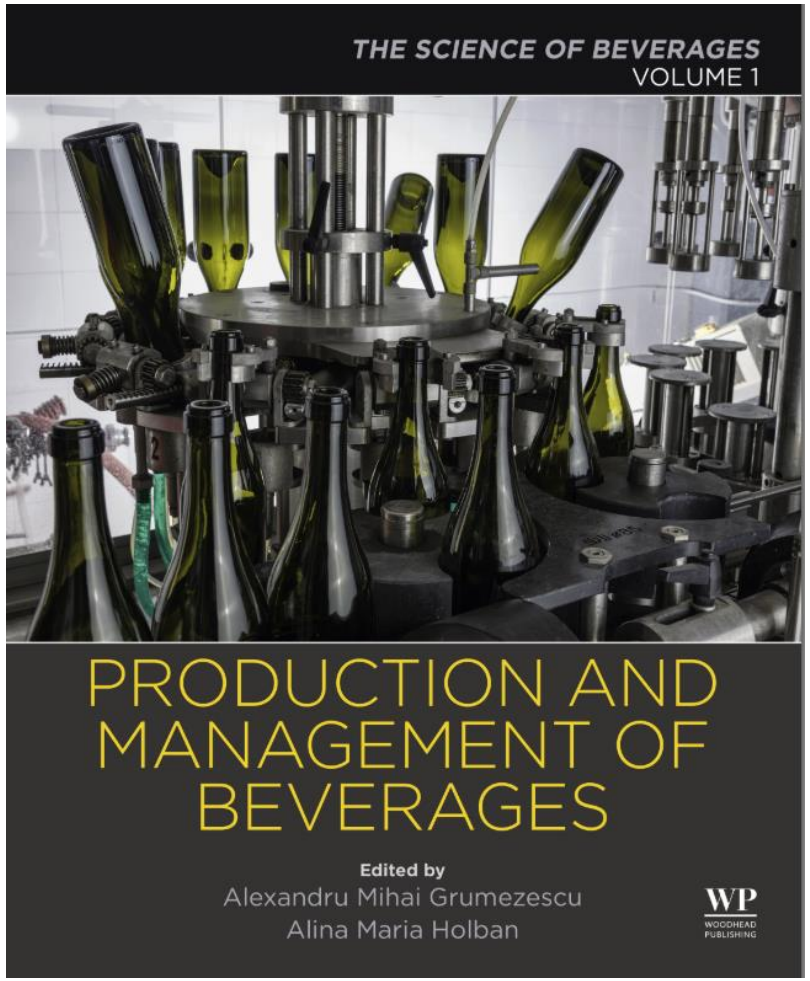


Hydrodynamic cavitation

HCT Lab gaining reputation



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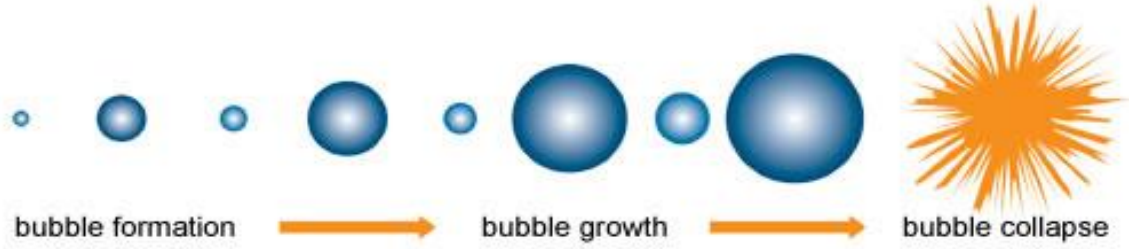
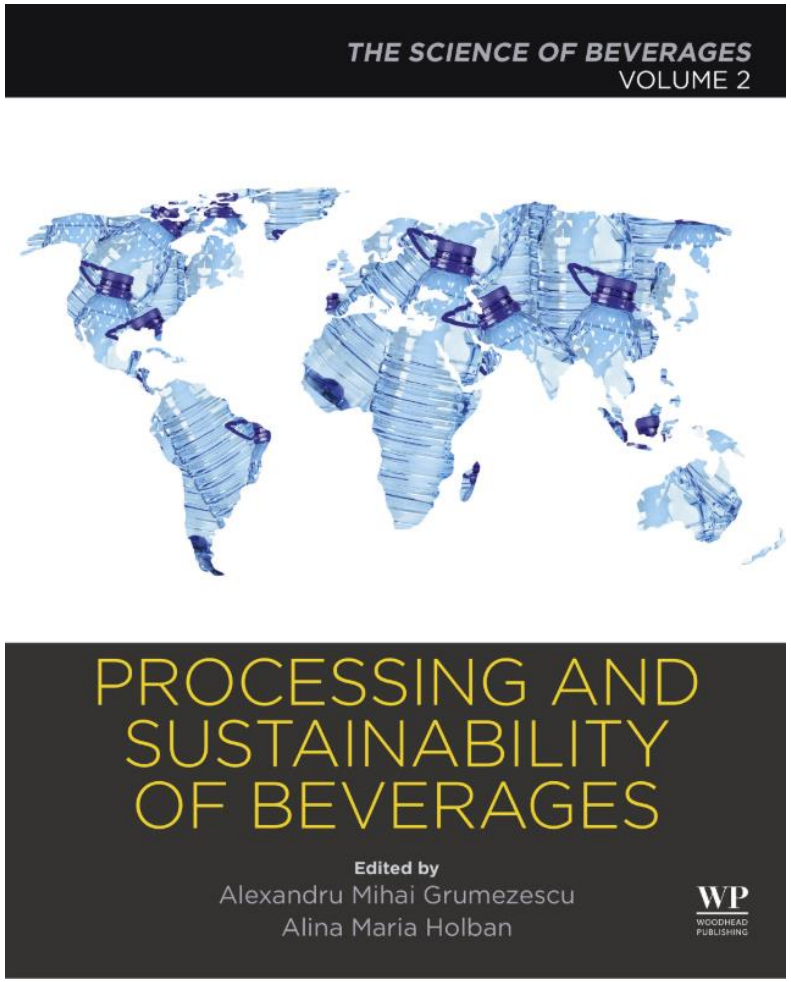
HYDRODYNAMIC CAVITATION-ASSISTED PROCESSING OF VEGETABLE BEVERAGES: REVIEW AND THE CASE OF BEER-BREWING

