Achievements and Expertise of French public labs

Research & Developpement on CO₂ Utilisation
The ADEME (French Environment and Energy Management Agency) founded Club CO2 in 2002 with the support of the IFP Energies Nouvelles (IFPEN - formerly French Petroleum Institute) and BRGM (Bureau of Geological and Mineral Research). Since March 19th, 2016, Club CO2 became a non-profit association registered under French law with the BRGM as Chairman and EDF and IFPEN as administrators. The Club brings together the actors of the industrial world and of research.

Key element in the organization of French research in the field of carbon capture and storage, it serves as a response to the need of a more effective management for national efforts, while creating better public visibility. The members of the Club are all key players in the industry, research and development.

As a clearinghouse for information, dialogue and good practices among its members on CCUS research and technological developments, the Club encourages cooperation at a national level between public and private sectors, and several research projects have since then been initiated under its tutelage.

The main objectives of Club CO2 are:

- Identification of guidance lines and challenges for scientific and technical programs
- Promotion of contacts and information exchanges
- Encouragement of collaborative projects between public and private researchers

With dedicated working groups, Club CO2 has achieved several actions to promote CCUS. Club CO2, through its "WG CO2 Utilisation," is pursuing its involvement in the promotion of CO2 utilisation (CCU) as a means of reducing the carbon footprint of the economy.

One objective is knowledge sharing on technologies and products concerning the CO2 utilisation through elaborating an inventory with a regular update. Also several events on CO2 utilisation were organized to tackle the techno-economic and environmental issues.

www.captage-stockage-valorisation-co2.fr/en/home
contact.clubco2@ademe.fr
The main goal of this brochure is to show the wide variety of skills and expertises that are used for the development of new and innovative CO₂ utilisation technologies.

It is not the exhaustive picture on the French research laboratories working on CO₂ utilisation.

Most of these laboratories presented in this brochure contributed to Mission Innovation - Challenge 3-CCUS. The French Researchers and Club CO₂ elaborated the french priorities research directions (PRDs). These PRDs were used by the French participants as an input for the workshop “Mission Innovation -CCUS Experts”* held September 26–28, 2017 in Houston, Texas.

The next step will be an update of this directory with more french research laboratories.

Club CO₂ thanks all researchers who participate to the elaboration of this brochure.

*The Mission Innovation CCUS Experts’ Workshop discussed basic research and development (R&D) needs in CO₂ capture, CO₂ utilisation, geologic storage, and cross-cutting CCUS topics. Experts established a set of Priority Research Directions (PRDs), which have the potential to make a significant impact on CCUS technology performance. The report includes 30 PRDs to guide future CCUS R&D.
BRGM is France’s reference public institution for Earth Science applications in the management of the surface and subsurface.

BRGM is involved in the development of powerful technological breakthroughs in the Post-Combustion CO₂ capture:

1. fundamental research and experimentation: in-depth understanding of phenomena (mechanisms and kinetics)
2. multi-scale modelling
3. development of laboratory-scale devices
4. semi-pilot implementation
5. proof of concept and extrapolation

**SELECTED REFERENCES**

- BETELU S. ET AL. (2018) Procédé d’obtention de (nano)particules minérales enrobées de carbone. FR 18 50596
- BETELU S. ET AL. (2018) Procédé et dispositif de capture et/ou de libération d’espèces anioniques assisté par électrolyse. FR 18 50597
- SERON A. ET AL. (2009) Procédé de séparation de CO₂ d’un mélange de gaz par des oxydes mixtes amorphes. WO2010149871
- SERON A. ET AL. (2005) Procédé de synthèse en phase aqueuse de composés de type Hydroxydes Doubles Lamellaires. WO2006090069

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C2P2
Chimie, Catalyse, Polymères & Procédés

General description of the activities

C2P2 – CHIMIE, CATALYSE, POLYMERES & PROCÉDÉS is a CNRS research unit (UMR 5265 under triple tutelage CPE Lyon, U. Lyon and CNRS).

The major focus of the research at the C2P2 is on the use of fundamental chemistry, catalysis, and chemical engineering to enhance our ability to produce organic, inorganic and composite materials, and to propose the processes used for this purpose.

KEY COMPETENCES IN CCU
Chemical valorization of CO₂, through catalysis towards solar fuels, organic carbonates and polymers.

KEY EQUIPMENTS IN CCU
Catalytic Materials Synthesis - High pressure reactor fully equipped with ballast and temperature controller – Polymerization reactors

KEY PROJECTS IN CCU
MOF based catalytic systems for CO₂ photo(electro) reduction
Erasmus Mundus H2020 SINCHEM “Sustainable industrial chemistry” (2013-2020)
Azaphosphatranes in confined space for CO₂ valorization
ANR AZAP-CO₂ (2014-2019)
Carbon Dioxide Activation for monomer and polymer syntheses
Associate CO₂ with a-olefins/L,3-dienes to synthesize platform molecules of industrial relevance, such as acrylate- or lactone-based monomers
ANR-JC CaDiAc (2015-2019)

SELECTED REFERENCES

GENERAL REVIEWS/EDITORIALS
• “Catalysis for CO₂ conversion to introduce renewable energy in the value chain of chemical industries” G. Centi, E. A. Quadrelli, S. Perthoner Energy Environ. Sci. 6, 1711 (2013)

SOLAR FUELS
• “Enhanced formation of ąC1 products in the electroreduction of CO₂ by adding a carbon dioxide adsorption component to a gas diffusion layer-type catalytic electrode” ChemSusChem 10(22), 4442–4446 (2017)
• “Role of small Cu nanoparticles in the behaviour of nanocarbon-based electrodes for the electrocatalytic reduction of CO₂” Marepally B., Ampelli, C. Genovesi C., Tavella F., Veyre L., Quadrelli E. A., Perathoner S., Centi G. J. CO₂ Util. 21, 534-542 (2017)

