# Exploring the Viability of Utilizing TreatedWastewater as a Sustainable Water Resource for Green Hydrogen Generation Using Solid Oxide Electrolysis Cells (SOECs)

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## Introduction

The European Union aims to achieve carbon neutrality by 2050, prompting substantial investments in sustainable energy research, particularly in the realm of renewable sources (RESs). Italy, anticipating an energy demand of 366 TWh by 2030, is obligated by the EU to fulfill 75% to 84% of this demand through RESs[1]. A promising solution to meet this requirement is the production of green hydrogen through water electrolysis, specifically employing Solid Oxide Electrolysis Cells (SOECs). SOECs offer advantages over Alkaline Electrolyzers (AEs) and Proton Exchange Membranes (PEMs) since they can utilize treated wastewaters, eliminating the necessity for pure water, which is already scarce[2,3]. This study centers on exploring the potential of SOECs to operate effectively in high-temperature conditions and utilize water in its gaseous form as the inlet source, commencing with treated wastewaters derived from municipal wastewater treatment plants..

## Materials and Methods

Four distinct treated wastewaters, each characterized by differences in capacity, industrial load, and treatment scheme, underwent evaluation for their potential as feedstock in hydrogen production through Solid Oxide Electrolysis Cells (SOECs). The study employed Aspen Plus software to simulate the entire process. SOECs were spotlighted for their energy-efficient role in hydrogen production, leveraging thermal energy with a specific focus on water and air vaporization and heating. The research extensively outlined the setup of the electrolysis stack, placing emphasis on the segregation and utilization of different streams and the recuperation of residual heat from the cell products. The modeling approach for the SOEC stack encompassed equations addressing cell voltage, potential, and electric power consumption. Furthermore, the study delved into a thermal model that integrated energy and mass balance equations for various components, albeit utilizing a simplified modeling approach..

## Results and Discussion

This study illustrates that treated municipal wastewater acquired from wastewater treatment plants (WWTPs) of diverse capacities, industrial loads, and treatment schemes can function as an optimal water source for Solid Oxide Electrolysis Cells (SOECs) to generate "clean" hydrogen. Specifically, Italy is targeting the installation of 5 GW of electrolysis capacity by 2030 in alignment with the European Union's energy transition initiative. The propositions presented in this article, leveraging wastewater from various WWTPs as renewable energy sources, have the potential to aid in achieving this goal. To elaborate further, in the Best-case Scenario (BS) where a SOEC operates for 7,500 hours with a moderate power of 2.12 V supported by wind and conventional energy, a WWTP (referred to as WWTP C) with a capacity of 120,500 P.E., an average flow rate of 27,500 $m^3$/d, and an industrial load of 11%, can produce 0.10 Mt/y of hydrogen (equivalent to about 15% of the national target). Simultaneously, a larger WWTP (referred to as WWTP A - capacity of 620,600 P.E., average flow rate of 155,300 $m^3$/d, and an industrial load of 15%) can generate 1.46 Mt/y, surpassing the national target. Even in the Worst-case Scenario (WS) with solely wind energy (resulting in reduced operating time to 2,000 hours per year), WWTP A remains a significant contributor, producing 0.39 Mt/y, while WWTP C contributes 0.03 Mt/y[4].