Lorenzo Albanese, Francesco Meneguzzo
Institute of Biometeorology, National Research Council, Florence, Italy

DOI: 10.1016/B978-0-12-815260-7.00007-9



Hydrodynamic cavitation
HCT Lab gaining reputation



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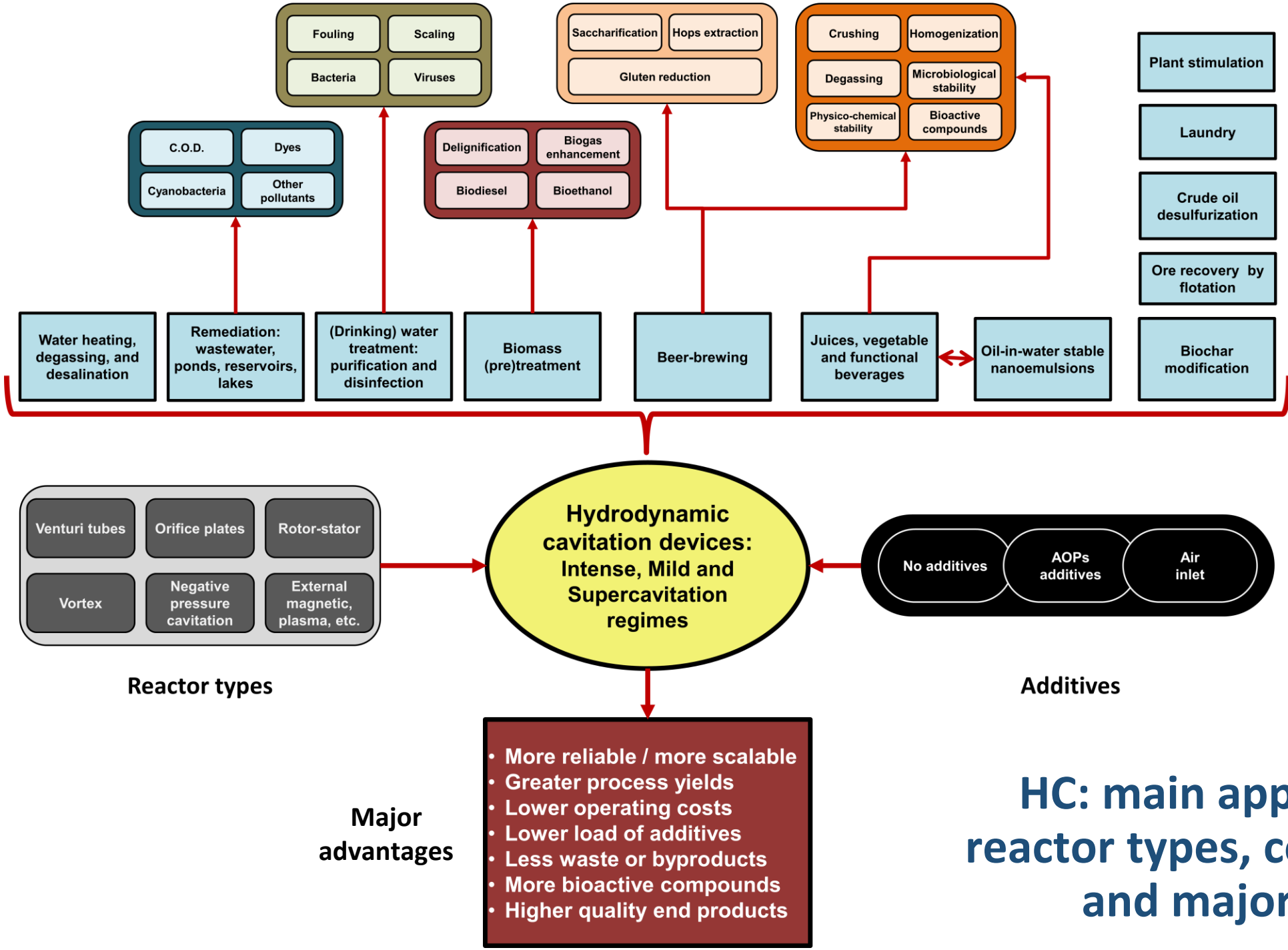
HYDRODYNAMIC CAVITATION TECHNOLOGIES: A PATHWAY TO MORE SUSTAINABLE, HEALTHIER BEVERAGES, AND FOOD SUPPLY CHAINS

