

Manipulating Micellar Environments for Enhancing Transition Metal-Catalyzed Cross-Couplings in Water at Room Temperature

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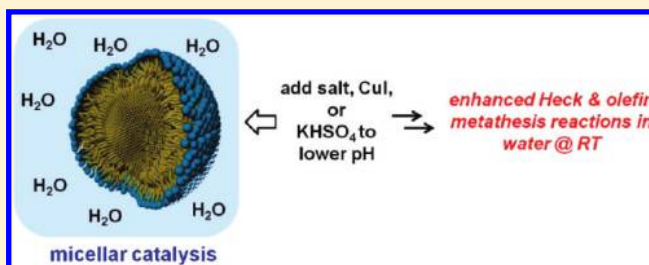
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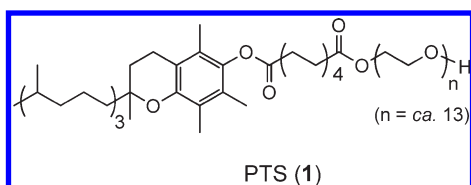
S Supporting Information

ABSTRACT: The remarkable effects of added salts on the properties of aqueous micelles derived from the amphiphile PTS are described. Most notably, Heck reactions run in the presence of NaCl lead to couplings on aryl bromides in water at room temperature. Olefin cross- and ring-closing metathesis reactions run in the presence of small amounts of pH-lowering KHSO_4 are also accelerated, another phenomenon that does not apply to typical processes in organic media. These salt effects allow, in general, for synthetically valuable C–C bond-forming processes to be conducted under environmentally benign conditions. Recycling of the surfactant is also demonstrated.



INTRODUCTION

Micellar catalysis is a well-known phenomenon in organic synthesis.¹ Typically, an amphiphilic species of the anionic, cationic, or nonionic variety spontaneously aggregates in water at low concentrations forming “normal” (as opposed to “inverted”) micellar arrays. Such particles can be organized into spheres, rods or worms, vesicles, or combinations thereof, with their polar portions outwardly interacting with the surrounding water, while their nonpolar subsection(s) make up the interior. These lipophilic cores function as hosts for organic compounds; in essence, as solvent. Given the huge influence of solvent effects in organic chemistry, variations in the nature of amphiphiles could well determine the level of success realized in various synthetic transformations. We have identified a first generation “designer” surfactant in PTS (Polyoxyethanyl α -Tocopheryl Sebacate; **1**)² as a generally useful nanoparticle-forming reagent that enables several Pd- and Ru-catalyzed “name” reactions,³ as well as asymmetric CuH-catalyzed 1,4-reductions,⁴ to be carried out in purely aqueous media at room temperature. In this contribution we describe further advances in PTS nanotechnology; advances applied to especially useful cross-coupling chemistry resulting from either control of nanoparticle size via adjustments in ionic strength,⁵ or through the expediency of changes in pH, of the surrounding water.



RESULTS AND DISCUSSION

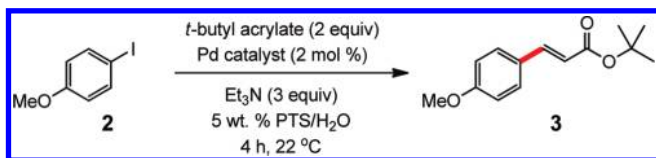
Salt Effects on Reactions in Aqueous PTS. *Heck Reactions.*⁶ The impetus for studying reactions in solutions of PTS/ H_2O of varying ionicity followed from early trials using seawater as the reaction medium, in place of standard HPLC-grade water. Unexpectedly, significant rate accelerations were observed in Heck couplings between an acrylate and either an aryl iodide or bromide.⁷ As shown in Table 1, iodide **2** and *t*-butyl acrylate, using $(\text{P}^t\text{Bu}_3)_2\text{Pd}$ as catalyst, reacted in 5 wt % PTS/ H_2O (0.5 M global concentration of aryl halide) at room temperature in the presence of Et_3N to afford **3** in 96% yield after four hours (entry 2).⁸ Of the many catalysts that were screened (Figure 1), only $(\text{P}^t\text{Bu}_3)_2\text{Pd}$ was effective. Catalysts originating at the Pd(II) oxidation state (entries 1, 4–6) gave low levels of conversion, or no reaction at all (entries 7–10) even in the presence of excess zinc metal (entry 8). Surprisingly, switching from the Pd(0) species **5** to the analogous Pd(0) catalyst **11**, where only one of three *t*-butyl groups on each phosphorus is replaced by a *p*-dimethylaminophenyl residue, completely inhibits the coupling. Reducing the amount of PTS from 5 to 2 wt % with the same catalyst led to moderate product formation in the same time frame (entry 3). In seawater, the yield reached 98% within one hour (entry 11).