CARBONATES
• “Zinc–Azatrane Complexes as Efficient Catalysts for the Conversion of Carbon Dioxide into Cyclic Carbonates” B. Bousquet, A. Martinez, V. Dufaud ChemCatChem, 10, 843 (2018)

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POLY CARBONATES
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Achievements and Expertise of French public labs

CEA-LITEN

Laboratoire d’Innovation pour les Technologies des Energies nouvelles et les Nanomatériaux

General description of the activities

Energy efficiency, renewable energies and advanced materials

FIELD

Development of reactor and processes for CO₂ hydrogenation

KEY COMPETENCES IN CCU

Reactor design for CO₂ hydrogenation to methane and methanol, performance and durability assessment

KEY EQUIPMENTS IN CCU

Catalytic test bench, reactor manufacturing workshops, CAD & numerical simulation

KEY PROJECTS IN CCU

JUPITER-1000, CO₂-SNG, POLYGEN, STORE&GO, METHYCENTRE

SELECTED REFERENCES


PATENTS: FR3027663, WO2016042063, FR3010641, FR2996630, WO2014029933, FR2982876

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CEISAM
Chimie Et Interdisciplinarité
Synthèse, Analyse, Modélisation

General description of the activities

The core activity of the researches undertaken in the group of Fabrice ODOBEL au CEISAM laboratory focuses on the development of molecular materials for the conversion of solar energy into electricity (solar cells) and into fuel (artificial photosynthesis).

FIELD
Chemical synthesis, photochemistry, photo-electrochemistry, artificial photosynthesis, solar fuel, hydrogen production, CO₂ photo-reduction, dye chemistry

KEY COMPETENCES IN CCU
Development of photocatalytic devices for CO₂ reduction
Artificial photosynthesis
Sensitization of p-type semiconductor

KEY EQUIPMENTS IN CCU
Solar simulator
Photoelectrochemical cell for solar fuel production
Gas chromatography for detection and analyses of gas

KEY PROJECTS IN CCU
Development of photocatalytic devices for solar fuel production based on sensitized p-type semiconductor

SELECTED REFERENCES

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MINES PARIS TECH
Research University, CES – Centre for Energy Efficiency of Systems

General description of the activities
Gas-Liquid Transfers and Processes

FIELD
Process and chemical engineering, CO₂ capture, recycling, carbon-free electricity

KEY COMPETENCES IN CCU
Modeling, Simulation, Experimental

KEY EQUIPMENTS IN CCU
The experimental apparatus has been designed to measure absorption rates for a CO₂

KEY PROJECTS IN CCU
Study of post-combustion CO₂ capture by solutions of ammonia and organic amines
Assessment using direct and indirect contactors by kinetic, thermodynamic approaches and modeling
Performance Assessment of Oxy-Coal Power Plants through an Exergy-based Process Integration Methodology Energy;
Recycling and valorization of Carbon Dioxide;
Composite and microporous membrane contactors for intensified gas-liquid processes in CO₂ postcombustion capture:
Experiments and Modelling.

SELECTED REFERENCES
1. Y. EL FOUIH, C. BOUALLOU
Recycling of carbon dioxide to produce ethanol

2. Y. REDISSI, C. BOUALLOU
Valorization of carbon dioxide by co-electrolysis of CO₂/H₂O at high temperature for syngas production

3. H. ER-RBIB, C. BOUALLOU, F. WERKOFF
Production of synthetic gasoline and diesel fuel from dry reforming of methane
Energy Procedia 2012; 29:156 - 165

4. E.S. VAN-DAL, C. BOUALLOU
Design and simulation of a methanol production plant from CO₂ hydrogenation
Journal of Cleaner Production 2013; 57: 38-45

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General description of the activities

Transformation and valorization of CO₂ – Utilization of CO₂ as a carbon source towards attractive alternative solutions for synthesizing useful chemicals and energy rich products (fuels).

Our main research activities: explore the potential of new molecular catalysts e.g. metallic complexes for efficient and selective electro-, photo-, and photoelectro-catalytic reduction of CO₂.

Our main research activities: explore the potential of new molecular catalysts e.g. metallic complexes for efficient and selective electro-, photo-, and photoelectro-catalytic reduction of CO₂.

SELECTED REFERENCES


E. TORRALBA-PENALVER, Y. LUO, J.-D. COMPAIN, S. CHARDON-NOBLAT, B. FABRE. Selective catalytic electroreduction of CO₂ at silicon nanowires (SiNWs) photocathodes using non-noble metal-based manganese carbonyl bipyridyl molecular catalysts in solution and grafted onto SiNW. ACS Catal. 5, 6138–6147, 2015


GEPEA LABORATORY
University of Nantes - CNRS

General description of the activities

The GEPEA laboratory is a French Joint Research Unit of the University of Nantes, CNRS, Oniris, IMTA (France). It is working on the design and optimization of processes for microalgae valorization.

This multi-disciplinary research group proposes an integrated approach, including (1) screening of strains and metabolic optimization, (2) culture systems and photobioreactor engineering (from state-of-the-art raceways to newly developed intensified technologies), and (3) metabolites extraction and purification through bio-refining approach. In 2015, the GEPEA Laboratory has developed the AlgoSolis R&D Facility, belonging to the University of Nantes.

This core facility was designed to address issues related to the up-scaling and industrial optimization of microalgal processes. Various breakthrough technologies have been developed (solar photobioreactors, wet-biomass extraction processes, culture medium recycling,...). AlgoSolis R&D Facility allows also investigating microalgal culture on industrial effluents (CO₂, waste water,...).
General description of the activities

Our team is dedicated to high temperature fuel cells & electrolysers. Our strong research now is on the capture and valorization of carbon dioxide in molten carbonates.