Lorenzo Albanese, Francesco Meneguzzo
Institute of Biometeorology, National Research Council, Florence, Italy

DOI: 10.1016/B978-0-12-815259-1.00010-0



HC: main applications fields, reactor types, common additives, and major advantages

Why Hydrodynamic Cavitation?

Fully-proven straightforward upscale capabilities

Higher process yields

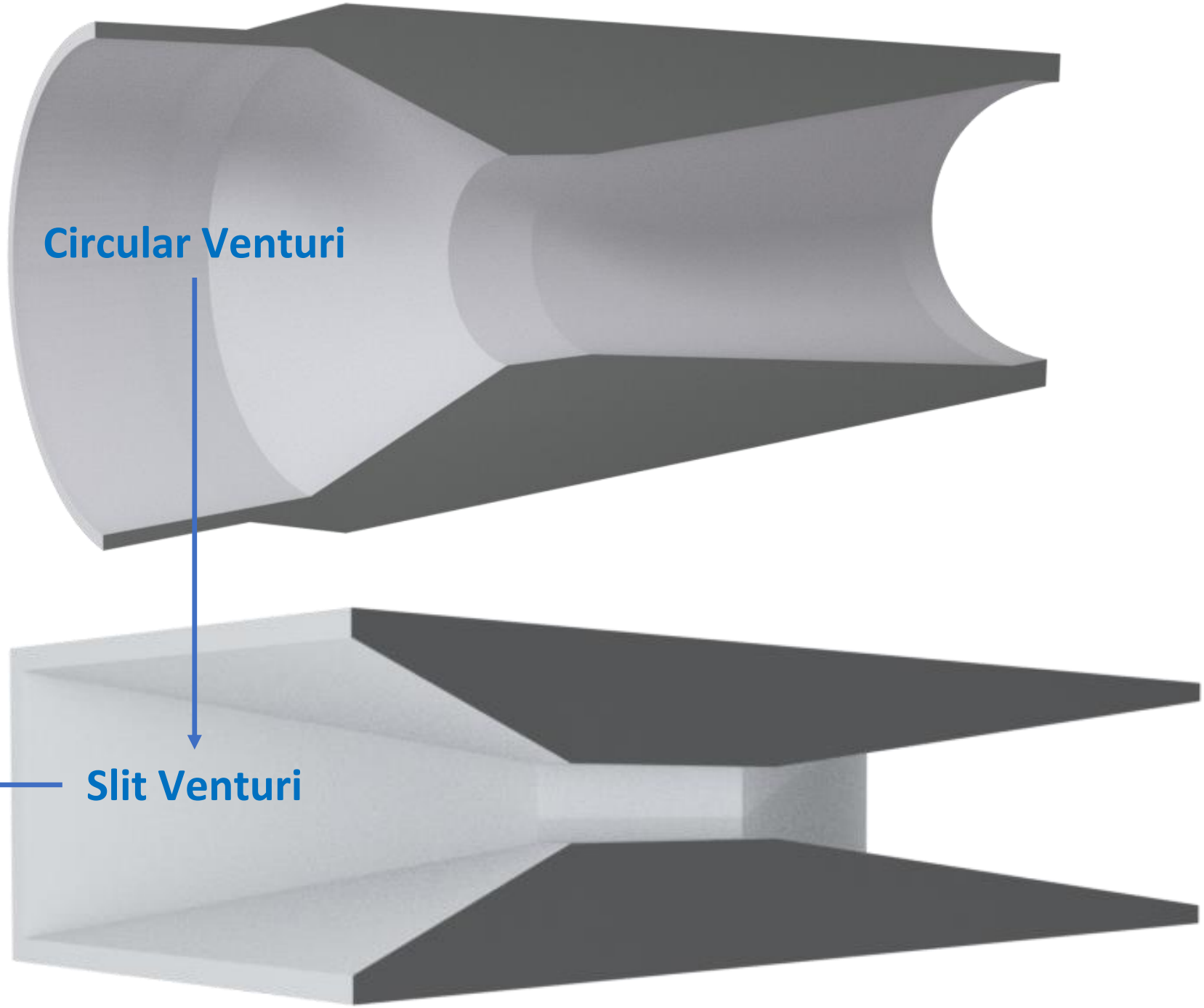
Process yield measured by the actual net production of desired products per unit supplied electrical energy, for HC-assisted or different processes, sometimes in synergy with other AOPs, thermal and other processes

HC process yields → greater by a factor >1.3 to >35 than alternative processes, such as thermal treatment, acoustic cavitation, high-pressure homogenization, high-speed homogenization, ultraviolet irradiation, pulsed electric field, catalytic hydrodesulfurization, etc., in a variety of applications, in food, energy, and materials fields.

