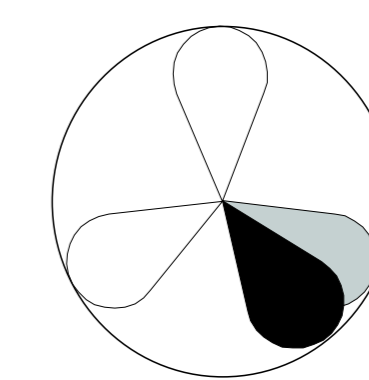


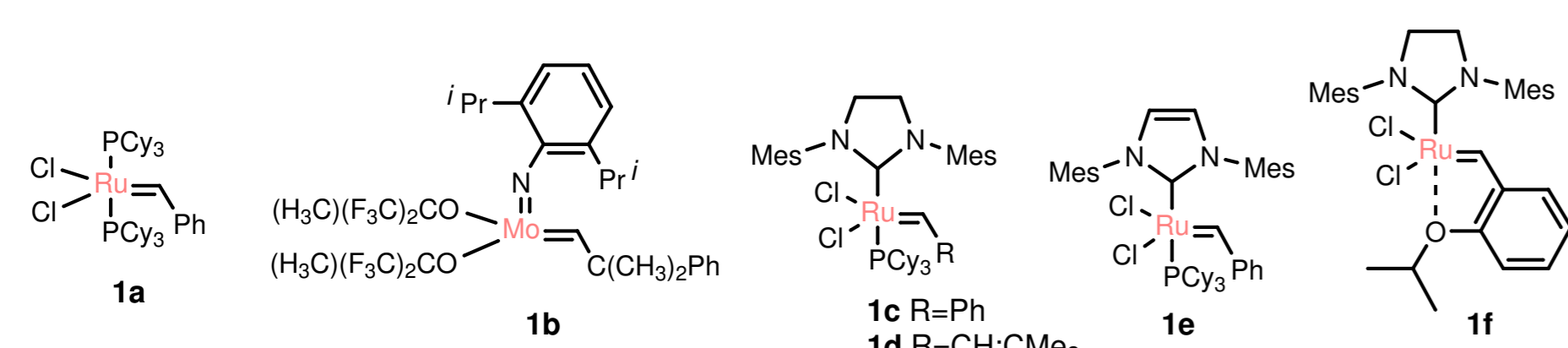
# New applications of Ru-based metathesis catalysts bearing *N*-heterocyclic carbene ligands



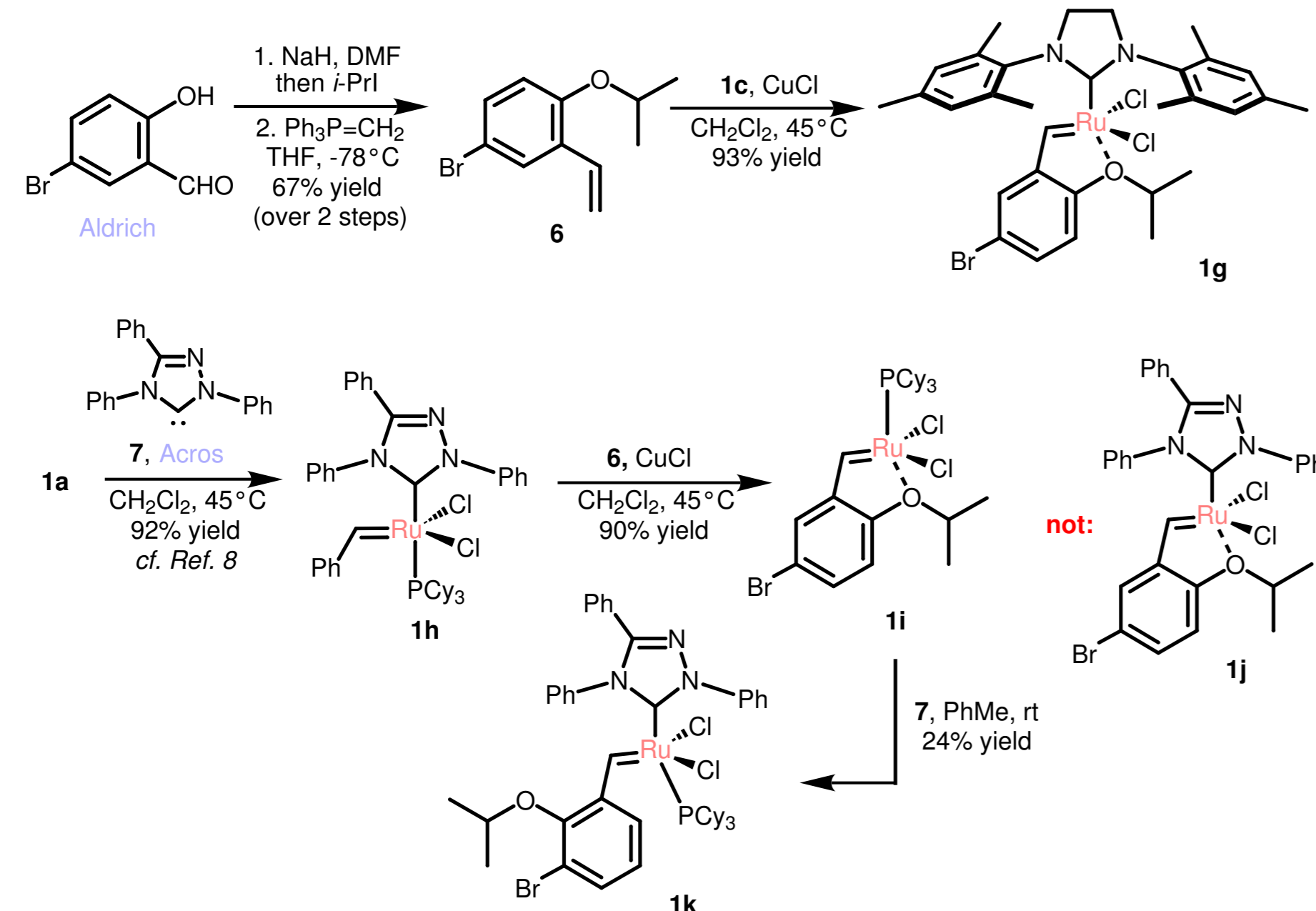
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## 1 “Second generation” catalysts for olefin metathesis