The effect of adding NaCl (3 M) to HPLC grade water, rather than using seawater, was even more pronounced with iodide **12**, where the cinnamate was obtained in 96% yield after three hours at room temperature (Scheme 1). In the absence of salt, this

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Table 1. Catalyst Screening for Heck Reactions



entry	catalyst	conversion (%) ^a
1	4	<5
2	5	96 ^b
3 ^c	5	68 ^b
4	6	50
5	7	25
6	8	<5
7	9	NR
8 ^d	9	NR
9	10	NR
10	11	NR
11 ^e	5	98 ^b

^a Based on GC. ^b Yield of chromatographically pure materials. ^c Using 2 wt % PTS/H₂O. ^d Zn dust (20 mol %) used. ^e Reaction run in seawater for 1 h.

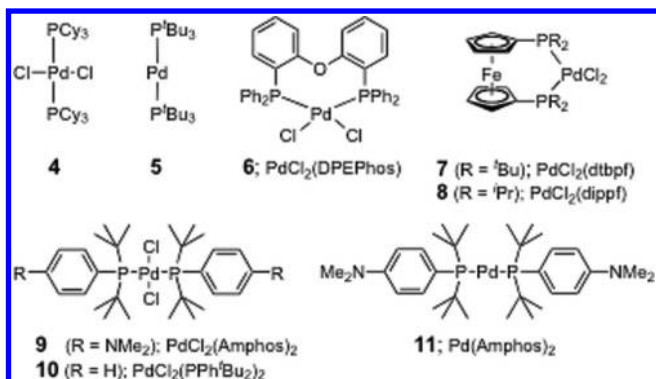


Figure 1. Palladium catalysts screened for Heck reactions.

reaction takes eight hours at 50 °C to realize the same yield at the same concentration. A similar effect was also observed for naphthyl iodide **13**, where the reaction is done within three hours when NaCl is present in solution; otherwise, 24 h are required to reach completion.

Comparisons between PTS/water and PTS/seawater with other surfactants were made in reactions with both aryl iodides and bromides. The former educt type was studied using iodobenzoate **14** along with *t*-butyl acrylate. As illustrated in Table 2, BASF's solutol⁹ as the nanoparticle-forming amphiphile in water, as with PTS in pure water or seawater, led to high-yielding reactions (entries 1–3). Other surfactants including cremophor¹⁰ (entry 4) and TPGS¹¹ (entry 5), however, were not as effective. The corresponding reaction “on water”¹² (entry 6) gave the lowest level of conversion, which is consistent with observations made in related micellar chemistry.¹³

More challenging aryl bromides **16** and **18** were expectedly sluggish at ambient temperature (Table 3), with neither PTS (entries 1 and 8) nor solutol (entries 2 and 9) affording synthetically useful amounts of cinnamates after fourteen hours.

Scheme 1. Effect of NaCl on Heck Reactions in PTS/water

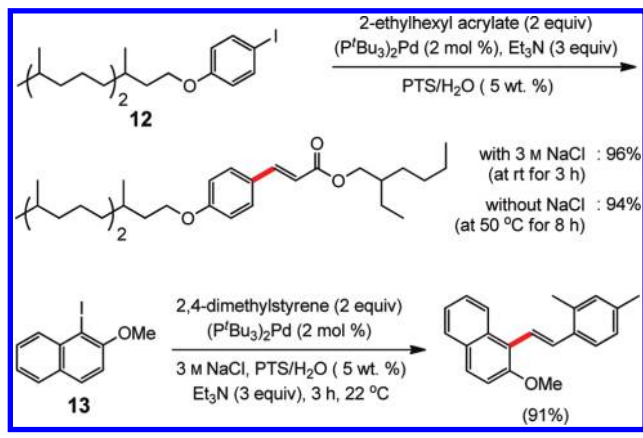
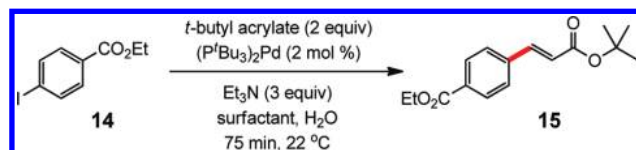


Table 2. Comparison of Amphiphiles for Heck Couplings in Water



entry	surfactant ^a	yield (%) ^b
1	PTS	99
2	PTS in seawater	98
3	Solutol	97
4	Cremophor	57
5	TPGS	60
6	“on water”	48

^a Five wt % used in all cases. ^b Chromatographically pure materials.