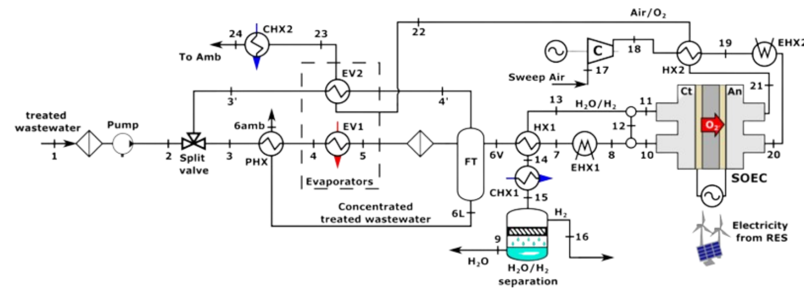


**Figure 1**. Layout of SOEC stack.

Converting this hydrogen production into electricity, Italy's increasing electricity demand in 2030 necessitates an annual addition of 8.6 to 10.7 GW of capacity. In the best-case scenario, WWTP A alone has the capability to fulfill 20% of the electricity demand, while in the worst-case scenario, it could cover 5.4%. For WWTP C, contributions amount to 1.3% in the best scenario and 0.4% in the worst scenario. These results underscore the considerable potential of harnessing wastewater as a sustainable and renewable energy source to address Italy's electricity requirements.

## Significance

This research illustrates that processed municipal wastewater sourced from diverse wastewater treatment facilities can serve as a superb water reservoir for Solid Oxide Electrolysis Cells (SOECs) to generate environmentally friendly hydrogen. The main objective is to emphasize the practicability and energy sustainability of utilizing wastewater as a non-potable water source for producing green hydrogen within the framework of a circular economy. This approach demonstrates efficiency in energy usage, cost-effectiveness, and holds the potential to transform the landscape of clean energy production, especially in regions with limited access to drinkable water. The amalgamation of wastewater treatment and hydrogen production has the capacity to address various sustainability objectives and contribute significantly to a decarbonized future.

## References

1 European Commission, *Communication from the commission to the European parliament, the council, the european economic and social committee and the committee of the regions - A European strategy for data*, 2020.
2 D. F. Di and L. Setti, 2022, 1–40.
3 M. A. Laguna-Bercero, *J. Power Sources*, 2012, **203**, 4–16.
4 J. Arnal and M. I. Tecnalia, *H2AEOLUS-Environmental performance analysis*.

# EXPLORING THE VIABILITY OF UTILIZING TREATED WASTEWATER AS A SUSTAINABLE WATER RESOURCE FOR GREEN HYDROGEN GENERATION USING SOLID OXIDE ELECTROLYSIS CELLS (SOECS)

**Marina Maddaloni**[1,2,3], Matteo Marchionni[4], Alessandro Abbá[2], Michele Mascia[4], Vittorio Tola[4], Maria Paola Carpanese[5], Giorgio Bertanza[2] and Nancy Artioli[1,2,*]

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## ABSTRACT

This research addresses the European Union's pursuit of carbon neutrality by exploring the potential of water electrolysis for hydrogen production, offering a promising solution for decarbonizing existing energy systems. The **S**olid **O**xide **E**lectrolysis **C**ell (**SOEC**) is particularly attractive due to its capability to utilize impure water sources.

Using *Aspen Plus software*, this study models a **SOEC** supplied with four distinct streams of real treated municipal wastewaters of Lombardy (Italy).

Simulation analysis reveals that two wastewater streams can be efficiently evaporated and treated within the **SOEC** avoiding the generation of waste liquids with excessive pollutant concentrations.

## OBJECTIVE

- To demonstrate the possibility and energy viability of using treated municipal wastewaters obtained from real **W**aste**W**ater **T**reatment **P**lants (**WWTPs**) of varying capacities, industrial loads and treatment schemes to produce "clean" hydrogen from **SOEC**.