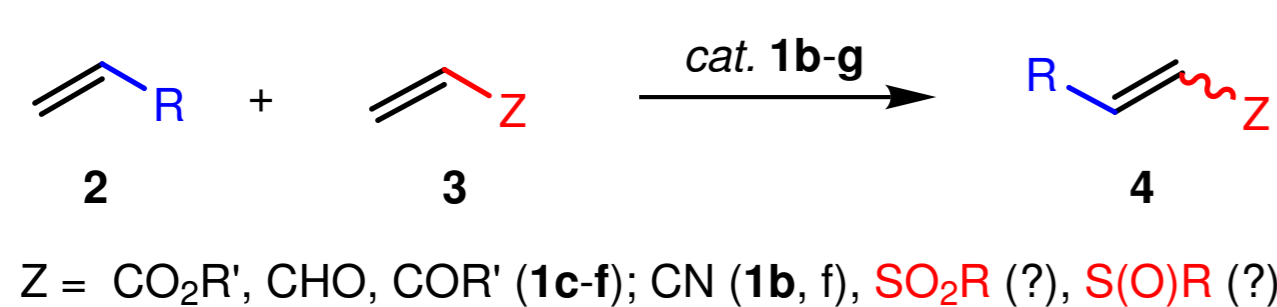


The development of well-accessible metathesis catalysts combining high activity with an excellent tolerance to a variety of functional groups has been key to the widespread application of olefin metathesis in organic synthesis and polymer chemistry. The most notable examples of such catalysts are the “Grubbs-type” ruthenium carbenes **1a–e** bearing bulky electron-rich phosphine and heterocyclic carbene ligands [1] and the phosphine-free complex **1f** described recently by Hoveyda. [2]