FIELD
High temperature fuel cells and electrolysers: electrolysis of CO$_2$ in molten salts

KEY COMPETENCES IN CCU
CO$_2$ electrolysis & solubility in molten carbonates

KEY EQUIPMENTS IN CCU
Electrochemical platform coupled with gas chromatography, as well as thermal analysis coupled with IR/MS/GC.

KEY PROJECTS IN CCU
From the feasibility of the process (CO$_2$ electrolysis into CO) to test & pre-pilot devices

SELECTED REFERENCES

D. CHERY, V. ALBIN, A. MELÉNDEZ-CEBALLOS, V. LAIR, M. CASSIR
“Mechanistic approach of the electrochemical reduction of CO$_2$ into CO at a gold electrode in molten carbonates by cyclic voltammetry”
Int. J. Hydrogen Energy 41 (2016) 18706

D. CHERY, V. LAIR, M. CASSIR
“CO$_2$ electrochemical reduction into CO or C in molten carbonates: a thermodynamic point of view”
Electrochimica Acta 160 (2015) 74

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D. CHERY, V. LAIR, M. CASSIR
“Overview on CO$_2$ valorisation: challenge of molten carbonates”,
ICARE
Institut de Combustion, Aérothermique, Réactivité et Environnement

General description of the activities

My research topics concern the turbulent combustion, control of flames, burners and pollutant emissions.

FIELD
Combustion

KEY COMPETENCES IN CCU
Oxy-combustion

KEY EQUIPMENTS IN CCU
Combustion system plants

KEY PROJECTS IN CCU
CO₂ Energ/ Capt with 4 author partners

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SELECTED REFERENCES

www.larep.fr/orleans/2015/11/02/deux-structures-du-cnrs-recompensees-pour-leurs-recherches-de-technologies-vertes.11646883.html
www.agence-nationale-recherche.fr/Projet-ANR-10-EESI-0003
General description of the activities

Integrated CO₂ CCUS with coupled metal recovery.

We investigate the interactions between lean and rich solutions with additional molecular species in order to modulate the thermodynamics and kinetics of capture and develop convergent/integrated capture and utilization processes.

Currently, our main focus consist in valorizing CO₂-rich solutions for mineral carbonation and valuable/toxic metals recovery.

FIELD
Molecular and supramolecular chemistry

KEY COMPETENCES IN CCU
Design, analysis and implementation of complex molecular systems for CO₂ capture and utilization (as pre-ligand for metal separation or as catalyst)

KEY EQUIPMENTS IN CCU
Batch (ball-mill; microwave) & continuous flow reactors; spectroscopic, chromatographic and calorimetric platforms

KEY PROJECTS IN CCU
MA2RSCO2SCARE
ANR-12-JS07-0011-01
2012 - 2016
Multi-component self-Assembled ARchitectures based on CO₂ for Selective CApture of Rare Earth metals
ProCO₂Met
SATT SE & AURA 1502
2016 - 2018
Continuous Flow Process utilizing CO₂ for Metal separation

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SELECTED REFERENCES

LECLAIRE, G POISSON, F ZIARELLI, G PEPE, F FOTIADU, F.M. PARUZZO, A.J ROSSINI, J.-N. DUMEZ, B. ELENA-HERRMANN, L. EMSLEY.
Structure elucidation of a complex CO₂-based organic framework material by NMR crystallography
Chem. Sci. 2016, 7, 4379-4390

J. SEPTAVAUX, G. GEOFFROY, J. LECLAIRE
Dynamic covalent chemistry of carbon dioxide: opportunities to address environmental issues.

J. LECLAIRE, G CANARD, F FOTIADU, G POISSON
Method for detecting, capturing and/or releasing chemical elements.

C. DE BELLEFON, J. LECLAIRE, G. POISSON, R. PHILIPPE, J. SEPTAVAUX, L. VANOE
Continuous process for the detecting, capturing and releasing chemical elements
2017 PCT/EP2017/060186

1ST PRIZE LYON START’UP WEEK-END 2017

EXCELLENCE CHAIR IN CHEMISTRY, IMUST CONSORTIUM
ICCF / TIM
Institute of Chemistry of Clermont-Ferrand/Thermodynamics and Molecular Interactions

General description of the activities

Experimental thermodynamic measurements and thermodynamic modeling of the absorption of gas (CO\textsubscript{2}, annex gases) in aqueous solutions of amines (capture) and of salts (storage in deep saline aquifers).

**FIELD**
Thermodynamics, physical chemistry, gas dissolution

**KEY COMPETENCES IN CCU**

**KEY EQUIPMENTS IN CCU**
Mixing calorimeters, phase equilibrium cells, densimeters, viscosimeters

**KEY PROJECTS IN CCU**
ACACIA (FUI – Axelera): Développement de technologies et de procédés de captage du CO\textsubscript{2} en post-combustion directement sur fumées de sources fixes (partner)
VALORCO (PIA – Arerne): Valorisation et Réduction des émissions de CO\textsubscript{2} en Industrie (partner)
DACOOTA (ANR/NSERC n°12-IS09-0001): Demixing Amines for CO\textsubscript{2} capture: Thermodynamic and Spectroscopic Approach (leader)
SIMODEX (ANR/NSERC n°15-CE06-0010): Understanding CO\textsubscript{2} capture processes: a combination of reactive molecular simulation, thermodynamic modelling and experiments (leader)

**SELECTED REFERENCES**


COULIER, Y., LOWE, A. R., COXAM, J. Y., & BALLERAT-BUSSEROLLES, K., ACS Thermodynamic Modeling and Experimental Study of CO\textsubscript{2} Dissolution in New Absorvents for Post-Combustion CO\textsubscript{2} Capture Processes Sustainable Chemistry & Engineering, 6(1), 918-926 (2017)


**Thermodynamic representation of the CO\textsubscript{2} capture process using demixing amines**

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**General description of the activities**

**FIELD**
Material science, Physical chemistry, Electrochemistry, Electrochemical synthesis, electrochemical engineering.