## METHODOLOGY

1


Preliminary study

↓

2

SOEC simulation

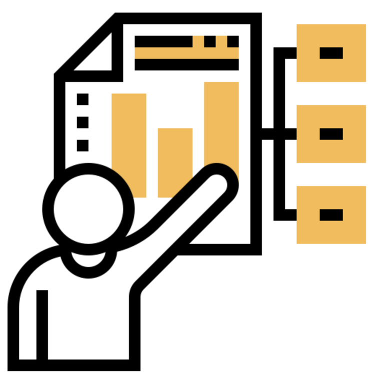
↓

3

Data analysis

↓

4



CONCLUSIONS

## RESULTS & DISCUSSION

| | WWTP A | WWTP B | WWTP C | WWTP D |
|---|---|---|---|---|
| | Vaporization = 27% | **Not usable.** Vaporization < 10%. | Vaporization = 10% | **Not usable.** Excessive pollutants concentration. |
| Capacity [P.E.] | 620,600 | 160,000 | 120,500 | 52,000 |
| Average flow rate [m$^3$/d] | 155,300 | 50,400 | 27,500 | 23,300 |
| Industrial load [%] | 15 | 19 | 11 | 25 |
| WWTP scheme | Activated sludge with pre- and post-denitrification; tertiary filtration | Membrane bioreactor (MBR) with pre-denitrification | Activated sludge with alternating oxic/anoxic cycles; tertiary filtration | Activated sludge; tertiary filtration |

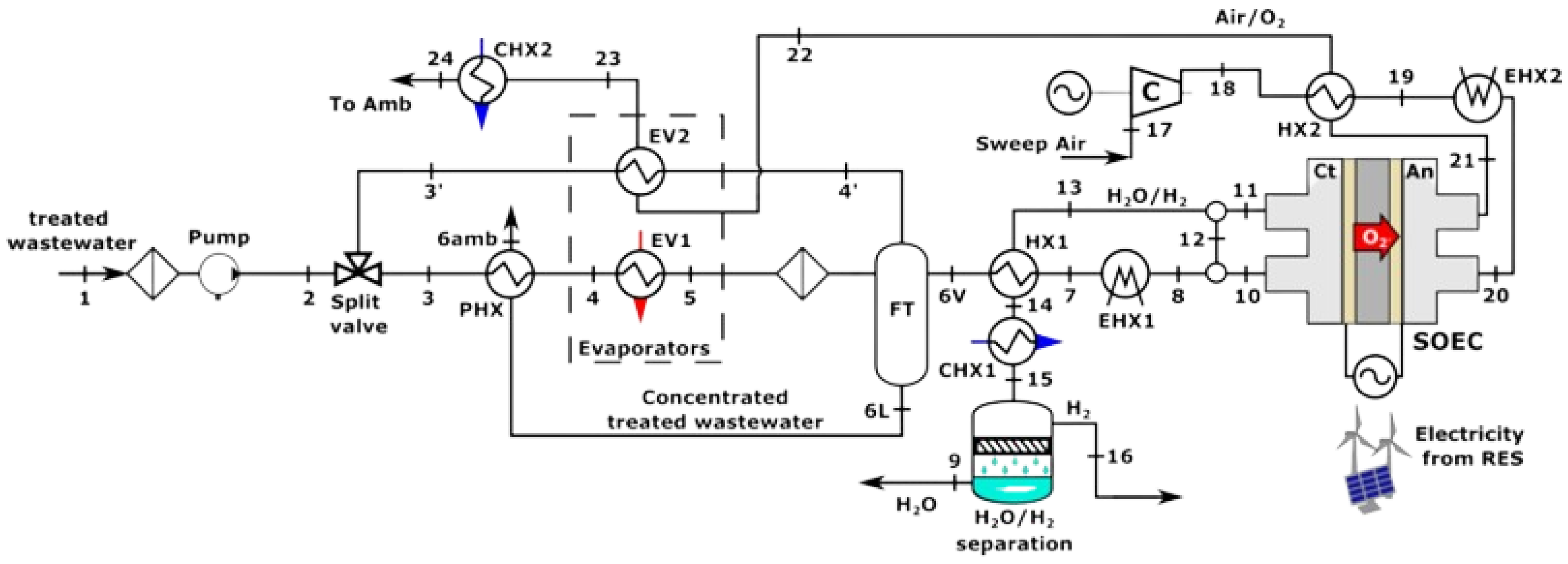



**Fig.1:** Layout of SOEC stack

$H_2$ WWTP(A) WWTP(C)

4067 t/d 268 t/d

### BEST SCENARIO

| | |
|---|---|
| 2.12 V | POWER |
| 7500 h/y | OPERATION HOUR |
| WWTP A= 1.46 Mt/y<br>WWTP C = 0.10 Mt/y | $H_2$ PRODUCTION |
| WWTP A= 20 %<br>WWTP C = 1.3 % | % ENERGY DEMAND |