Effort currently undertaken at HCT Lab

Design and implementation of more advanced and performing HC reactors

Aimed at increasing performances (process yields) by many times



HC: compliant with Green extraction principles

1. **Use of renewable, plentiful plant resources**

2. **Solvent free:** water is the only solvent.

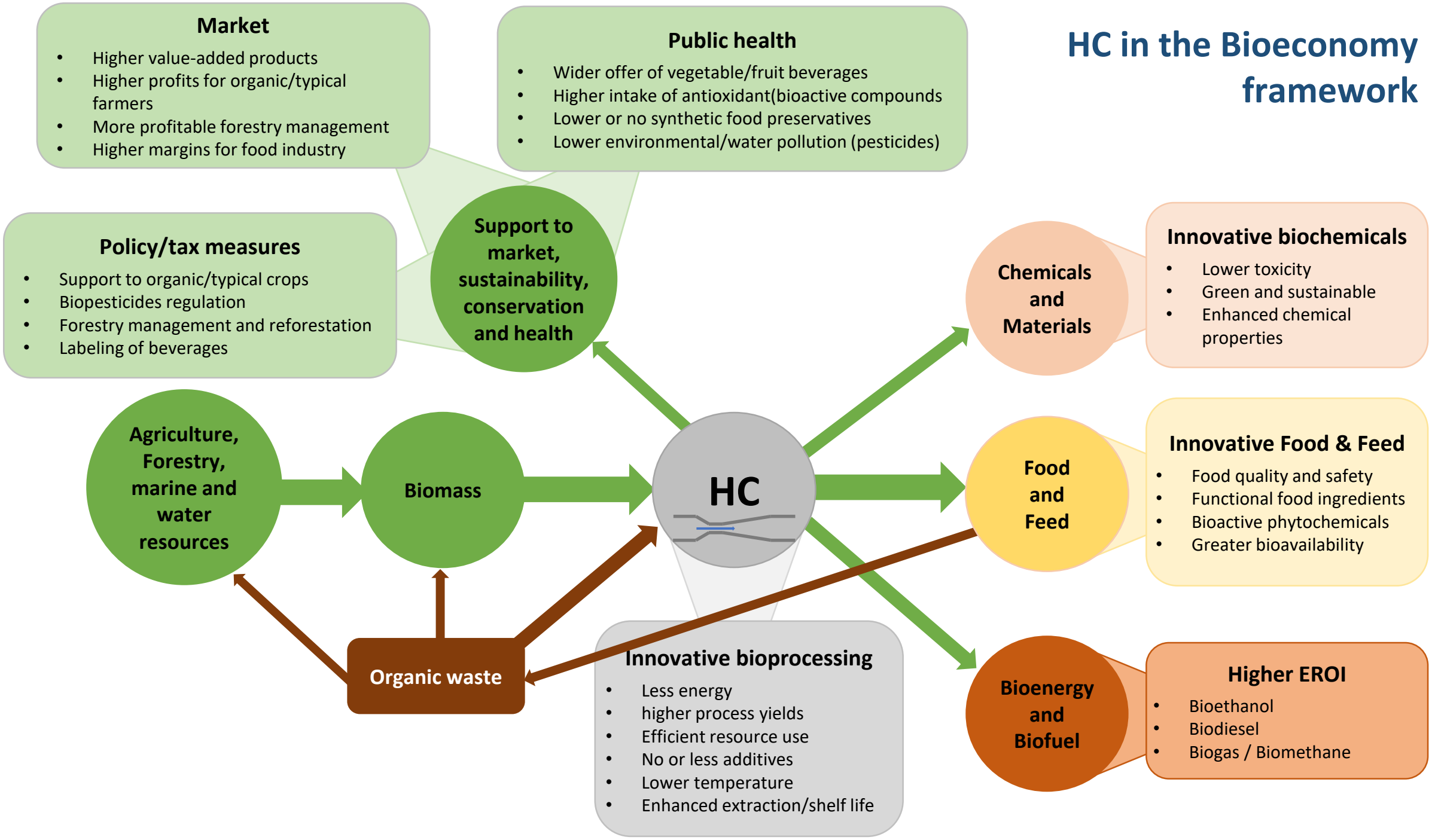
3. **Reduce energy consumption:** lower process temperature, greater heating efficiency, simplification of process steps, and intrinsic pretreatment (*e.g.*, grinding) of raw materials, higher efficiency in the extraction, and reduction in processing time.

4. **Co-products instead of waste:** Residual fraction of the original raw material, separated from the aqueous solution, could be reused (anaerobic digestion, biochar) by the bio- and agro-refining industry.

5. **Reduce unit operations and favor safe, robust and controlled processes:** only two operations (*i.e.*, HC processing, and mechanical separation), equipment generally simple, safe, robust, scalable and easily controllable.