**KEY COMPETENCES IN CCU**
Elaboration and multiphysics characterization of nano-structured electrochemical and photo-electrochemical interfaces for the selective reduction of carbon dioxide in water media at near-ambient temperature conditions.

**KEY EQUIPMENTS IN CCU**
- General electrochemical equipment (potentiostat, RDE, RRDE, etc.).
- General photo-electrochemical equipment (quartz cells).
- Analysis of CO$_2$ reduction products (Gas chromatography, NMR).
- AFM-SECM for local scale in-situ electrochemical characterization.

**KEY PROJECTS IN CCU**
- ANR Chalcocat.
- Financial support from the industry sector.
- Several international collaborations.

Typical CO$_2$ reduction experiment using a CuGa3Se5 thin film photo-electrode: setup and GC analysis showing reduction products.

Catalytic ink printer and experimental setup used for the testing of polymer electrolyte membrane (PEM) CO$_2$ electro-reduction cells.

**SELECTED REFERENCES**
- F. DE GUGLIELMO, PHD THESIS, University Paris-Sud, 2013

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www.icmmo.u-psud.fr/Labos/ERIEE/
General description of the activities

The Institute is composed by more than a hundred of scientists concerned by the development of advanced research related to energy, environment and health.

The complementarities of the various research teams contribute to solve global issues ranging from molecules design, properties, and applications for applications in the fields of Energy, Environment or Health.

At the forefront of new technologies and the development of innovative materials, the Institute is organized in three research departments:

- Catalysis and Materials
- Molecular Chemistry and Analytics
- Polymer Engineering

FIELD
Heterogeneous catalysis, kinetic studies

KEY COMPETENCES IN CCU
Development of catalytic materials for the hydrogenation of CO₂ into fuels.

KEY EQUIPMENTS IN CCU
Catalytic set-ups from Patm to 80 bar, from Tatm to 800 °C, equipped with online GC Surface characterization by H₂-TPD, CO₂-TPD, NH₃-TPD, N₂O chemisorption

KEY PROJECTS IN CCU
- ANR Vitesse2 (2010-2014): «Industrial and energetic valorization of CO₂ by efficient use of decarbonized electricity: Stabilization of the electric grid and electricity storage»

SELECTED REFERENCES

G. MIGNANI, B. PAVAGEAU, J. JOLLY, A.C. ROGER, F. OCAMPO, M. FREY
«Procédé d’alcanation du CO₂ utilisant comme catalyseur un composé comprenant du nickel sur un support à base d’oxyde de cérium.»
Brevet français no 12/01176 du 20/04/2012

F. OCAMPO, B. LOUIS, A.C. ROGER
«Methanation of carbon dioxide over nickel based Ce0.72Zr0.28O2 mixed oxide catalysts prepared by sol-gel method»

F. OCAMPO, BENOIT LOUIS, L. KIWI-MINSKER, A.C. ROGER
«Effect of Ce/Zr composition and noble metal promotion on nickel based CexZr1-xO2 catalysts for carbon dioxide methanation.»
Applied Catal A: General 392, 36-44 (2011)

P.A. USSA ALDANA, F. OCAMPO, K. KOBL, B. LOUIS, F. THIBAULT-STARZYK, M. DATURI, P. BAZIN, S. THOMAS, A. C. ROGER
«Catalytic CO₂ valorization into CH₄ on Ni-based ceria-zirconia. Reaction mechanism by operando IR spectroscopy»

K. KOBL, S. THOMAS, Y. ZIMMERMANN, K. PARKHOMENKO, A.C. ROGER
«Power-law kinetics of methanol synthesis from carbon dioxide and hydrogen on copper-zinc oxide catalysts with alumina or zirconia supports»

M. FREY, T. ROMERO, A.C. ROGER, D. EDOUARD
«Open cell foam catalysts for CO₂ methanation: Presentation of coating procedures and in situ exothermicity reaction study by infrared thermography»
Catal Today 273, 83-90 (2016)

M. FREY, A.C. ROGER, D. EDOUARD, G. GEFRAYE, A. BENGAGOUER
«Aluminium open cell foams as efficient support for CO₂ methanation catalyst: pilot scale reaction results»
Energy Technology 5(11), 2078-2085 (2017)

J.F. PORTHA, K. PARKHOMENKO, K. KOBL, A.C. ROGER, S. ARAB, J.M. COMMENGE, L. FALK, IND.
Kinetics of Methanol Synthesis from Carbon Dioxide Hydrogenation over Copper-Zinc Oxide Catalysts.»

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ICSM  
Institut de Chimie Séparative de Marcoule

General description of the activities

The “Institut de Chimie Separative de Marcoule” (ICSM) is a joint research unit (CEA, CNRS, UM, ENSCM). The scientific mission of ICSM originates from the unavoidable rarefaction of fossil fuels, as well as their global impact on climate and is focused on decarbonized energies.

The ICSM is mainly involved in recycling and material science to address improved safety requirements and ecological issues in the use of low carbon energies (nuclear and renewable).