However, heating the reaction in PTS/H₂O to 40 °C drove the coupling to completion (entry 3). On the other hand, when the aqueous phase contained PTS and NaCl (3 M), essentially complete conversion was observed for both substrates, and high yields of the desired products **17** and **19** were obtained at ambient temperature (entries 4 and 10). Dropping the salt concentration from 3 M in NaCl to either 1 or 2 M led to far slower reactions (48% and 68% yields, respectively, after the same 14 h). The salt effect on the corresponding reaction in solutol was also minimal (entry 5), as expected (*vide infra*). When run “on water,”¹² again, limited conversion was noted (entry 6). An identical Heck reaction on **16** run in toluene afforded enoate **17** in only 40% yield, along with a significant amount of the product of reduction of the aryl bromide, in addition to small amounts of unreacted starting halide remaining (entry 7).¹⁴

Several examples of related cinnamates prepared using NaCl-containing PTS/HPLC water are illustrated in Table 4. The nature of the ester in the acrylate partners appears to be of no consequence. Both electron-rich and -poor aryl bromides react equally well under these micellar conditions in 4–14 h (0.5 M global concentration) at ambient temperatures. Lower levels of PTS (e.g., 2 wt %) led to reactions that were equally rapid but not as clean, judging from TLC analyses.

Table 3. Comparison of Amphiphiles for Heck Couplings in Water

16

conditions^a →

17

entry	surfactant ^b	yield (%) ^c
1	PTS	43
2	solutol	32
3	PTS at 40 °C	94
4	3 M NaCl, PTS/water	95
5	3 M NaCl, solutol/water	46
6	"on water"	30
7	toluene	40

18

conditions^a →

19

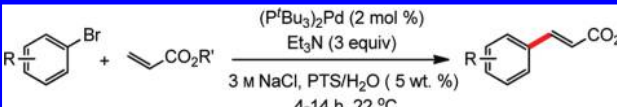
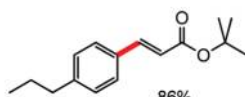
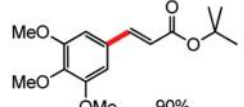
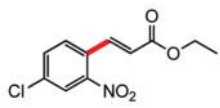
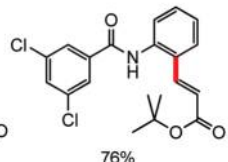
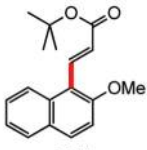
entry	surfactant ^b	yield (%) ^c
8	PTS	18
9	solutol	21
10	3 M NaCl, PTS/water	98

^a Conditions: *tert*-butyl acrylate (2 equiv), cat. **5** (2 mol %), Et₃N (3 equiv) surfactant/H₂O, 22 °C, 14 h. ^b Five wt % used in all cases. ^c Chromatographically pure materials.

Olefin Metathesis.¹⁵ Early in our studies on room temperature olefin ring-closing and cross-metathesis reactions (RCM and CM, respectively) in aqueous nanoparticles of PTS, we described conditions that avoided both chlorinated solvents and heat.¹⁶ Type 1 olefins¹⁷ studied focused mainly on terminal alkenes, although *E*- or *Z*-disubstituted systems readily participated. Not included previously in our work were couplings involving trisubstituted olefins of the isopropylidene variety.¹⁷ The impetus to examine Type 1 olefins of this sort derived not only from an interest in extending the limits of metathesis in micelles, but in anticipation that this naturally occurring array might be amenable to analog formation. Table 5 lists several examples of such educts and their derived products from cross-metathesis in water at room temperature using the Grubbs-2 catalyst. Reaction efficiencies are high in all cases, although a tetrazole (entry 5) and ethyl chrysanthemate (entry 7) did not give full conversion under the standard conditions employed (0.5 M, 12 h). While racemic citronellol TBS ether was smoothly converted to the corresponding enoate over twelve hours (84%; entry 8), the identical reaction run in 3 M aqueous NaCl/PTS afforded essentially the same yield (86%) but in half the time. The corresponding acetate derivative also led to good yields in CM reactions with *t*-butyl and 2-ethylhexyl acrylates (entry 9).

The effect of added NaCl was not significant, in general, for cross metathesis reactions involving Type 1 alkenes other than those containing an isopropylidene unit. Even in the case of especially challenging couplings using Type 2 olefins such as methyl vinyl ketone (MVK),¹⁸ reactions in PTS/water with

Table 4. Heck Couplings of Aryl Bromides with Acrylates

	
products (isolated yields; %)	
	86%
	90%
	84%
	76%
	82%

added NaCl were only slightly faster (Table 6, entry 1 vs 2). Trials that replaced water totally (HOAc, entry 7), or in large measure (MeOH, entry 3; EtOH, entry 4; 95% EtOH; entries 6 and 10) gave inferior levels of conversion. On the other hand, rather than adding NaCl, addition of small amounts of KHSO₄ (0.02 M) had a much greater impact; e.g., in the case of MVK, the resulting acidic conditions (pH 2)¹⁹ drove this reaction to almost full conversion, with either the Grubbs-2 (entry 11) or Neolyst M2 catalyst (entry 12). Replacing water with 95% EtOH led to only trace amounts of product enone (entry 13). Figure 2 illustrates graphically the effect of added KHSO₄ relative to both aqueous PTS and CH₂Cl₂ alone.