6. **Aim for a non-denatured and biodegradable extract without contaminants:** absent any additives, water and raw materials can be the only ingredients. HC process does not denature the antioxidant compounds.

HC in the Bioeconomy framework



HCT Agrifood Lab – History in brief (to 2018)

From water / greenhouse heating

To brewing …..

- **Patent No. WO/2018/029715** (2016)
- **Trademark No. 017894648** (2018)

Co-owners

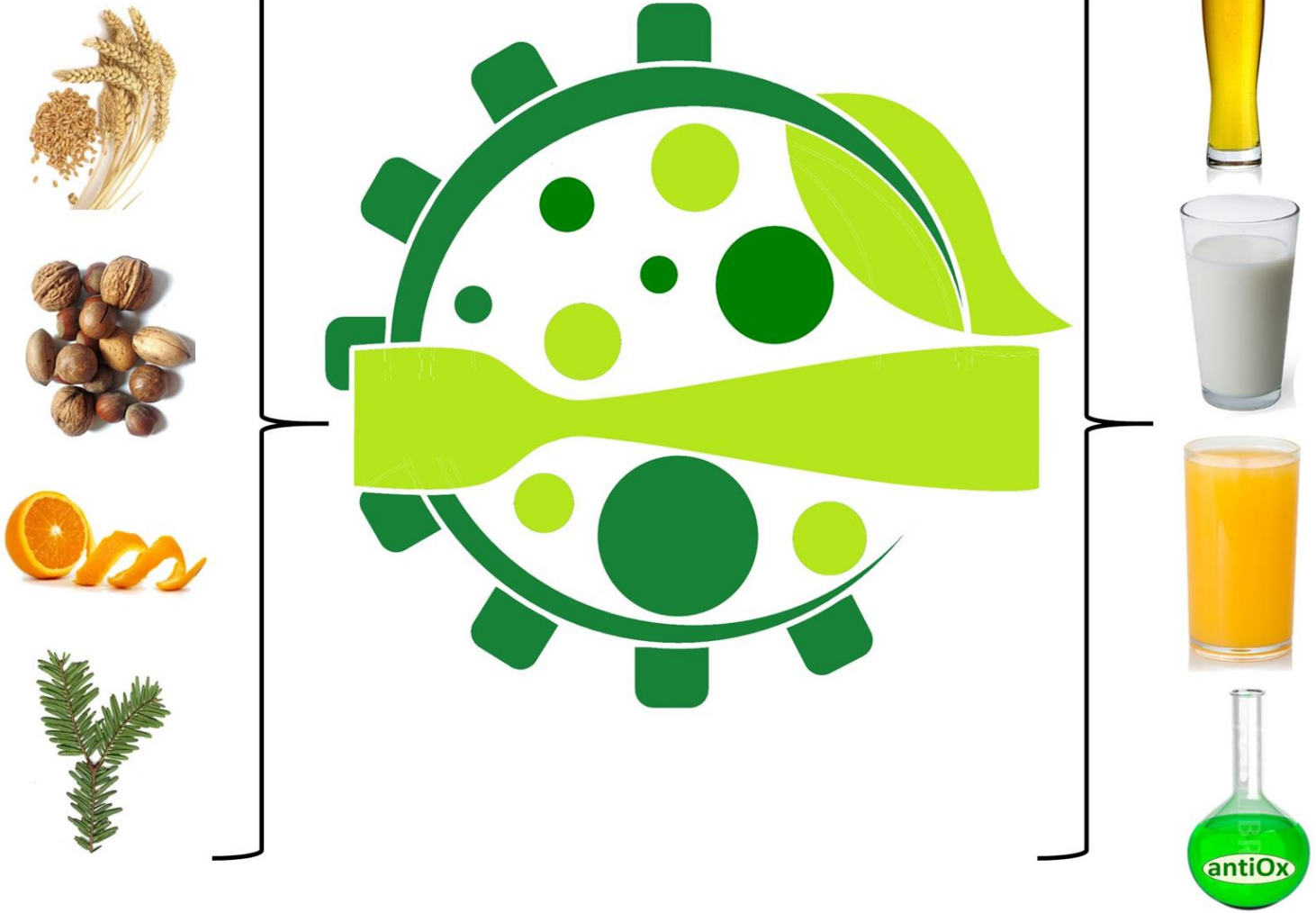
National Research Council (CNR)

National Research Council of Italy

BYSEA S.r.l.

BYSEA SRL

HCT Agrifood Lab – **Main activities**



Important results in different technical fields, such as

- **pasteurization of food liquids;**
- **beer brewing;**
- **extraction of bioactive compounds**;
- **enhancement of biochar properties**, and others.

Clear advantages over competing techniques were identified for all the above-mentioned applications

HCT Agrifood Lab – **Pasteurization of food liquids**

Project T.I.L.A.