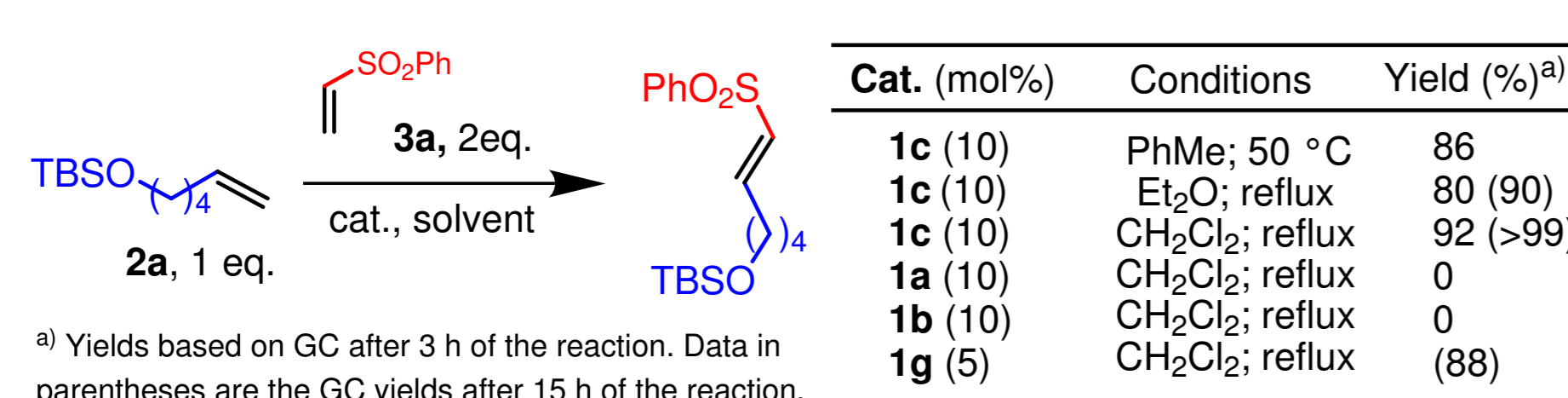


Following the same route we have prepared complex **1g**, as a stable, inert towards oxygen and moisture bright-green microcrystalline solid. We envisaged that the C-Br bond could be used for attachment of the isopropoxystyrene part of **1g** to solid support (cf. Section 3). Unfortunately our attempts to prepare other Hoveyda-type complexes (e.g. **1j**) met no success.

## 2 Cross-metathesis reaction of vinyl sulfones and sulfoxides



Substituted  $\alpha,\beta$ -unsaturated sulfones are generally well accepted as useful intermediates in organic synthesis, e.g. as Michael acceptors and as  $2\pi$  partners in cycloaddition reactions. [3] Therefore, we decided to investigate the cross metathesis of readily available vinyl sulfones and sulfoxides with terminal olefins. [4]

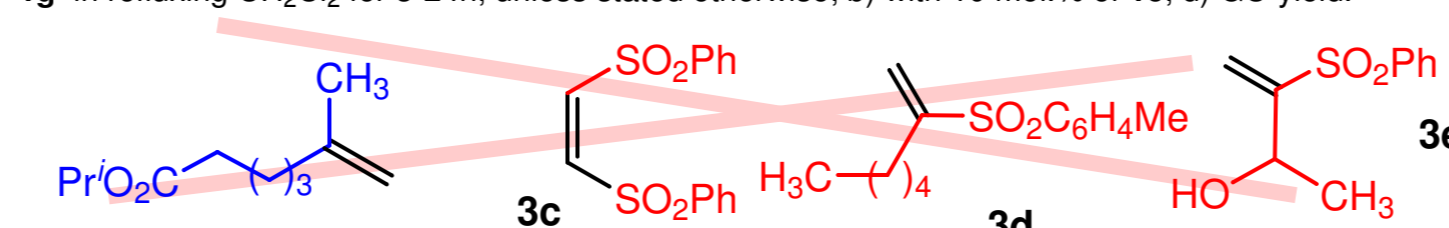


Test reactions between olefin **2a** and phenyl vinyl sulfone **3** were performed under argon, at 45 °C. The Grubbs' and Schrock alkylidenes **1a, b** did not react under these conditions, however, in the case of NHC-ruthenium complexes **1c, g** corresponding product was formed in high yields and with excellent stereoselectivity as the (*E*)-isomer was the only product detected by GC and NMR.

Under such conditions the reaction of terminal alkenes **2** with phenyl vinyl sulfone **3a** and divinyl sulfone **3b** proceeds smoothly to give the corresponding products **4** in moderate to good yields. In all reported cases the (*E*)-alkene was the only isomer detected by GC/MS and NMR.