Under these slightly acidic conditions, acetal **22** remained intact (Scheme 2). Not only MVK but also ethyl vinyl ketone and phenethyl vinyl ketone coupled with olefin **20** to give products **23** and **24** in 88% and 81% yields, respectively, under these standard conditions (Scheme 3). Curiously, no product was observed from the control reaction performed "on water" in the presence of KHSO₄ (0.02 M) with phenethyl vinyl ketone.

Although **20** reacted with MVK in a highly efficient manner (Table 6, entry 11, and Table 7, entry 1), coupling with acrylonitrile could only be achieved to the extent of 30%. Nonetheless, under these room temperature conditions, reaction in the typically used solvent²⁰ CH₂Cl₂ gave product in only 4% yield after the same four hours (Table 7, entry 2). Acrolein is another difficult case in CH₂Cl₂ at ambient temperature (9%),^{18a,21} and while aqueous PTS led to an improved 43% yield after 8 h, the presence of KHSO₄ raised the yield to 70% under otherwise identical conditions (entry 3). Likewise, the corresponding CM with a vinylphosphonate²² gave the best yield (65%) under these pH-adjusted conditions.

Ring-closing metathesis reactions, either in 3 M aqueous NaCl/PTS solutions, or in the presence of KHSO₄, were only marginally improved relative to that achieved in PTS/H₂O alone (Table 8). The best result (92% yield; entry 3) was obtained through the expediency of added KHSO₄. The corresponding

Table 5. Olefin CM Reactions in 2.5% aqueous PTS^a

entry	substrate	olefinic partner	product	yield (%) ^b
1				92
2				97
3				84
4				88
5				90 ^c (55) ^d
6				88
7 ^e				83 ^c (50) ^d
8				84, 86 ^f (tBu) 82 (Et)
9				80 (tBu) 78 (2-ethylhexyl)

^a Reaction were conducted at 0.5 M over 12 h at 22 °C using 3 mol % Grubbs-2. ^b Chromatographically pure materials. ^c Based on recovered starting material. ^d Isolated. ^e Mixture of *cis* and *trans* isomers. ^f Reaction run in 3 M aqueous NaCl/PTS for 6 h.

experiment in the absence of PTS (i.e., “on water”; entry 4), as in all previous comparisons herein, was not competitive.

Catalysts other than those in the Grubbs-1, -2, and Grubbs-Hoveyda-1 series, including those shown in Figure 3, have all been tested for their compatibility with micellar conditions, and ultimately, their effectiveness in olefin metathesis reactions. Among the Umicore series of Neolyst catalysts,²³ an RCM example (Table 9) suggested that the internally chelated species Neolyst M51 mediates a very efficient cyclization, while catalyst Neolyst M2 is apparently preferred for cross-metathesis (Table 10). Likewise, among the two ruthenium carbene Zhan catalysts²⁴ RC-303 and RC-304 tested in a challenging cross-metathesis example with MVK, RC-303 was found to work well, even in the absence of KHSO₄, while being roughly comparable

Table 6. Salt Effect on Olefin CM Reactions in 2.5% aq. PTS

entry	conditions	conversion (%) ^a
1	PTS/water	64
2	3 M NaCl, PTS/water	75
3	PTS/water—methanol ^b	59
4	PTS/water—ethanol ^c	54
5	2.5% solutol/water	33
6	95% ethanol	22
7	AcOH	20
8	CH ₂ Cl ₂	30
9	CH ₂ Cl ₂ +PTSA (10 mol %)	<5
10	PTS/95% ethanol	28
11	0.02 M KHSO ₄ PTS/water	95
12	0.02 M KHSO ₄ PTS/water ^d	94
13	0.02 M KHSO ₄ PTS/95% ethanol	<5

^a Based on ¹H NMR. ^b Water:methanol = 19:1. ^c Water:ethanol = 19:1. ^d Neolyst M2 used instead of Grubbs-2.

