MODERN PLANT

for a holistic approach for water depuration

Workshop

Sewage advanced treatMent combining resOurce recovery, emerging pollutants DEgradation and caRbon dioxide emissioN reduction: a new strategy to turn a ProbLem into AN opporTunity

16 July 2025, Bari (Italy)
CNR – Istituto di Ricerca Sulle Acque
Viale De Blasio 5 – 70132, Bari (BA)

Scientific Program, Abstracts and List of Speakers/Participants

Workshop

Sewage advanced treatMent combining resOurce recovery, emerging pollutants DEgradation and caRbon dioxide emissioN reduction: a new strategy to turn a ProbLem into AN opporTunity – *MODERN PLANT*

In last decades, increasing attention has been paying on a series of emerging pollutants (EPs) which have been verified to be present in effluents of Wastewater Treatment Plants (WWTPs) after conventional treatments. In fact, WWTPs were originally thought to remove organic pollutants using biological processes, ignoring the presence in the sewage of organic molecules persistent and recalcitrant to these technologies. **To completely degrade these organic pollutants, a further treatment (Advanced Oxidation Processes) needs to be applied, with a consequential increase in the already high management costs.**

On the other side, most municipal WWTPs, as presently configured, mainly oxidize organic pollutants generating a large emission of carbon dioxide and consuming a large amount of energy. However, the energetic content of raw sewage is ten times the energy usually necessary for depuration. **Potentially, sewage could not only sustain the energetical need for treatment, but it could also produce an excess of energy or resources, turning WWTPs into producers of chemicals and energy.**

In the MODERN PLANT project, the main target is to design novel green chemical and biological technologies for the treatment and valorization of municipal wastewater in a unique integrated process capable to recover resources (carbon and nutrients) while removing emerging pollutants. New valorisation approaches will be optimised on sewage and sludge to exploit their starting chemical potential.

A new configuration of WWTP will be designed and experimentally tested to reduce carbon dioxide emissions, final sewage sludge generation, management costs and energy needs, improving the recovery of resources and destroying EPs.

16th July 2024		
8:30-9:00		Registration
9:00 - 9:10	Giuseppe Mascolo	Wellcome and Opening
9:10 - 9:20	*Chairman: Prof. Anjie Li and Dr. Carlo Pastore*	*Description of the event: objectives of the MODERN PLANT project*
9:20-9:40	Dr. Antonella Angelini	Integrated recovery and valorization of cellulose-rich sludge from Wastewater Treatment Plants for the production of High-Value products
9:40-10:00	Dr. Lin Lin	A method for sustainable iron phosphate production by mining municipal sewage sludge for battery electrodes
10:00-10:20	Dr. Camilla Maria Braguglia	Green medium chain carboxylic acids production from municipal sludge and food waste: an holistic strategy towards modern plants
10:20-10:40	Dr. Valeria D'Ambrosio	Recovery, transformation and use of hexanoic acid: closing the loop in WWTPs
10:40-11:00	Dr. Felipe De Jesus Villalobos	Sewage sludge grease monitoring and recovery in Mexico: a case study
11:00-11:20	Coffee Breack	
11:20-11:40	Dr. Carlo Pastore	A solvent free procedure to recovering grease from sewage sludge
11:40-12:00	Dr. Luigi di Bitonto	Optimizing the oxidative treatment of sewage sludge: the combined role of HCl and H□O□ in organic pollutant removal
12:00-12:20	Dr. Ji Bin	MBGS as a sustainable process for ibuprofen-containing wastewater treatment
12:20-12:40	Dr. Anjie Li	Biosolids valorization and antibiotic removal of microalgae-bacteria granular sludge during wastewater treatment
12:40-13:00	Eng. Nicola Tselikas	The new Directive (EU) 2024/3019 on urban wastewater treatment. Advanced treatments in wastewater treatment plants and resource and material recovery: new ambitious challenges and opportunities for Integrated Water Service operators
13:00-13:30	Round Table	A new perspective for WWTPs and water depuration
13:30-14:30	Light lunch	
14:30-16:30	Visit of WWTP of Bari West	
16:30-17:30	Official Meeting for the MODERN PLANT project and closing	

