Summary of the thesis

In 1991, Arduengo isolated and fully characterized the first $N$-Heterocyclic Carbene (NHC), thereby confirming the existence of these stable divalent carbon species postulated almost thirty years earlier by Wanzlick. Since then, the enthusiasm for these highly nucleophilic and strongly basic compounds has steadily increased in the scientific community. Their reactivity with respect to organic compounds is very rich and is relatively well-documented since the middle of the 1960’s. Their strong electron-donicity and their moderate $\pi$-acidity make them almost universal ligands. NHC complexes have indeed been prepared with practically all the metals from the periodic table. Their high nucleophilicity also allowed to successfully employ them as organocatalysts. The state of the art in these three fields as well as the properties of NHCs and their electronic and steric characterizations are discussed in the introduction of this manuscript.

The second chapter is devoted to the synthesis and characterization of imidazol(in)ium dithiocarboxylates (NHC•CS$_2$ adducts), carboxylates (NHC•CO$_2$ adducts) and thiocarboxylates (NHC•COS adducts) and to their applications in organic synthesis and in coordination chemistry.

First, because NHC•CO$_2$ adducts do not require any reagents to generate free carbenes in solution, we proposed them as precursors of NHC to promote various Michael additions. Preliminary catalytic assays of a set of five representatives of this zwitterion family in a carbamichael addition previously reported in the literature highlighted the net superiority of 1,3-dicyclohexylimidazolium carboxylate (ICy•CO$_2$). Subsequently, we showed the efficiency of our catalytic system to promote sulfa-, and phospha-Michael additions. Eventually, the same precatalyst showed efficiency to initiate various sulfa-Michael/aldol organocascades.

Second, we looked at the synthesis of a representative set of five imidazol(in)ium thiocarboxylates. Their characterization indicated a probable loss of the thiocarboxylate group. Hence, we tested their efficiency as carbene’s precursors in two benchmark reactions usually catalyzed by NHCs. 1,3-Dicyclohexylimidazolium thiocarboxylate (ICy•COS) turned out to be most effective to promote transesterification/acetylation, while 1,3-bis(2,4,6-trimethylphenyl)imidazolinium thiocarboxylate (SIMes•COS) afforded a quantitative yield in the benzoin condensation. Moreover, reaction of NHC•COS betaines with a half-equivalent of ruthenium dimer [RuCl$_2$(p-cymene)]$_2$ led to [RuCl$_2$(p-cymene)(NHC•COS)]
complexes in which the zwitterions were bonded to ruthenium by the sulfur atom only. This is a remarkable result because NHC•CO_2 zwitterions behaved like efficient NHC precursors leading to metal-NHC complexes, while imidazol(in)ium dithiocarboxylates showed no signs of dissociation. They behaved as κ^2-S,S’ chelating ligands and led to metal-(S_2C•NHC) complexes. Finally, catalytic tests of these new complexes bearing NHC•COS adducts in the Ring-Opening Metathesis Polymerization (ROMP) of cyclooctene, in the Atom Transfer Radical Polymerization (ATRP) of methyl methacrylate and in the synthesis of enol esters resulted in low yields. However, they provided evidence for the rearrangement of the starting complexes in Ru-NHC species under the experimental conditions adopted.

The third chapter is devoted to the synthesis of azolium enolates and their characterization, as well as their involvement in the Staudinger reaction and to their coordination chemistry to ruthenium.

Our interest initially focused on the general mechanism of the NHC-catalyzed Staudinger reaction. Literature reports two plausible mechanisms for the [2 + 2] cycloaddition between ketenes and electron-poor imines. The first one, called "Imine-first" involves an azolium amide, while the second one, called "Ketene-first" goes through an azolium enolate. Synthesis and full characterization of these two types of zwitterionic adducts combined with their catalytic assay in the reaction between diphenylketene and N-tosylbenzaldimine allowed us to acquire a strong experimental evidence in favor of the "Ketene-first" observed path.

We were then interested by probing the diastereoselectivity observed during NHC-catalyzed [2 + 2] cycloadditions between unsymmetrical ketenes and various N-sulfonylbenzaldimines. In order to investigate the parameters that influenced the stereoselectivity during these reactions, we prepared and fully characterized two new betaines (S)IMes•EtPhC=C=O and we performed catalytic assays in the reaction between ethylphenylketene and different N-sulfonylbenzaldimines, during which we varied various experimental parameters. We showed that steric hindrance of the catalyst is critical, poorly hindered NHCs favoring cis diastereoisomers, while trans-β-lactams were essentially produced when more congested catalysts were used. The reaction solvent is also a critical parameter, N,N-dimethylformamide allowing to obtain the best diastereoisomeric ratio, 16:84, in favor of the trans isomer. Finally, the reaction temperature and the nature of the substituent on the N-sulfonylated imine are less important.
The last part of this chapter concerned the coordination of NHC•ketene adducts to ruthenium. Our starting hypothesis was that these betaines could provide simultaneously an NHC ligand and an alkylidene precursor (a ketene) to the metal. By this way and from adequate metallic precursors, we envisioned to synthesize second-generation Grubbs type complexes, benchmark catalysts for olefin metathesis, in one step and without the need to handle diazo compounds. Although the first exploratory experiments did not lead to the expected results, they provided crucial information to help achieve these syntheses in future investigations.