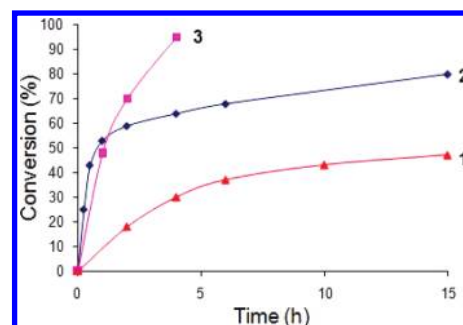
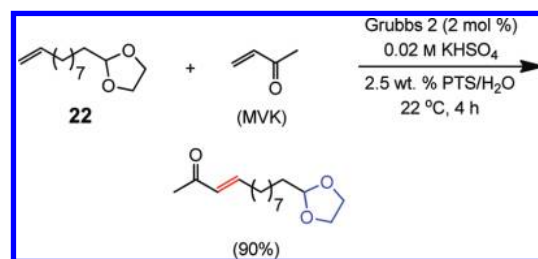


Figure 2. Conversion versus time profile for CM reaction of olefin 20 and MVK with Grubbs-2 catalyst in CH₂Cl₂ (1), PTS/water (2), and 0.02 M KHSO₄, PTS/water (3), as measured by ¹H NMR spectroscopy.

Scheme 2. Olefin CM Reaction in the Presence of an Acetal



to both the Grubbs-2 and Neolyst M2 analogs at lower pH (Table 11). Not surprisingly, with no phosphine ligand present in RC-303 and GH-2, the rate of their catalysis is unaffected by the presence of acid in the aqueous medium.^{19a}

Another option for improving olefin cross metathesis under micellar conditions is inclusion of a copper salt in the medium. Surprisingly, although CuCl is routinely used to assist with formation

Scheme 3. Olefin CM Reactions with Vinyl Ketones

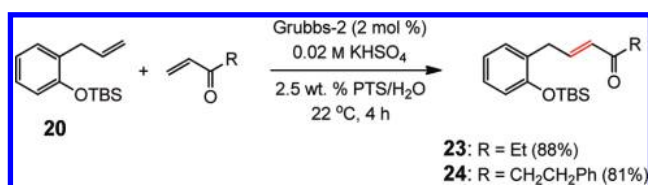
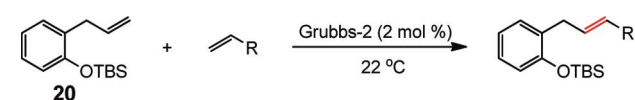


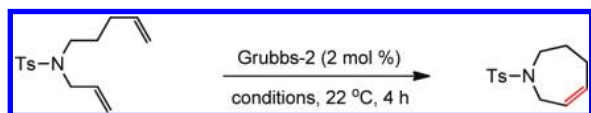
Table 7. More Difficult Olefin CM Reactions



entry	R	time (h)	yield (%) ^{a,b}		
			PTS	PTS/KHSO ₄ ^c	CH ₂ Cl ₂
1	COMe	4	74 ^d	91	30
2	CN	4	20	30	4
3	CHO	8	43	70	9
4	P(O)(OEt) ₂	4	51	65	39

^a Chromatographically pure materials. ^b Two and a half wt % PTS used.^c KHSO₄ (0.02 M) used. ^d Reaction run for 12 h.

Table 8. RCM Under Aqueous Conditions



entry	conditions	yield (%) ^a
1	PTS/water	85
2	3 M NaCl, PTS/water	90
3	0.02 M KHSO ₄ PTS/water	92
4	0.02 M KHSO ₄ /water	42

^a Chromatographically pure materials.

of Grubbs-Hoveyda-1 or Grubbs-Hoveyda-2 ruthenium carbene complexes,²⁵ use of copper to accelerate metathesis reactions is rare.²⁶ Among several Cu(I) and Cu(II) species investigated, CuI (3 mol %) has been found to enhance the extent of conversion to product alkenes at room temperature.²⁷ Thus, as illustrated in Table 12, three cases were studied: entry 1 is particularly noteworthy, as numerous attempts (by varying the nature and percentage of the surfactant, reaction temperature, and the amount of catalyst) to drive this coupling beyond the 55% reported previously had not been successful.^{16a} The examples in entries 2 and 3 reflect problems normally encountered due to Type 1 olefin homocoupling, especially involving styrenes.^{17,28} Standard conditions for each of these examples compare well with those typically employed (refluxing CH₂Cl₂ over ca. 12 h). Levels of carbene catalyst needed in organic media are also rarely less than 5 mol %, ²⁹ whereas with nanomicelles in water, 2 mol % is sufficient. Attempts to apply the benefits of both added KHSO₄ and CuI did not lead to a cumulative effect.