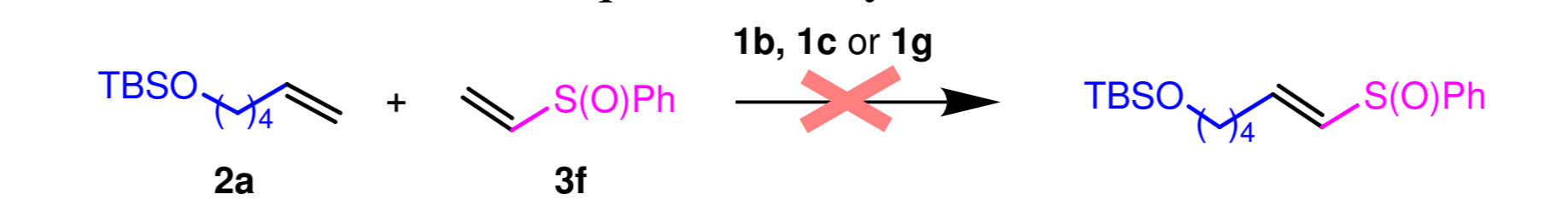
2	3	Product 4	Cat. 1	Yield (%) <sup>a)</sup>
			1c	81 <sup>b)</sup>
			1c	74
			1g	71
			1c	33 <sup>b)</sup>
			1g	41
			1c	59

<sup>a)</sup> Isolated yields of analytically pure compounds. All reactions were carried out with 5 mol.% of **1c** or **1g** in refluxing CH<sub>2</sub>Cl<sub>2</sub> for 3–24h, unless stated otherwise; <sup>b)</sup> with 10 mol.% of **1c**; <sup>d)</sup> GC-yield.



It is notable that the tri- and tetrasubstituted sulfones cannot be prepared using this methodology, as we observed no metathesis reaction when disubstituted alkene or sulfone was used.

Our attention then turned to the cross-metathesis reaction of vinyl sulfoxides. To our surprise, the commercially available phenyl vinyl sulfoxide (**3f**) failed to react, as the starting materials were recovered after the reaction almost quantitatively.

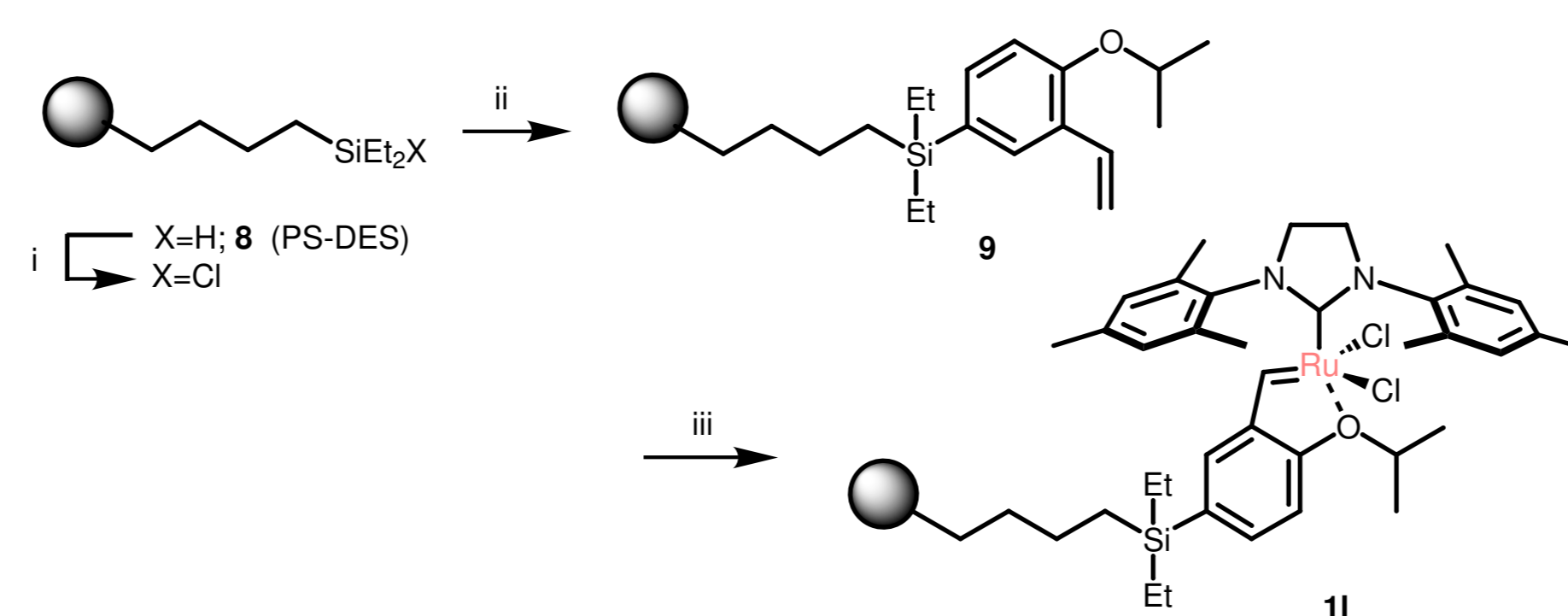


Georg has demonstrated the ability of dimethylsulfoxide (DMSO) to sequester traces of ruthenium. [5] In a control experiment DMSO (50 eq. relative to **1c**) almost completely inhibited cross-metathesis between olefin **2a** and sulphone **3a**.