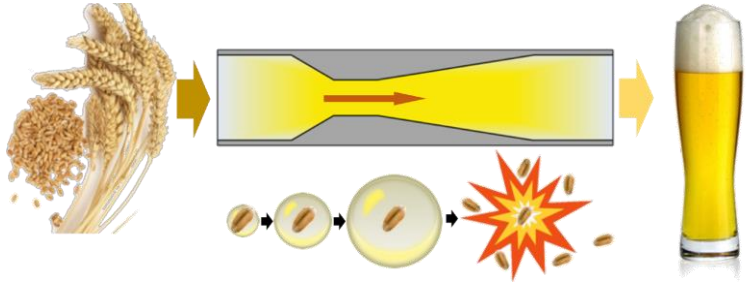
- **Co-financing** – Tuscany Regional Government
- Lethality induced on *Saccharomyces Cerevisiae* achieved **90%**

  effectiveness @ **10 °C below thermal processes**;
- **Venturi** reactor outperformed orifice plate;
- **Energy saving > 30%** w.r.t. purely thermal processes;
- Development/validation of *bulk* and *microbiological* **models**;
- Much room for further **improvement** (*e.g.*, **supercavitation**).

Reactors

HCT Agrifood Lab – **Beer brewing**

Project T.I.L.A.



Energy saving ≥ 40%

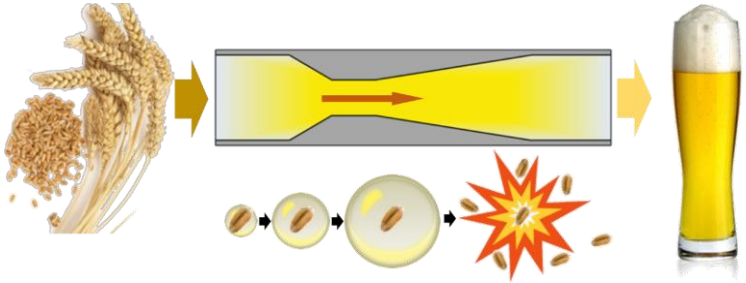
Time saving up to 60% or more

Simplified process → Unnecessary / **dry milling**

boiling all processes completed at T< 100°C

- **No caramelization** (volumetric heating)
- **Higher availability (extraction) of starch and enzymes from malt**
- **Proven stability of produced wort (sugars)**
- **Proven feasibility up to 100% raw unmalted grains**
- **Degassing of undesired volatile compounds (DMS)**
- **Pasteurization at moderate temperatures**
- **Increased extraction of hops and grains healthy polyphenols and antioxidant activity** → increased shelf life
- Special cavitation regime → **strong gluten reduction up to *"Gluten-free"***
- **Intrinsic pulverization of spent grains** → greater value as feedstock, fertilizer (biochar), and anaerobic digestion substrate;
- **Beer quality** (Excellent foamability and foam stability → *due to micropyrolysis of saturated fats*)