The potential for applications of this technology to synthesis is demonstrated by the cross-coupling reaction between olefin 25 and ethyl vinyl ketone (Scheme 4). This combination serves as a

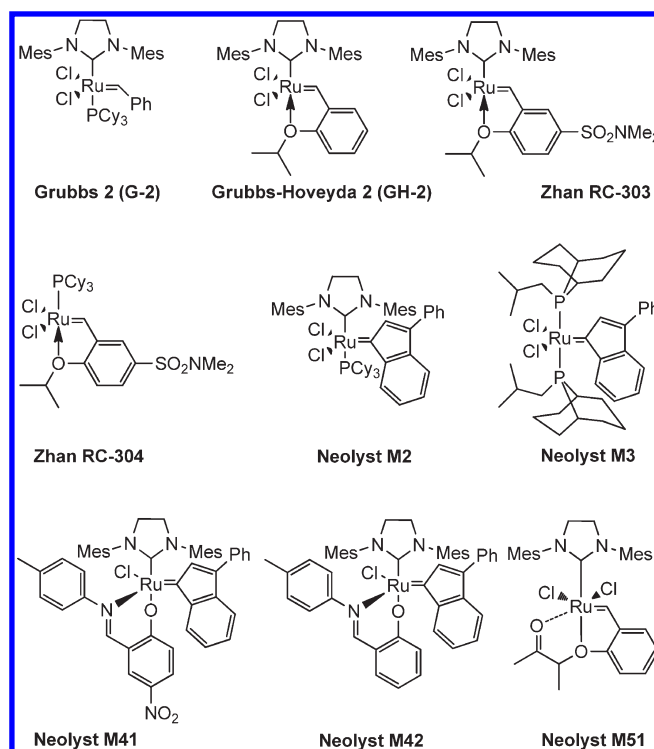
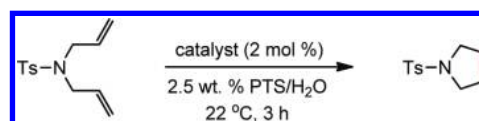


Figure 3. Structures of Ru-based catalysts used for olefin metathesis.

Table 9. Olefin RCM Reactions Using Neolyst Catalysts



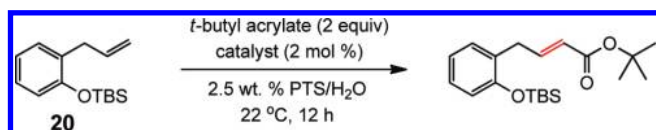
entry	catalyst	conversion (%) ^a
1	Neolyst M41	N.R.
2	Neolyst M42	N.R.
3	Neolyst M3	84
4	Neolyst M51	100 (99) ^b
5	Neolyst M2	82

^a Based on ¹H NMR. ^b Yield of chromatographically pure materials.

close model system to that used by Rychnovsky and co-workers in their synthesis of (+)-epicalyxin F, which relied on olefin metathesis (without complication due to the chalcone fragment) as a crucial means of attaching the required carbon framework for subsequent intramolecular conjugate addition.³⁰ Under conditions that employed an organic solvent (PhH), heat (60 °C), time (24 h), and catalyst (20 mol %), enone 27 was obtained in modest (47%) yield (60% brsm). The corresponding reaction between model enone 25 and ethyl vinyl ketone could be effected in water at room temperature in eight hours using 4 mol % of the Grubbs-2 Ru carbene to give 26 in 75% yield.

Salt Effects. The positive impact on reaction rates observed due to the salts present in seawater on Heck reactions suggested that the nature of the PTS micellar nanoreactors was being perturbed. A DLS experiment on PTS in seawater revealed that the average particle size had increased from ca. 25 to 75 nm in diameter. A study on particle size vs concentration of NaCl in HPLC-grade water revealed a steady increase in the average

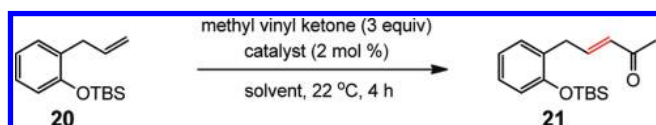
Table 10. Olefin CM Reactions Using Neolyst Catalysts



entry	catalyst	conversion (%) ^a
1	Neolyst M41	N.R.
2	Neolyst M42	N.R.
3	Neolyst M3	27 (40) ^b
4	Neolyst M51	80
5	Neolyst M2	99 (93) ^c

^a Based on ¹H NMR. ^b Homocoupling product. ^c Yield of chromatographically pure materials.