The ICSM has 5 scientific and technical pillars:

- **Understanding separation processes**: Characterization at the molecular and supramolecular level all in correlation with thermodynamics.
- **Optimizing separation processes**: The aim is here to synthesize, formulate and implement a knowledge-based recycling technology.
- **Green chemistry**: Implement the twelve principles of green chemistry as well as those of “green extraction engineering”.
- **Anticipating life-cycle**: Studies of surface degradation and material production.
- **Methods in modeling and observations at meso-scale**: Modelling and analytical developments for separation and materials properties.

**FIELD**
Main Fields and skills:
- Synthesis and characterization and reactivity of molecular species (organic, coordination compounds) and materials (ceramics, hybrid, porous).
- Physical-Chemistry for supramolecular speciation in complex organic media, at the liquid-liquid interface and in porous solids.

**Mesoscale Modelling**
- Ultrasound approaches for hydrometallurgy and materials
- Analytical and methodological development essentially for Material Characterization

**KEY COMPETENCES IN CCU**
- Separation and Purification of valuable main or secondary products obtained by a CO₂ conversion process, essentially into carbonates.
- Synthesis of materials (Metal-Organic Frameworks on ITO-FTO surface) and molecular compounds (Ru-Co compounds) for photo induced charge separation which could be used for CO₂ reduction, usually in the frame of collaboration (College de France)

**KEY EQUIPMENTS IN CCU**
- Material characterization:
  - Environmental Electronic Microscopy,
  - X-ray small angle diffusion and wide angle diffraction

**KEY PROJECTS IN CCU**
- VALORCO
  - Small projects (CNRS, Université de Montpellier) for molecules and materials for photophysical assisted charge separation.

**SELECTED REFERENCES**

*X. Wang, V. Goudy, G. Genesio, J. Maynadie, D. Meyer, M. Fontecave*  
“Ruthenium-cobalt dinuclear complexes as photocatalysts for CO₂ reduction”  
Chemical Communications, 53, 5040-5043 (2017)

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IFPEN
IFP Energies Nouvelles

General description of the activities

IFP Energies nouvelles (IFPEN) is a major research and training player in the fields of energy, transport and the environment. From research to industry, technological innovation is central to all its activities, structured around three strategic priorities: sustainable mobility, new energies and responsible oil and gas.

As part of the public-interest mission with which it has been tasked by the public authorities, IFPEN focuses on:

• providing solutions to take up the challenges facing society in terms of energy and the climate, promoting the transition towards sustainable mobility and the emergence of a more diversified energy mix;

• creating wealth and jobs by supporting French and European economic activity, and the competitiveness of related industrial sectors.

An integral part of IFPEN, its graduate engineering school – IFP School – prepares future generations to take up these challenges.

FIELD
Chemical synthesis, process and chemical engineering, geology...

KEY COMPETENCES IN CCU
Carbone capture using amines, Electro reduction, Photocatalysis, Chemical process...

KEY EQUIPMENTS IN CCU
Pilot units for CO₂ capture (amines) and for CO₂ electro reduction

KEY PROJECTS IN CCU
VALCO₂ – French Research program coordinated by SOLVAY

SELECTED REFERENCES
NUMEROUS PATENTS AND PUBLICATIONS.

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Achievements and Expertise of French public labs

IFSTTAR
Institut Français des Sciences et Techniques Transports Aménagement Réseaux

General description of the activities

Industrial ecology, circular economy, eco-design, symbiose industrielle

FIELD
Process engineering, civil engineering

KEY COMPETENCES IN CCU
Life Cycle Assessment

KEY EQUIPMENTS IN CCU
Software and databases for Life Cycle Assessment

KEY PROJECTS IN CCU
Algoraff (BIP ADEME), Cimentalgues (BIP ADEME), Algoroute (ANR)

SELECTED REFERENCES

VENTURA A., 2 avril 2012, Approches Systémiques et Eco-conception - Une réflexion sur les fondements conceptuels et les applications de l’Analyse de Cycle de Vie, Mémoire d’Habilitation à Diriger des Recherches


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Systemic modeling of technological actions
Identification of action levers in a complex system using statistics

Complete references: https://scholar.google.fr/citations?user=RsfIyxcAAAAJ&hl=fr
IRCELYON
Institut de Recherches sur la Catalyse et Environnement de Lyon

**General description of the activities**

IRCELYON brings together competences in catalysis (heterogeneous, homogeneous, enzymatic and photocatalytic systems) to remediate environmental problems such as air or water pollution, but also to valorize biomass (vegetal oils, lignin, starch, cellulose, algae, CO₂...)

**FIELD**
Chemical catalysts design, synthesis and evaluation

**KEY COMPETENCES IN CCU**
- CO₂ capture by MOF or enzymatic systems
- Use of Sc-CO₂ as green solvent to extract fatty alcohols from sugar cane mud
- Catalytic CO₂ coupling to epoxides

**KEY EQUIPMENTS IN CCU**
Stainless steel reactors including CO₂ supercritical tests

**KEY PROJECTS IN CCU**
- Catalytic CO₂ valorization to cyclic carbonates

**SELECTED REFERENCES**

**J. MOL. CAT. A, CHEMICAL, 2014, 381, 161-170**
"Novel Cr(III) complexes with N₄-donor ligands as catalysts for the coupling of CO₂ and epoxides in supercritical conditions CO₂"  

**CHEMCATCHEM, 2012, 4 (11), 1725-1728**
"The Origin of the Activity of Amine-Functionalized Metal-Organic Frameworks in the Catalytic Synthesis of Cyclic Carbonates from Epoxide and CO₂"

**J. MOL. CAT. B: ENZYMATIC 2009, 60, 163-170**
"Biocatalytic capture of CO₂ with carbonic anhydrase and its transformation to solid calcium carbonate"

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General description of the activities

CO₂ capture and valorization in molten carbonates: physico-chemical properties, high temperature electrolysis, molten carbonate fuel cell.