## 3 A PS-DES immobilized ruthenium carbene

Despite the major advantages offered by the ruthenium catalysts bearing NHC-ligands, they share some disadvantages. Since metathesis reactions are expected to be used in pharmaceutical processes, the most undesirable feature of these complexes is that they decompose to form highly coloured ruthenium by-products, which are difficult to remove from the reaction products. From the point of view of chemical-economy recyclability is another important attribute. Several attempts have been made to immobilise ruthenium carbenes **1a–c** on solid supports. However, in the most cases endeavours to prepare catalysts immobilised on solid supports met with only limited success and the resulting polymer-supported carbenes were found to be less reactive than their homogeneous analogues. Moreover, their recovery and reuse led to significant losses in activity.

The need for further developments in this area led us to try yet another approach to efficiently immobilise a metathesis catalyst. [6] From numerous polymeric linkers known, we selected the butyldiethylsilyl polystyrene (PS-DES, **8**) [7] due to its advantages, such as availability, stability, high loading capacity and good swelling characteristics in solvents commonly used for metathesis.



Reagents and conditions: i, 1,3-dichloro-5,5-dimethylhydantoin, CH<sub>2</sub>Cl<sub>2</sub>, rt, 5h; ii, **6**, *t*-BuLi, Et<sub>2</sub>O, –78 °C then 9, THF, –78 °C to rt, 24h; iii, **1c**, CH<sub>2</sub>Cl<sub>2</sub>, rt, 24h, 4 times.

The catalyst was obtained as deep-green beads showing ruthenium loading of 0.22–0.35 mmol/g (as determined from the mass increase

and ICP-MS analysis of Ru). Samples of resin **11** have not lost activity after three months of storage in air at room temperature. PS-DES supported complex **11** (2.5–5.0 mol%) was then tested for activity using representative substrates for ring-closing metathesis.

Substrate	Product	Conversion, time <sup>a)</sup>	
		Supported Catalyst <b>11</b>	Reference Catalyst
		41%, 3h quant., 8h <sup>b)</sup>	<b>1g</b> : 90%, 3h quant., 8h <sup>b)</sup>
		78%, 16h <sup>b)</sup>	<b>1g</b> : 86%, 16h <sup>b)</sup>
		quant., 8h <sup>b,c)</sup>	<b>1g</b> : quant., 8h <sup>b,c)</sup> <b>1c</b> : quant., 8h <sup>c)</sup>
		R=Me 0%, 16h R=H 95%, 7h <sup>d)</sup>	<b>1g</b> : 45%, 16h <b>1a</b> : 95%, 5h <sup>d)</sup>
		2 quant., 5h	<b>1g</b> : quant., 5h
		3 quant., 5h	<b>1g</b> : quant., 5h <b>1a</b> : 79%, 8h <sup>d)</sup>
		4 79%, 4h	<b>1g</b> : quant., 4h <b>1a</b> : 80%, 18h <sup>f)</sup>
		5 30%, 6h 95%, 24h	<b>1g</b> : 98%, 6h

<sup>a)</sup> GC yield. General conditions: catalyst (5.0 mol%),  $c_{\text{olefin}}=0.02\text{M}$ , CH<sub>2</sub>Cl<sub>2</sub>, 45 °C.  
<sup>b)</sup> with 2.5 mol% of catalyst. <sup>c)</sup> Reaction was performed in the presence of 2 eq. of *n*-butyl acrylate. <sup>d)</sup> Ref. 8. <sup>e)</sup> Performed at rt. <sup>f)</sup> Isolated yield.

Ring-closing metathesis of several challenging substrates goes cleanly, with usually high conversion, as determined by GC-MS and <sup>1</sup>H NMR analysis. Importantly, the same batch of the catalyst can be used sequentially in different reactions and can be recycled more than five times without significant loss in activity.

## References

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