Table 11. Effect of pH on Olefin CM Reactions Using Metathesis Catalysts

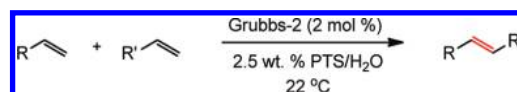


entry	catalyst	conversion (%) ^{a,b}	
		PTS	PTS/KHSO ₄ ^c
1	RC-304	0	0
2	RC-303	88	90
3	G-2	64	95
4	Neolyst M2	64	94
5	GH-2	61	62

^a Based on ¹H NMR. ^b Two and a half wt % PTS used. ^c KHSO₄ (0.02 M) used.

diameter with increasing ionic strength; at 3 M NaCl, nanoparticles averaging 110 nm are present (Figure 4). Other salts led to highly variable changes in particle size, although given the influence of factors such as viscosity on DLS measurements,³¹ no quantitative inferences as to relative particle size should be made. What does follow literature precedent is the qualitative sense of particle growth due to the “salting out” effect for NaCl, as well as several other salts (e.g., Na₂SO₄, NaBr, KCl, LiCl, etc.), a well-known phenomenon for nonionic surfactants.⁵ On the other hand, weakly hydrated salts such as iodides and thiocyanates lead to a “salting in” effect, where water is directed in and around the micellar array, thereby reducing particle size. Salts such as NaCl, however, effectively compete for, and thus withdraw, water (of hydration) from the PEGylated portions of PTS micelles thereby increasing particle size. These effects of halides are further manifested by additional Heck reactions on **16** run in the presence of 3 M NaBr and 3 M NaI (Scheme 5). Thus, while the corresponding couplings in 3 M NaCl led to product cinnamate **17** in 95% yield, those run in smaller micelles gave considerably slower reactions. Nonionic surfactants other than PTS responded to an increase in ionic strength due to the presence of NaCl in a similar albeit far less pronounced fashion. Particle size increases for solutol, TPGS, and Triton X-100, all initially in the 10–13 nm range in pure water, do not exceed, on average, 42 nm in diameter. Brij 30, which forms 110 nm micelles

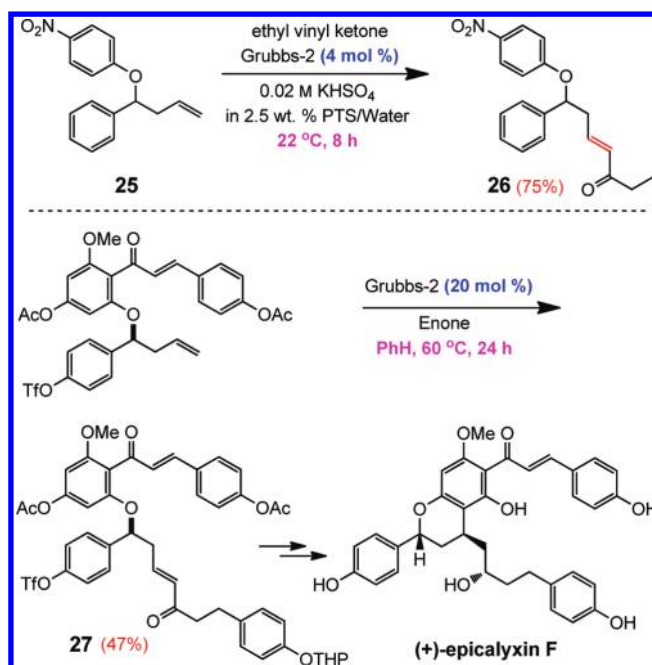
Table 12. Effect of CuI on Olefin CM Reactions



entry	product	time (h)	yield (%) ^a	
			without CuI	with CuI ^b
1		20	55	80
2		12	74	92
3		15	72	81

^a Chromatographically pure materials. ^b 3 mol % CuI.

Scheme 4. Comparison of Conditions with a Close Literature Example



in aqueous solution at room temperature, forms turbid mixtures of particles of roughly twice their size in the presence of 3 M NaCl. None of these alternative media, with or without added salts, led to consistently competitive results in cross couplings relative to those in PTS.

Data on PTS in water acquired from DLS measurements provide insight as to the average particle size in solution but no information as to particle shape(s) or individual micelle sizes. An alternative technique, cryo-TEM,³² serves well in this capacity, giving a good indication of the nature of the micelles present. For PTS alone, cryo-TEM showed that both spherical micelles of ca. 10 nm are plentiful, along with a mix of worm- and rod-shaped

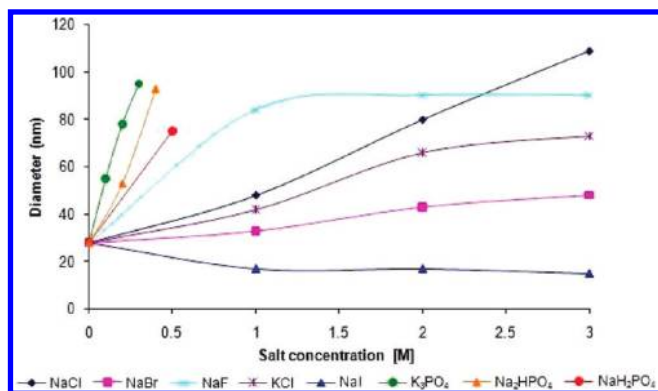


Figure 4. Effect of different salt concentrations on the diameter of PTS micelles.