5 GW POWER CAPACITY BY 2030

### WORST SCENARIO

| | |
|---|---|
| POWER | 2.12 V |
| OPERATION HOUR | 2000 h/y |
| $H_2$ PRODUCTION | WWTP A= 0.39 Mt/y<br>WWTP C = 0.03 Mt/y |
| % ENERGY DEMAND | WWTP A= 5.4 %<br>WWTP C = 0.4 % |

- Two of the four wastewater streams could be effectively evaporated and treated within **SOEC**, without generating waste liquids containing excessive pollutant concentrations.
- By evaporating 27% of the first current and 10% of the second, it was estimated that 26.2 kg/m$^3$ and 9.7 kg/m$^3$ of green $H_2$ could be produced, respectively.
- Considering to have 5 GW of installed power capacity by 2030, this $H_2$ production could meet anywhere from 0.4% to 20% of Italy's projected electricity demand.

UKCC 2024

**10th UK Catalysis Conference, 3-5 January 2024**
**Loughborough, UK**

| Wednesday, 3rd January | | | |
|---|---|---|---|
| 11:00 | Registration desk opens at Burleigh Court Hotel | | |
| 12:30 | Lunch at Holywell Park | | |
| 13.50 | Welcome – Conference commences at Holywell Park | | |
| | Chair – Prof. Chris Hardacre | | |
| 14.00 | PI 01 – Prof. Richard Catlow *(Turing Lecture Theatre)* | | |
| 14.45 | Coffee | | |
| | *Session A (Turing Lecture Theatre)* CatalysisHub session | *Session B (Brunel/Murdoch Lecture Theatre)* | *Session C (Stephenson Lecture Theatre)* |
| **Chair/IT** | Beale/Centeno | Kondrat/Mazumdar | Garforth/Inrirai |
| 15.15 | K1 (Weller) | O4 | O11 |
| 15.35 | | O5 | O12 |
| 15.55 | O1 | O6 | O13 |
| 16.15 | O2 | O7 | K2 (Matam) |
| 16.35 | O3 | O8 | |
| 16.55 | Coffee | | |
| **Chair/IT** | Artioli/Maddaloni | Lennon/Wilding | Wang/ Nieva De La Hidalga |
| 17.25 | K3 (Fey) | O9 | O14 |
| 17.45 | | O10 | O15 |
| 18.10 | Careers Question Time – *(Turing Lecture Theatre)* | | |
| 20.00 | Dinner | | |

## Thursday, 4th January

| | | | |
|---|---|---|---|
| | Chair – Prof. Graham Hutchings | | |
| 9.00 | PI 02 – Prof. Silvia Bordiga *(Turing Lecture Theatre)* | | |
| | *Session A (Turing Lecture Theatre)* | *Session B (Brunel/Murdoch Lecture Theatre)* | *Session C (Stephenson Lecture Theatre)* |
| **Chair/IT** | Mitchell/Olsen<br>RSC INTEREST GROUP APPLIED CATALYSIS session | Simons/Asad | Petkov/Collins |
| 10.00 | K4 (Zhang) | O18 | O28 |
| 10.20 | | O19 | O29 |
| 10.40 | O16 | O20 | O30 |
| 11.00 | Coffee | | |
| **Chair/IT** | Paterson/Ross | Matam/Mazumdar | Delarmelina/Maddaloni |
| 11.30 | K5 (Gibson) | O21 | O31 |
| 11.50 | | O22 | O32 |
| 12.10 | O17 | O23 | O33 |
| 12.30 | Lunch | | |
| | Chair – Prof. Richard Catlow | | |
| 14.00 | PI 03 – RSC Award Lecture – *(Turing Lecture Theatre)* | | |
| 14.45 | Coffee | | |
| | *(Turing Lecture Theatre)* | *(Brunel/Murdoch Lecture Theatre)* | *(Stephenson Lecture Theatre)* |
| **Chair/IT** | Mulholland/Centeno<br>RSC INTEREST GROUP SURFACE REACTIVITY & CATALYSIS session | Garforth/Mohammad | Weller/Inrirai |
| 15.15 | K6 (Artioli) | O24 | O34 |
| 15.35 | | O25 | O35 |
| 15.55 | K7 (Hermans) | O26 | O36 |
| 16.15 | | O27 | O37 |
| 16.35 | Coffee | | |
| 17.00 to 19.00 | **Poster session** | | |
| 20.00 | Conference Dinner | | |