Integrated recovery and valorization of cellulose-rich sludge from Wastewater Treatment Plants for the production of High-Value products

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Cellulose, mainly from toilet paper, represents about 30% of household sewage and is a valuable but underused resource in wastewater. Dynamic sieving is an innovative technology that can be integrated easily into standard wastewater treatment plants (WWTPs) to produce a marketable cellulosic sludge. A pilot study at a small WWTP placed in Lecce, Italy, reveals that by treating 1000–1300 m^3 of sewage daily, around one ton of wet cellulosic sludge per week can be produced containing up to 44–48% of cellulose.(%weight on TS) Two innovative strategies were tested to turn this sludge into valuable products: 1) the direct enzymatic hydrolysis in which the cellulose was easily broken down into glucose without extra treatment (yield of glucose: 41.6%; enzymatic efficiency of 86.5%) 2) the chemical treatment with a deep eutectic solvent (ChCl:$AlCl_3{\cdot}6H_2O$:Alev) in which 62–72% of the cellulose was converted into valuable chemicals like 5-HMF and levulinic acid and humins. This is the first reported use of a DES directly on cellulosic sludge from municipal wastewater.
These methods highlight the potential of wastewater cellulose recovery for sustainable production of bio-based chemicals and fuels.

Dr. Antonella Angelini. Graduated in Chemistry cum laude at the University of Bari in 2007, got her PhD in Chemical Science in 2010 from University of Bari during which she trained in the development of homogeneous and heterogeneous catalysts for the conversion and activation of CO_2. In 2011 she started her postdoctoral activity working on several innovative methodologies for the conversion of waste carbon into valuable products within projects financed by public and private entities (University of Bari, TOTAL SpA, Novamont). She is co-founder of IC2R srl, a startup that develops new chemical reactions and catalysts to transform spent carbon into more valuable and sustainable products such as chemicals, materials, or fuels. After an experience in a private company on the management of a liquid waste plant, in 2024 she joined the Water Research Institute of the National Research Council of Italy (CNR-IRSA) as a Research Scientist to work on the topic of the Green Chemistry. She is co-author of 33 indexed scientific publications (HI: 20, Scopus) and has participated to several international and national conferences.

A method for sustainable iron phosphate production by mining municipal sewage sludge for battery electrodes

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The growing demand for phosphate to produce lithium iron phosphate ($LiFePO_4$) batteries for energy storage has raised concerns of the rapid depletion of phosphorous resources. This study explores a more sustainable approach by recovering $FePO_4$ from P-rich sludge, sourced locally from wastewater treatment plants. The P and Fe in these sludge was solubilized by acidogenic fermentation, followed by selective re-precipitation and sintering to obtain high-purity crystalline $FePO_4$. The extraction process achieved a recovery rate of 62%, with a $FePO_4$ purity of 99.3%, surpassing the typical industrial supplies (93.8%). The $LiFePO_4$/C cathode prepared using the recovered $FePO_4$ had a discharge capacity of 143.3 mAh/g after 50 cycles, similar to the control (140.1 mAh/g) prepared with standard reagent $FePO_4$ ($p = 0.14 > 0.05$). This new process for recovery of battery-grade $FePO_4$ from P-rich sludge provides a significant economic advantage over the conventional methods of recovery of less valuable P fertilizers.

Dr. Lin LIN is an Associate Professor of Tsinghua University. She received her Ph.D. in Environmental Engineering from The University of Hong Kong. Dr. Lin's research focuses on environmental electrochemistry, particularly in water pollution control and resource recovery. She has led thirteen research projects from National Key R&D Plan of China, National Natural Science Foundation of China, etc. Dr. Lin has published over 80 peer-reviewed papers, including 41 as first or corresponding author in leading journals such as *Nature Water*, *PNAS*, *Water Research*, and *Environmental Science & Technology*. She holds 2 U.S. patents and 10 Chinese invention patents, among which 2 have been successfully licensed with a total transfer value of approximately RMB 2 million.