FIELD
Physico-chemistry, process and chemical engineering

KEY COMPETENCES IN CCU
High Temperature Electrochemistry in Molten Carbonates

KEY EQUIPMENTS IN CCU
Molten carbonate (MC) Electrolysis/Fuel Cell Set-up, coupled to GC. Solubility of gases in MC, DSC-TGA coupled to FTIR and GC-MS

KEY PROJECTS IN CCU
EquipeX 2011: PLANEX (Planète expérimentation: simulation et analyse in situ en conditions extrêmes)
ANR 2018: MCEC (Compréhension & Optimization of high temperature CO₂ Electrolysis in Carbonates)

Platform for High Temperature Fuel/Electrolysis Cell in Molten Carbonates

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SELECTED REFERENCES
D. CHERY, V. LAIR, M. CASSIR
CO₂ electrochemical reduction into CO or C in molten carbonates: a thermodynamic point of view.

A. MELENDEZ-CEBALLOS, A. BROUZGOU, C. CRAPART, V. ALBIN, V. LAIR, AND M. CASSIR
Chronopotentiometric Approach of CO₂ Reduction in Molten Carbonates.

A. MELENDEZ-CEBALLOS, V. ALBIN, V. LAIR, A. RINGUEDE AND M. CASSIR
A kinetic approach on the effect of Cs addition on oxygen reduction for MCFC application
**General description of the activities**

The Institute of Molecular Sciences brings together a community of organic chemists and physical chemists interested in molecular structures, and working on their creation, synthesis, characterization, reactivity and analysis in various environments.

**FIELD**
- Spectroscopy, Molecular modeling, Thermodynamics, Chemical synthesis

**KEY COMPETENCES IN CCU**
- Cyclic carbonate synthesis, CO₂ catalysis, CO₂ sourced polyurethanes, CO₂ sourced polycarbonates, CO₂ capture and separation

**KEY EQUIPMENTS IN CCU**
- In situ high pressure spectroscopy (Infrared, Raman, Uv-Vis, Neutron)
- High pressure batch reactor 1-30 ml and glass capillaries (P=1-50 MPa / 90K-600K)

**KEY PROJECTS IN CCU**
- International French-Belgian project on CO₂ sourced polymers
- ANR MI2C project on gas selectivity in gas hydrates

**SELECTED REFERENCES**

**M. ALVES, B. GRIGNARD, R. MEREAU, C. JEROME, T. TASSAING, C. DETREMBLEUR**


**S. GENNEN, B. GRIGNARD, T. TASSAING, C. JEROME, C. DETREMBLEUR**


**MEREAU, B. GRIGNARD, A. BOYAVAL, C. DETREMBLEUR, C. JEROME, T. TASSAING**


**C. PETUYA, F. DAMAY, S. DESPLANCHE, D. TALAGA, A. DESMEDT**


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**Arnaud DESMEDT**
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General description of the activities

Our team of molecular chemists works on the conversion of CO₂, CO, waste plastics and biomass by-products to high value-added chemicals in a sustainable manner, and the facilitation of energy storage with the development of alternative liquid fuels. Following a knowledge-driven approach, we synthesize novel molecular catalysts (organic, organometallic or inorganic) and investigate their modes of action through mechanistic studies.

To expand the scope of fine chemicals available from CO₂, our idea is to design novel catalytic transformations where CO₂ is reacted, in a single step, with a functionalizing reagent and a reductant that can be independently modified, to produce a large spectrum of molecules. This method has been successfully applied to synthesize methylamines, formamidines, aminals, esters...
General description of the activities

The research activity of the LCMT is focused on both fundamental and applied aspects of molecular chemistry.

The scientific aim at LCMT laboratory is to develop new and innovative methods in organic synthesis and catalysis for an application in green chemistry, material sciences and bioorganic chemistry: development of cheap, environmentally friendly, and sustainable technologies for the production of molecules and macromolecules [atom and energy saving syntheses, catalyses, new activation technologies (MW), new media for clean processes]...

This scientific aims are underlined through 3 main objectives:

1. Development of new synthetic methods in the field of heterochemistry and metal mediated chemistry;
2. Identification of reaction intermediates and elucidation of reaction mechanisms in order to perform high yielding and highly selective reactions;
3. Development of new organic and hybrid materials with specific properties. The molecular and macromolecular engineering is thus the core business of the laboratory. In the field of catalysis, we have recently made important contributions to the chemical activation of small molecules such as H₂, CO₂ by iron-based complexes, in an effort to address contemporary energy challenges (storing energy into chemical bonds and producing fuels).

FIELD
Catalysis, organometallic chemistry.

KEY COMPETENCES IN CCU
Molecular catalysis
Hydrogenation
Mechanisms

KEY EQUIPMENTS IN CCU
Autoclaves, GC, GC/MS, NMR, HPLC

KEY PROJECTS IN CCU
Photochemical conversion of CO₂ into formate

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SELECTED REFERENCES
Chemistry, a European Journal, 2015, 21, 7066.
The research activity of the LEM is focused on both fundamental and applied aspects of molecular and biomolecular electrochemistry. The aim is to contribute to the general understanding of all aspects of electron transfer chemistry coupled to both molecular changes and/or dynamical electron transport within molecules and, on the basis of the fundamental advances, to develop new applications.

In the field of catalysis, we have recently made important contributions to the electrochemical activation of small molecules such as H₂, O₂, H₂O, CO₂ by metal complexes or catalytic films, in an effort to address contemporary energy challenges (storing energy into chemical bonds and producing fuels).

**SELECTED REFERENCES**


General description of the activities

Based in Toulouse, France, the Laboratoire de Génie Chimique (LGC) is a joint research institute directed by the French National Centre for Scientific Research (CNRS) and two universities, the Institut National Polytechnique de Toulouse (INP Toulouse) and the Université Paul Sabatier (UPS).