| Friday, 5th January | | | |
|---|---|---|---|
| | *Session A (Turing Lecture Theatre)* | *Session B (Brunel/Murdoch Lecture Theatre)* | *Session C (Stephenson Lecture Theatre)* |
| **Chair/IT** | Freakley/Centeno | Zhang/Mohammad | Lin/Olsen |
| 9.00 | K8 (Nastase) | O40 | O46 |
| 9.20 | | O41 | O47 |
| 9.40 | O38 | O42 | O48 |
| 10.00 | Coffee | | |
| **Chair/IT** | Dingwall/Ross | Fey/Asad | D'Agostino/Collins |
| 10.30 | K9 (Wang) | O43 | O49 |
| 10.50 | | O44 | O50 |
| 11.10 | O39 | O45 | O51 |
| | Chair – Prof. Matthew Davidson | | |
| 11.35 | PI 04 – Prof. Walter Leitner *(Turing Lecture Theatre)* | | |
| 12.20 | Closing remarks | | |

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# PLENARY AND KEYNOTE SPEAKERS

UKCC 2024 will feature a number of plenary and keynote presentations from leaders across all areas of catalysis.

## PLENARY SPEAKERS

### Prof. Walter Leitner

Max Planck Institute for Chemical Energy Conversion, Germany

*New Carbon Sources for the Energetic and Chemical Value Chain: Challenges and Opportunities for Catalysis - TEN YEARS AFTER!*

### Prof. Sir Richard Catlow

Cardiff Catalysis Institute, UK

*Modelling of Catalytic Structures and Mechanisms: Achievements and Challenges*

### Prof. Silvia Bordiga

University of Turin, Italy

*MOFs and MOFs derivatives used as catalysts*

## KEYNOTE SPEAKERS

**Dr. Nancy Artioli, University of Brescia, Italy and Queen's University Belfast, UK**
**Dr. Natalie Fey, University of Bristol, UK**
**Dr. Emma Gibson, University of Glasgow, UK**
**Prof. Ive Hermans, University of Wisconsin-Madison, USA**
**Dr. Santhosh Matam, Cardiff University, UK**
**Dr. Stefan Nastase, King Abdullah University of Science and Technology, Saudi Arabia**
**Dr. James Paterson, BP, UK**
**Dr. Xiaodong Wang, Lancaster University, UK**
**Prof. Andrew Weller, University of York, UK**
**Dr. Xiaolei Zhang, University of Strathclyde, UK**