Her research work has received numerous honors, including the prestigious Geneva Invention Exhibition "City of Geneva Award", First Prize of Environmental Technology Progress Award by the China Environmental Protection Industry Association, Excellence Award of the Guangdong Youth Science and Technology Award for Ecology and Environment. She currently serves as a Youth Editorial Board Member of *Journal of Hazardous Materials Advances* and was honored with the 19th "Excellent Advisor and Mentor" Award of Tsinghua University.

Green medium chain carboxylic acids production from municipal sludge and food waste: a holistic strategy towards modern plants

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Within the context of urban development and societal transitions, cities should become major circular bioeconomy hubs increasing their liveability and resilience. Urban biodegradable waste represents a significant untapped biological resource with the potential to promote a more sustainable and circular economy through the implementation of the biorefinery concept. This study provides a comprehensive exploration of chain elongation process for urban waste as sludge and food waste through an open-culture biotechnological production platform without adding chemicals (i.e. buffering agents). We developed a stable bioprocess implemented in a single bioreactor where the presence of food waste promoted the in situ production of lactate further converted into caproate (a medium chain carboxylic acid with 6 C-atoms) in a natural buffered system thanks to presence of sludge. Results demonstrated that shorter HRTs (Hydraulic Retention Time) and daily feeding strategies steered the fermentation pathway towards caproate with the conversion of more than 30% of the soluble organics deriving from the waste.

Dr. Camilla Braguglia is Senior Scientist of the Water Research Institute (IRSA) of the Italian National Research Council (CNR), where she leads since 2008 the Research team on Waste Treatment and Valorization. She graduated in Chemistry at the University of Rome La Sapienza and obtained a PhD in Industrial Chemical Processes from the same University. Her main research interests falls within the broad area of environmental biotechnology for waste minimization, decontamination and biomass valorization, in particular bioenergy and chemicals production. The approach is to study and develop efficient technological solutions with particular attention to the fundamental aspects of the processes together with the technological transferability. She (co)-authored 90 articles in peer-reviewed ISI Journals and International Book chapters, and is co-inventor of one patent on medium chain carboxylic acids production from organic waste.

Recovery, transformation and use of hexanoic acid: closing the loop in WWTPs

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Medium-chain carboxylic acids (MCCAs), such as hexanoic acid, can be obtained through chain elongation anaerobic fermentation of organic by-products and wastes. This work presents a valorization strategy for hexanoic acid within the framework of wastewater treatment plants (WWTPs), contributing to the broader vision of converting such infrastructures into circular biorefineries. Hexanoic acid can be biologically produced via microbial chain elongation from sewage sludge, eventually in co-digestion with external organic substrates.
One of the major challenges in MCCA recovery lies in their partial solubility in water: to overcome this limitation, green solvents can be used to extract the water-soluble fraction. Among them, ethyl hexanoate, which can itself be produced from hexanoic acid via catalytic esterification, can show a promising dual functionality: as both a valorised product and an effective green solvent for complete hexanoic acid recovery.
This study outlines a circular and integrated strategy that combines the biological production, recovery, catalytic upgrading of hexanoic acid and its application in the further valorization of sewage sludge through lipids extraction. These results demonstrate how WWTPs can evolve from conventional infrastructures into decentralized biorefineries, capable of generating biobased products and high value chemicals from low-value residues. By embedding bioprocesses and green chemistry into existing treatment frameworks, WWTPs can play a central role in the transition toward a more sustainable and resource-efficient circular bioeconomy.

Dr. Valeria D'Ambrosio is a postdoctoral fellow at the Water Research Institute of the National Research Council (IRSA-CNR) in Bari, Italy, within the group led by Dr. Carlo Pastore. Her research focuses on sustainable strategies for biomass valorization into high-value chemicals. Her expertise includes biomass characterization, catalytic and enzymatic processes, lipid extraction, and conversion of greases and oils into biofuels. She received her Ph.D. in Chemical and Molecular Sciences from the University of Bari (with honors) and a master's degree in Chemistry from the University of Pisa (110/110). She has authored 11 peer-reviewed publications (H-index: 6) and presented at over 10 national and international conferences, contributing to the advancement of biomass valorization.