Its core activities are dedicated to advanced research in chemical and process engineering.

With over 160 permanent scientists and engineers, and as many PhD students and post-doctoral fellows, LGC pursues industry-driven research across all scales necessary for development of state-of-the-art and innovative industrial processes, from the smallest molecular or particulate scale right through to large scale industrial systems.

With six research departments, LGC has the ability to address the widest spectrum of activities in the field of chemical and process engineering.

www.lgc.cnrs.fr

FIELD
Chemical and process engineering

KEY COMPETENCES IN CCU
CO₂ valorisation by mineral carbonation – process development and thermo-kinetic modelling

KEY EQUIPMENTS IN CCU
Batch autoclaves and continuous bench-scale stirred media mill for attrition-leaching process

KEY PROJECTS IN CCU
2018-2021 CARBOSCORIES 2: production of construction materials by mineral carbonation of Ni mining waste
Key outcomes: Development of a bench-scale continuous attrition-leaching pilot process; valorisation of mineralisation products in the construction sector.
Project partners: LGC, LMDC, CNRT, BRGM
Funding: ACE Caledonian Energy Agency No. CS17-3160-00.

2015-2016 CARBOSCORIES: mineral carbonation of Ni mining waste
Key outcomes: validation of the attrition-leaching mineralisation process for valorisation of Ni pyrometallurgical waste.
Project partners: LGC, BRGM, IPGP
Funding: National Centre for Technology Research - CNRT “Nickel and its environment”.

2009-2012 CARMEX: Ex-situ mineral carbonation of ultramafic ores and mining waste
Key outcomes: proof of concept of the attrition-leaching process for mineralization of silicate ores and mining waste.
Project partners: LGC, BRGM, BioIS, IPGP, Total E&P
Funding: ANR French National Research Agency No. ANR-08-PCO2-002; Total E&P.

SELECTED REFERENCES


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Achievements and Expertise of French public labs

**General description of the activities**

The Laboratory of Reactions and Chemical Engineering (300 people) develops the scientific and technological knowledge necessary for the synthesis and recycling of materials and functional products, through chemical, physico-chemical and biological processes and the design, the optimization and the control of the elaboration processes and the related transformation of mass and energy.

**KEY COMPETENCES IN CCU**

- Material and liquid selection for selective carbon capture (solvents, polymers, adsorbents, membranes)
- Modelling and simulation of carbon capture processes (membrane contactors, membrane separation, Temperature and/or Pressure Swing Adsorption processes)
- Design and testing of bench-scale units for proof of concepts studies and model validation
- Evaluation of energy requirement and size for carbon capture (Process Systems Engineering simulation with tailor-made toolboxes)
- Life Cycle Analysis (LCA) of carbon capture processes.
- Kinetics study, Reactors design, and whole process conception (optimal reactors and separators association) for CO₂ valorization (methanation, methanol production ...)
- Carbonation of CO₂ (kinetics study and reactors design)
- CO₂ fermentation (H₂ enriched fermentation for methane production)
- Influence of copollutants on adsorbent performance for CO₂ capture

**FIELD**


**KEY EQUIPMENTS IN CCU**

- CO₂ capture pilots (solvents, polymers, adsorbents, membranes) / Kinetics catalytic reactors / Fermentation reactors / Carbonatation reactors
- CICADI Membrane contactor for post combustion CO₂ capture by chemical gas liquid absorption (ANR)
- CESAR (CO₂ Enhanced Separation and Recovery, FP7 project)
- AMELIE Membrane contactor for chilled ammonia process (ANR)
- Post combustion capture: solvents and processes (EDF PhD grant)
- ENERGYCAPT Membrane contactor for post combustion CO₂ capture by chemical gas liquid absorption (ANR)
- HIPERCAP Chemically reactive membranes for post combustion carbon capture (FP7)
- M4CO2 (Metal Organic Framework membranes for CO₂ capture (FP7)
- Photobioreactors for algae production (Kerosalig)
- Carbon capture from steel production plant (blast furnace) for methanol synthesis (VALORCO PIA project, ADEME)
- CO₂ use from flue gases for chemical production (ANR C2B, ANR Vitesse2)

**SELECTED REFERENCES**

Chabanon, E. et al., Chemical Engineering, 91, 7-22, 2015
Makhloufi, C. et al., Journal of Membrane Science, 455, 236-246, 2014

**KEY PROJECTS IN CCU**

- Simulation of CO₂ capture under precombustion conditions IGCC (ADEME EDF PhD grant)
- CO₂ capture by chemical gas liquid absorption (ANR)
- M4CO2 (Metal Organic Framework membranes for CO₂ capture (FP7)
- Photobioreactors for algae production (Kerosalig)
- Carbon capture from steel production plant (blast furnace) for methanol synthesis (VALORCO PIA project, ADEME)
- CO₂ use from flue gases for chemical production (ANR C2B, ANR Vitesse2)

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Achievements and Expertise of French public labs

General description of the activities

Design and optimization of efficient, safe and environmentally friendly processes:
Valorization and transformation of biomass for chemicals and energy, Capture and utilization of CO2, Microwave Processes, Process safety and reaction calorimetry.

FIELD
Chemical engineering, process intensification, process safety

KEY COMPETENCES IN CCU
Absorption, desorption, gas-liquid equilibrium, kinetics of transport, valorization, catalytic processes,

SELECTED REFERENCES
PATENTS:
AZZOUZ, R., BISCHOFF, L., LEVACHER, V., ESTEL, L., LEDOUX, A., DERROUICHE, S., CONTRERAS MORENO, V., MARSAIS, F.