HCT Agrifood Lab – **Beer brewing**

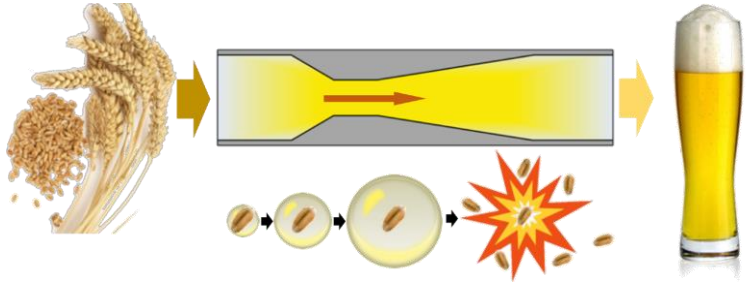


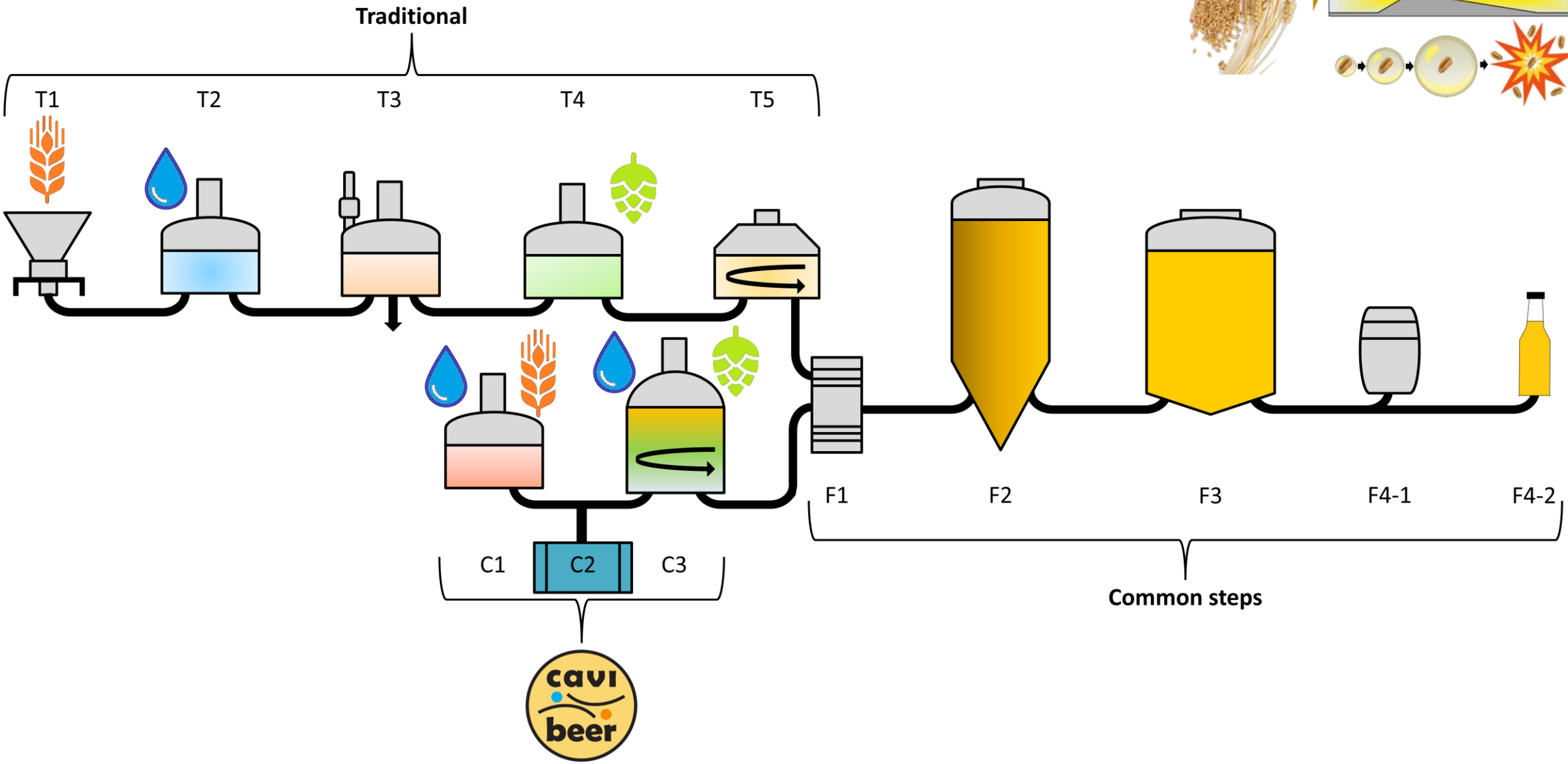
Attracted private financing for industrial development of the order of few hundred thousands Euro

Inauguration – May 24th, 2018

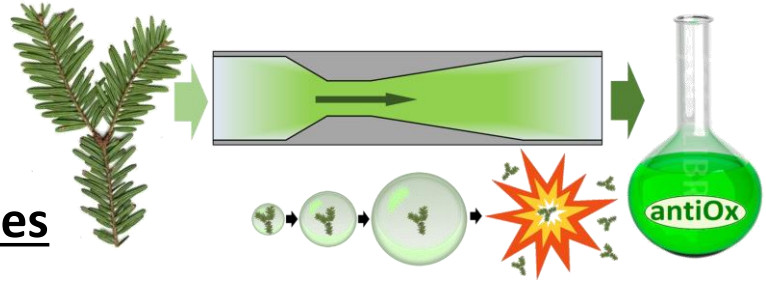
www.cavibeer.com

HCT Agrifood Lab – **Beer brewing**





HCT Agrifood Lab – **Extraction of fir needles**



<u>Extraction of antioxidant compounds (phenolics and flavonoids) from fir needles</u>

Water as the **only solvent** → extraction of high-quality and healthier products

DPPH antioxidant activity greater than reference substances (ascorbic acid, quercetin, and catechin), greater than synthetic antioxidant, and greater than several other extracts.

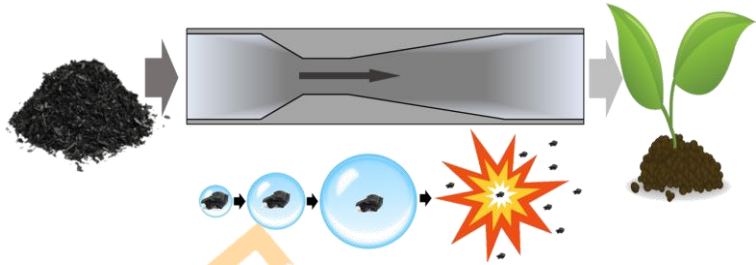
Short processing time → < 60 min vs 1-2 h in conventional extraction techniques

Raw material efficiency → <u>Low concentration</u> (0.44% w/w, dry basis)

Energy efficiency → only 0.04 kWh of electricity per liter of aqueous solution consumed during 60 min of process time

ability of HC processes to produce aqueous solutions endowed with functional bioactive compounds extracted from silver fir needles, by means of a fast and green process.