Sewage sludge grease monitoring and recovery in Mexico: a case study

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To implement new large-scale processes to produce consumer products, initial small-scale evaluation is essential. These assessments allow the identification of control variables, material and energy consumption, and times at each production stage. This step should not present any difficulties, especially when the feedstock composition remains constant. Therefore, understanding the feedstock composition and its seasonal changes can provide valuable information for its application as an input in industrial-scale plants.
Consequently, a chemical characterization monitoring study of the primary sludge generated at a municipal water treatment plant located in Aguascalientes, Mexico, was carried out per one year. The main objective was to assess the variation in lipid concentration, especially saponifiable lipids, present in the sludge for its subsequent use as a precursor for biodiesel synthesis. The primary sludge was collected at the beginning of each month, analysed and tested for the recovery and transformation of lipid into biodiesel.
The dried and dewatered sludge was subjected to extraction processes with ethyl butyrate and hexane, achieving a maximum lipid recovery of 17.4 and 23% of the dry sludge mass, respectively. Similarly, a maximum FAME (Fatty Acid Methyl Esters) formation of 70% was obtained from lipids extracted with ethyl butyrate. Various factors influencing lipid extraction were also analyzed, including the seasonal heterogeneity of sludge composition. This analysis showed that sludge physicochemical properties vary monthly, directly affecting the performance of extraction processes throughout the annual monitoring period. These factors are relevant and must be considered in the design and operation of larger-scale plants. Therefore, the composition of sludge varies by region, season, and disposal method in different countries.

Dr. Felipe de Jesus Villalobos Delgado is a chemical engineer with a Master of Science in Chemical Engineering and a PhD in Engineering Sciences in 2022. He is currently doing a postdoctoral fellowship at the Instituto Tecnológico de Aguascalientes. He has a background in engineering and basic sciences, especially in the area of physical chemistry. He has taught in biochemistry, technology, and basic sciences, with experience as a researcher focused on bioenergy generation from urban waste generated daily by society. Finally, he developed catalytic materials from urban waste, thus expanding waste recycling options, by focusing on the utilization of waste generated daily by human activities and its transformation into value-added products. He has expertise in computer programming and simulation tools, which allowed to conduct research on the prediction of the thermodynamic behavior of substances with limited information. Coauthor of 5 articles in the JCR and 1 popular article during the period 2019-2024 with more than 40 citations to date.

A solvent free procedure to recovering grease from sewage sludge

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Urban wastewater treatment produces around 10 million tons of urban sewage sludge per year on the European continent alone. It is also expected that this value will increase significantly (up to 13 million tons, 91/271/EEC) over the next ten years. For this reason, the management and treatment of urban sludge in an economically, environmentally and socially acceptable way represents one of the major problems that modern society will have to face.
A novel solvent free process for the recovery of lipids from municipal sewage sludge was developed and investigated. This approach was first tested and optimized on a laboratory scale before being scaled up to a pilot stage, processing two cubic meters of thickened sewage sludge per hour. The lipid recovery yield depended primarily on the original composition of the sewage sludge, with the yield reaching 73.3% for samples containing 66.2 g of lipid per kg of dewatered sludge. The potential for sustainable integration of this technology into various wastewater treatment plants, both with and without anaerobic digesters, was explored and validated. It was found that the co-generated by-products were found to be digestible under anaerobic conditions and lead to higher biomethane production than expected based on the initial biomethane potential of the sewage sludge, or could be dried efficiently, resulting in a high calorific residue that can generate the electrical and thermal energy required to operate the solvent-free process. These experimental results position this new process as a sustainable method for processing urban sewage sludge while recovering valuable resources.

Dr. Carlo Pastore, graduated "cum laude" in Chemistry at the University of Bari in October 2001, got his PhD in "Applied Enzymatic and Chemical Synthesis "by discussing the thesis entitled "Utilization of Carbon Dioxide for the functionalization of organic substrates with the assistance of metal complexes or enzymatic systems" in March 2005. Since 2011 he works as a researcher at the "National Council of Research" at the "Water Research Institute" (CNR-IRSA). Member of the Italian Chemical Society, Environmental Division and Chemistry for Technologies Division, Green Chemistry Group. His main research topics concern the chemical characterization of waste biomasses (urban organic waste, sewage sludge, vegetable and animal oils) to identify the relevant chemical potential and design/optimize innovative sustainable processes to recover resources to implement the "Circular Economy" scenario with new solutions.
He had coauthored more than 100 peer reviewed paper, 9 book chapter and three national patents (over 3000 citations, H-index 32, Scopus). He has been involved as Principal Investigator for IRSA in over ten international and national projects.