# List of Talks UKCC 2024

| # | Title | Authors |
|---|---|---|
| Pl 01 | Modelling of Catalytic Structures and Mechanisms: Achievements and Challenges | Richard Catlow |
| Pl 02 | MOFs and MOFs derivatives used as catalysts | Silvia Bordiga |
| Pl 03 | Innovation in Fischer-Tropsch Catalysis for an Applied Process | James Paterson |
| Pl 04 | New Carbon Sources for the Energetic and Chemical Value Chain: Challenges and Opportunities for Catalysis - TEN YEARS AFTER! | Walter Leitner |
| | | |
| K 01 | "Solid-State Molecular OrganoMetallic Catalysis: Crystalline Molecular Factories" | Andrew Weller |
| K 02 | Electrochemical $CO_2$ reduction over Cu-based gas diffusing electrodes: a study by complementary spectroscopic techniques | Santhosh Matam |
| K 03 | Towards Data-Led Prediction in Homogeneous Catalysis | Natalie Fey |
| K 04 | Mechanistic insights into the role of bi-functional and bi-metallic catalysts during hydrodeoxygenation of converting wastes into fuels | Xiaolei Zhang |
| K 05 | The Impact of Aging on the Structure-Activity Relationships of TWC Catalysts | Emma Gibson |
| K 06 | Novel synthesis approaches for $CO_2$ Hydrogenation catalysts using Ionic Liquids | Nancy Artioli |
| K 07 | Understanding Surface Reactions using Modulation Excitation Spectroscopy | Ive Hermans |
| K 08 | Methanol activation on Brønsted acid and defect sites in zeolites | Stefan Nastase |
| K 09 | Heterogeneous catalysis mediated cofactor regeneration for biosynthesis | Xiaodong Wang |
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| O 01 | Operando X-ray photoelectron spectroscopy at the solid-liquid interface | Charalampos Drivas, Elizabeth Jones, Robert Weatherup, Mark Isaacs and Christopher Parlett |
| O 02 | A Biocatalytic Approach Towards Alcohol Oxidation | Simon D. Anderson, Gavin J. Miller, Sebastian C. Cosgrove |
| O 03 | Influence of Sulfation on Activity & Stability of Metal oxide Catalysts for Vapor-phase Ketonisation of Volatile Fatty Acids | Ander Centeno, Gunjan Deshmukh, Maicon Delarmelina, Helen Daly, |

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| O 04 | Glucose isomerisation in zeolite Y: Adsorption effects on catalytic performances studied by NMR relaxation and in-situ DRIFTS | Carmine D'Agostino, Luke Forster, Mohamed M.M. Kashbor, James Railton, Sarayute Chansai, Christopher Hardacre and Marco Conte |
| O 05 | The Origins of High Selectivity Aniline Synthesis Catalysis with Pd/Al2O3: An In Situ Infrared Spectroscopic Study | Annelouise McCullagh, Stewart Parker and David Lennon |
| O 06 | Laser Induced Temperature-Jump Time-Resolved IR Spectroscopy of Zeolites from Nanoseconds to Seconds | Alexander P. Hawkins, Amy E. Edmeades, Christopher D.M. Hutchison, Michael Towrie, Russell F. Howe, Gregory M. Greetham and Paul M. Donaldson |
| O 07 | 2D-IR spectroscopy. Developing an ultra-fast IR laser technique as a tool for studying heterogeneous catalysts | Paul Donaldson, Alex Hawkins, Russell Howe and Greg Greetham |
| O 08 | Operando characterisation of the products of Fischer-Tropsch synthesis within catalyst pellets using magnetic resonance | Qingyuan Zheng, Jack Williams, Mick Mantle, Andrew Sederman, G. Bezemer, Constant Guédon and Lynn Gladden |
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| O 13 | Structure-activity relationships in Ni/$CeO_2$ for $CO_2$ methanation | Sining Chen and Andrew Beale |
| O 14 | Oxidation of Carbon Monoxide Over Ceria Supported Copper Catalyst | Oday Hakami, Abdullah Alhelali, Sarayute Chansai, Christopher Hardacre, Amanda Lea-Langton and Arthur Garforth |
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| O 21 | Catalytic Hydrogenation of Biomass-derived Furfural and Vanillin into Value-added Chemicals | Ganesh More and Rajendra Srivastava |
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| O 28 | Exploring the Relationship Between Heterogeneous Reaction Microkinetics and Apparent Kinetic Parameters | Fernando Vega-Ramon, Christopher Hardacre and Dongda Zhang |
| O 29 | Enabling High Throughput Kinetic Experimentation by Using Flow as a Differential Kinetic Technique | Gavin Lennon and Paul Dingwall |
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| O 36 | Structure Sensitive Catalysis: Efficacy of Cu on Manganese Oxide Catalysts in Levulinic Acid Hydrogenation | Nayan Jyoti Mazumdar, Praveen Kumar, Miryam Arredondo-Arechavala, Nancy Artioli and Haresh Manyar |
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