HCT Agrifood Lab – **Biochar enhancement**



<u>Processing of biochar manufactured by slow pyrolysis</u>

Objective: emulating the effect of increasing pyrolysis temperature while consuming far less energy

Method: cavitating "550°C" biochar in water

Results:

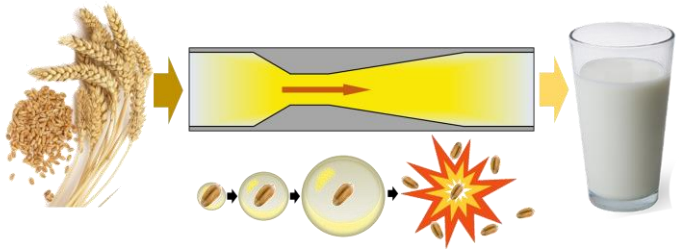
- During **30-min processing**, **increase of BET by 100% (≡ temperature +100°C)**, due to increase in **micro-porosity**;
- **HC-process yield higher by > one order of magnitude** than increasing temperature of slow pyrolysis;
- Preservation of acceptable levels of carbon concentration, as well as low values of the H/C ratio;
- Retention of the original level of the O/C ratio, and increased nitrogen content;
- Decrease of the ash content (contrary to increasing temperature in slow pyrolysis);
- Limited growth in pH, much smaller than increasing the working temperature in slow pyrolysis.

Overall, improvement of chemical composition

ability of HC processes to further activate biochar, by means of a fast and green process.

HCT Agrifood Lab – **Cereal-based beverages**

Project TIBEV



Co-financing – **Tuscany Regional Government**

Key Partner – **Organic Farm (old typical wheat varieties, legumes, etc.)**

Premise – **Cereal-based beverage as an intermediate product of brewing (before hopping)**

Main problem – **Microbiological stability (lower working temperatures)**

Hypothesized solution – **Dynamical shift of cavitation regime**

Main deliverables:

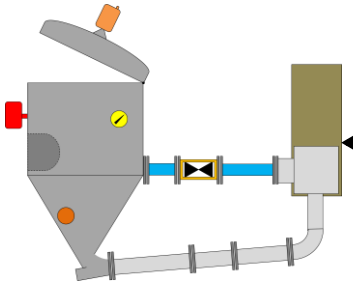
- **Demonstration of the technology with 3 cereal-based beverages (+ legumes?)**
- **Prototype plant 100-500 Lit**

HCT Agrifood Lab – Mission, Objectives & Challenges

Public tenders

Private financing

Dynamical, multi-functional



Analytical equipment and skills

HCT agrifood lab

Applications to a broad spectrum of bioresources

Objective

Today

TRL 9	System ready for full scale deployment
TRL 8	System incorporated in commercial design
TRL 7	Integrated pilot system demonstrated
TRL 6	Prototype system verified
TRL 5	Laboratory testing of integrated system
TRL 4	Laboratory testing of prototype component or process
TRL 3	Critical function: proof of concept established
TRL 2	Technology concept and/or application formulated
TRL 1	Basic principles observed and reported

Easier access to further funds

Together any other interested partner in CNR and the scientific community

HCT Agrifood Lab – Selected scientific publications

- Albanese, L.; Bonetti, A.; D'Acqui, L. P.; Meneguzzo, F.; Zabini, F. Affordable Production of Antioxidant Aqueous Solutions by Hydrodynamic Cavitation Processing of Silver Fir (Abies Alba Mill.) Needles. *Foods* **2019**, *8*, 65, doi:10.3390/foods8020065.
- Albanese, L.; Baronti, S.; Liguori, F.; Meneguzzo, F.; Barbaro, P.; Vaccari, F. P. Hydrodynamic cavitation as an energy efficient process to increase biochar surface area and porosity: A case study. *J. Clean. Prod.* **2019**, *210*, 159–169, doi:10.1016/J.JCLEPRO.2018.10.341.
- Albanese, L.; Meneguzzo, F. Hydrodynamic Cavitation-Assisted Processing of Vegetable Beverages: Review and the Case of Beer-Brewing. In *Production and Management of Beverages. Volume 1: The Science of Beverages*; Grumezescu, A., Holban, A. M., Eds.; Woodhead Publishing, **2018**; pp. 211–258 ISBN 9780128152607, doi:10.1016/B978-0-12-815259-1.00010-0.
- Albanese, L.; Meneguzzo, F. Hydrodynamic Cavitation Technologies: A Pathway to More Sustainable, Healthier Beverages and Food Supply Chains. In *Processing and Sustainability of Beverages. Volume 2: The Science of Beverages*; Grumezescu, A., Holban, A. M., Eds.; Woodhead Publishing, **2018**; pp. 319–372 ISBN 9780128152591, doi:10.1016/B978-0-12-815260-7.00007-9.
- Ciriminna, R.; Albanese, L.; Di Stefano, V.; Delisi, R.; Avellone, G.; Meneguzzo, F.; Pagliaro, M. Beer produced via hydrodynamic cavitation retains higher amounts of xanthohumol and other hops prenylflavonoids. *LWT - Food Sci. Technol.* **2018**, *91*, 160–167, doi:10.1016/j.lwt.2018.01.037.
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- Meneguzzo, F.; Albanese, L. A method and relative apparatus for the production of beer. Patent No. WO/2018/029715.