Optimizing the oxidative treatment of sewage sludge: the combined role of HCl and H_2O_2 in organic pollutant removal

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The present study investigates the synergistic effects of a reactive mixture of hydrochloric acid (HCl) and hydrogen peroxide (H_2O_2) on the solvent-free recovery of raw grease from municipal sewage sludge with simultaneous degradation of the main organic pollutants. In the pilot plant for grease recovery at the Bari West wastewater treatment plant (Italy, 240.000 Population Equivalents), sewage sludge samples were taken before and after chemical treatment to assess the effects of the reactive mixture on pollutant levels. The analytical focus was on monitoring a wide range of organic contaminants, including emerging pollutants whose impact on the environment is increasingly recognized, as well as specific classes such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). The comparative assessment of pollutant concentrations showed that the total amount of organic pollutants could be reduced by over 70 % after chemical treatment. This integrated approach represents a promising advance in wastewater treatment and supports environmentally friendly and sustainable urban infrastructure.

Dr. Luigi di Bitonto is a researcher at the Water Research Institute of the National Research Council of Italy (IRSA-CNR). He graduated with honors in Chemical Sciences and Technologies at the University of Bari "Aldo Moro" in 2010 and obtained his PhD in Chemical Sciences in 2014. During his doctoral studies, he focused on the valorisation of animals and plant biomass resources to produce third generation biofuels. He has experience in the University Consortium for Chemical Reactivity and Catalysis, where he was involved in the development of processes for the synthesis of "platform molecules" from residual biomass. From 2015 to 2017 he participated in numerous national and international projects as a scholarship holder and from 2017 to 2020 as a postgraduate at IRSA-CNR, including collaborations with private companies. His research during this period focused on the thermo-chemical conversion of sewage sludge into fine chemicals and/or liquid biofuels. He is co-author of 38 indexed scientific publications (Scopus and ISI), 4 book chapters, 5 patents and has participated in 36 international conferences.

MBGS as a sustainable process for ibuprofen-containing wastewater treatment

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Rising extreme weather events linked to greenhouse gas emissions accentuate the urgency for sustainable wastewater solutions. Conventional activated sludge processes face critical challenges, including high energy consumption, significant greenhouse gas emissions, and limited resource recovery. This study establishes microalgal-bacterial granular sludge (MBGS) as a high-performance, sustainable solution for treating wastewater contaminated with ibuprofen (IBU), a persistent and ecotoxic pharmaceutical pollutant. Enhanced by inorganic carbon supplementation (optimized at 72 mg/L $NaHCO_3$ or via CO_2), the MBGS system demonstrated exceptional IBU removal efficiency and significant reduction in environmental toxicity through robust biodegradation pathways. Despite IBU-induced stress triggering transient microbial community shifts (e.g., deformation of *Cyanobacteria*), the system exhibited remarkable resilience, driven largely by adaptive *Proteobacteria*. Beyond IBU detoxification, inorganic carbon augmentation simultaneously improved nutrient (N, P) removal and sludge settleability, while enriching functional microbial consortia (e.g., PAOs, *Chloroflexota*). The process further enables resource recovery via lipid/glycogen-enriched biomass with high calorific value. Collectively, MBGS overcomes critical limitations of energy-intensive conventional activated sludge, offering a carbon-capturing pathway with global potential to reduce CO_2 emissions by 102 million tons/year. This work positions MBGS as a versatile, eco-engineered technology for sustainable treatment of wastewater laden with emerging contaminants like pharmaceuticals.