Valorisation of CO2 with epoxides: Influence of gas/liquid mass transfer on reaction kinetics.

www.doi.org/10.1021/acspatr.6b00040

Designing and Demonstrating a Master Student Project To Explore Carbon Dioxide Capture Technology.
www.doi.org/10.1021/jchemed.6b00077

Mass Transfer Evolution in a Reactive Spray during Carbon Dioxide Capture.

Local measurement of mass transfer in a reactive spray for CO2 capture.
www.doi.org/10.1002/cjce.22123

Thermal risk assessment of vegetable oil epoxidation.


Pilot Plant Studies for CO2 Capture from Waste Incinerator Flue Gas Using MEA Based Solvent.

Oxygen Solubility Measurements in a MEA/H2O/CO2 Mixture.


KEY EQUIPMENTS IN CCU
Instrumented rector benches: carbonation, hydrogenation, micro-waves, gasification, high pressure..
Absorption - desorption units : packed bed, spray column, Lewis cell
Reaction calorimeters: Process Safety Workstation RC1, RC1e (high pressure), Adiabatic Accelerating Rate Calorimeter ARC, ARST reactor.
Thermal analyzers: TGA, DSC, Calvet micro-calorimeter, calorimetric bomb..
Gas and liquid chromatographs, physical properties measurement tools (viscosity, refractive index..)

KEY PROJECTS IN CCU
Interreg project on CO2 utilization using hydrogen media
ADEME project : CO2 valorization using alcohol
Regional project : methane and methanol synthesis via CO2 hydroge- nation
CCU using epoxides (industrial projet)
CCU using vegetable oils
Intensification of carbon capture using reactive spray

ARTICLES:
Investigation of the Physicochemical Properties for Vegetable Oils and Their Epoxidized and Carbonated Derivatives.
J. Chem. Eng. Data acs.jced.7b01075
hwww.doi.org/10.1021/acs.jced.7b01075

PATENTS:
AZZOUZ, R., BISCHOFF, L., LEVACHER, V., ESTEL, L., LEDOUX, A., DERROUICHE, S., CONTRERAS MORENO, V., MARSAIS, F.

Mass Transfer Evolution in a Reactive Spray during Carbon Dioxide Capture.

Local measurement of mass transfer in a reactive spray for CO2 capture.

Thermal risk assessment of vegetable oil epoxidation.


Pilot Plant Studies for CO2 Capture from Waste Incinerator Flue Gas Using MEA Based Solvent.

Oxygen Solubility Measurements in a MEA/H2O/CO2 Mixture.


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MARBEC
Marine Biodiversity, Conservation & Exploitation

General description of the activities

The research objectives of the MARBEC are:

- To describe marine biodiversity, understand its dynamics and the functioning of marine ecosystems
- To analyze the impact of anthropogenic pressure on these ecosystems and develop responses scenarii to global change
- To reconcile exploitation (especially fisheries and aquaculture), and conservation and respond to societal expectations (expertise, innovation, remediation).

FIELD
Marine Biodiversity, Bioremediation, Aquaculture

KEY COMPETENCES IN CCU
Applied phycology
CO₂ fixation by microalgae
Processes in biomass production/concentration in raceways
Microbiology
Biochemistry

KEY EQUIPMENTS IN CCU
Culture collection, automatized Photobioreactors, Raceways, DIC titrator, CHN analyzer, Imaging
PAM, Cytometry, Microscopy, spectrophotometer, spectrofluorimeter

KEY PROJECTS IN CCU
CO₂ bioremediation using Microalgae (VASCO2)
Use of wastewaters for Microalgae production (ANR PHYCOVER, IMTA Effect)

SELECTED REFERENCES
GALÉS A ET AL (2017)
Efficiency of CO₂ fixation in High Rates Algal Ponds under different pH using marine natural assemblages. 6th Congress of International Applied Phycology ISAP, 18-23 June 2017, Nantes.

FOUILLAND E (2012)

VASSEUR C ET AL (2012)

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**General description of the activities**

The research at PROMES-CNRS aims to develop innovative solar processes for CO₂ recycling into synthetic solar fuels from solar thermal energy. Novel materials are developed for CO₂ splitting into separate streams of CO and O₂ via two-step thermochemical redox cycles using concentrated solar energy as the source of high-temperature process heat.

The solar thermochemical approach to split CO₂ inherently operates at high temperatures and utilizes the entire solar spectrum, and as such provides an attractive path to solar fuels production with high energy conversion efficiencies in the absence of precious metal catalysts.

The study is focused on the synthesis and shaping of active materials including multivalent oxides and non-stoichiometric oxides, the characterization of their reactivity for CO₂ splitting (chemical yields and kinetics), and the design, testing and modeling of suitable solar reactor concepts.

**SELECTED REFERENCES**

**NAIR M. M., ABANADES S.**
Experimental screening of perovskite oxides as efficient redox materials for solar thermochemical CO₂ conversion
Sustainable Energy & Fuels, 2018, 2, 843-854

**DEMONTE A., ABANADES S.**
Solar thermochemical conversion of CO₂ into fuel via two-step redox cycling of non-stoichiometric Mn-containing perovskite oxides
Journal of Materials Chemistry A, 2015, 3, 3536-3546

**LE GAL A., ABANADES S.**
Flamant G., CO₂ and H₂O splitting for thermochemical production of solar fuels using non-stoichiometric ceria and ceria/zirconia solid solutions
Energy & Fuels, 2011, 25(10), 4836-4845

**ABANADES S., CHAMBON M.**
CO₂ dissociation and upgrading from 2-step solar thermochemical processes based on ZnO/Zn and SnO₂/SmO redox pairs
Energy & Fuels, 2012, 26(12), 6667-6674

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