Dr. Bin Ji is a Professor at Wuhan University of Science and Technology. Recognized as a “Distinguished Talent” in Hubei Province, he specializes in biological wastewater treatment and aquatic environmental remediation. He obtained his Ph.D. in Municipal Engineering from Wuhan University, conducted postdoctoral research at Nanyang Technological University, Singapore, and had an academic exchange at the National University of Singapore. Professor Ji has led several National Natural Science Foundation projects, published over 80 academic papers with more than 2000 citations, and is ranked among the world's top 2% scientists by ESI. He also serves as a reviewer and associate editor for multiple journals.

Biosolids valorization and antibiotic removal of microalgae-bacteria granular sludge during wastewater treatment

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Microalgae-Bacteria Granular Sludge (MBGS) technology offers a sustainable solution for wastewater treatment by synergizing pollutant removal with resource recovery. This study elucidated the role of extracellular polymeric substances (EPS) from aerobic granular sludge in enhancing *Chlorella vulgaris* growth (37.8% increase), lipid synthesis (18.5% increase), and flocculation (66.7% improvement) through bioactive metabolites like *N*-acyl homoserine lactones (AHLs) and humic acid. Transcriptomic analysis revealed upregulated fatty acid biosynthesis genes (*fabF, fabG, fabZ*), promoting biolipid accumulation. Encapsulating *C. vulgaris* in hydrogel mimicked MBGS microenvironments, boosting chlorophyll (71.4% increase) and indole-3-acetic acid (IAA) secretion, which enhanced bacterial viability and mitigated sulfamethoxazole (SMX) inhibition. The system achieved efficient SMX degradation (0.0334 h^{-1}, 61.1%) via cytochrome P450 pathways while reducing biological toxicity (84.0% decrease). These findings highlight MBGS as a promising technology for low-carbon wastewater treatment, resource recovery, and antibiotic risk mitigation.

Dr. Anjie LI is an Associate Professor of Beijing Normal University. She received her Ph.D. in Environmental Engineering from The University of Hong Kong. She currently serves as Executive Editor of *Current Research in Biotechnology* and was honored with the 14th "Excellent Young Faculty" Award of Beijing Normal University. Dr. Li's research focuses on environmental microbiology, particularly in water pollution control and resource recovery. She has led 4 projects from National Natural Science Foundation of China. Dr. Li has published over 60 academic papers in leading journals such as *Water Research*, *Chemical Engineering Journal* and *Bioresource Technology*. She holds 5 Chinese patents, among which 2 have been successfully transferred to environmental companies.

The new Directive (EU) 2024/3019 on urban wastewater treatment. Advanced treatments in wastewater treatment plants and resource and material recovery: new ambitious challenges and opportunities for Integrated Water Service operators

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The new Directive (EU) 2024/3019 implements the environmental objectives set by the European Green Deal and the EU Taxonomy Regulation. Like other production sectors, urban wastewater treatment, in addition to increasing the performance of its processes by improving sludge management and enhancing the safe reuse of treated wastewater, is also required to reduce its climate-altering emissions while pursuing the objectives of energy neutrality and resilient adaptation to climate change.
With these scenarios, Acquedotto Pugliese, the water operator in Puglia, is required to plan new and additional investments. This requires, more than ever, a systemic approach aimed at identifying local mitigation and decarbonization solutions and macro-strategies, as well as scouting for the most innovative technologies to maximize self-generation of energy and the recovery of water, materials, and nutrients.

Eng. Nicola Tselikas is a civil – hydraulic engineer.
At Acquedotto Pugliese, from 2007 to 2015, he was a member of WWTP Area staff of the Lecce Territorial Unit, responsible, for construction management, operation, and maintenance of WWTPs.
From 2015 to 2021, as head of WWTP Area in Foggia Territorial Unit, he was responsible for the management, operation, and maintenance of 68 WWTPs.
From 2022 to 2024, he was the Wastewater Tratment Area Manager which oversees the185WWTPs managed by Acquedotto Pugliese. He is currently the Head of the Green Management Area of the Environment and Energy Department

Scientific Committee

Dr. Carlo Pastore
Prof. Anjie Li

Local Organization Committee

Dr. Luigi di Bitonto
Dr. Antonella Angelini

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