Scheme 5. Impact of Halides on a Heck Coupling in PTS/Water at rt

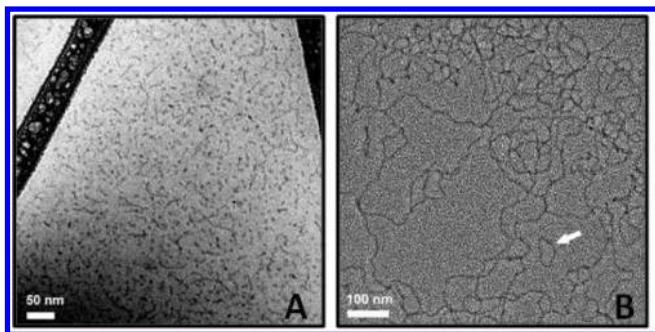
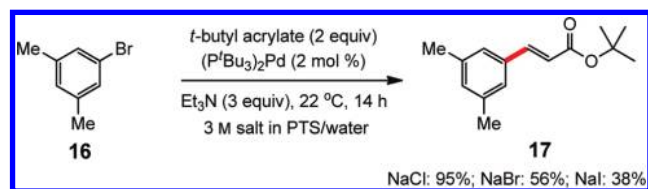
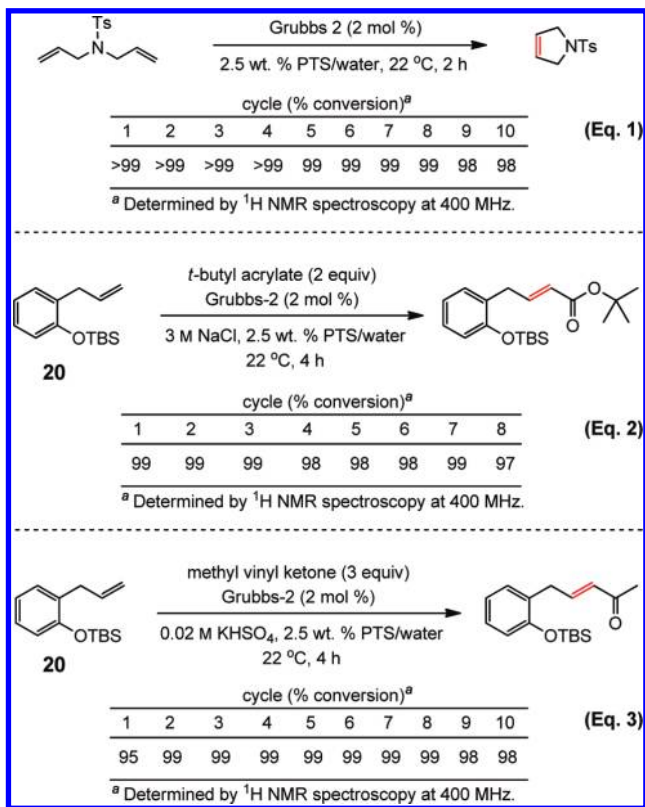


Figure 5. Cryo-TEM image of (A) aqueous PTS (50 nm scale) and (B) aqueous PTS in presence of 3 M NaCl (100 nm scale).

particles of considerably longer lengths (Figure 5A). Measurements on PTS in 3 M NaCl, in stark contrast, clearly revealed a fully interconnected, extended network (Figure 5B). In addition, smaller, irregularly shaped closed loops can also be discerned (white arrow). Thus, the enhanced cross-coupling chemistry (vide supra) resulting from an increase in ionic strength of the aqueous medium may be attributable to a dramatic change in the nature of the nanoreactors in which these Pd- and Ru-catalyzed couplings take place. While an explanation as to why such an array might correlate with better catalysis, as opposed to that seen with mainly spherical micelles formed by most other commonly used surfactants, remains to be clarified, there are lessons that can be learned from studies on both ionic and Gemini micelles.³³ Rate enhancements are greater in the latter (e.g., for selected hydrolysis reactions), an observation that has been attributed to greater binding constants (K_b) for both substrates and catalysts.³⁴

Scheme 6. Recycling of PTS



Recycling. Although PTS is used catalytically, the option to recycle this surfactant was examined using three olefin metathesis reactions: RCM; eq 1; CM; eqs 2 and 3 (Scheme 6). Reaction handling involved the addition of EtOAc once the reaction reached completion, stirring, and in-flask removal of solvent leaving the aqueous layer behind. Reintroduction of fresh educt(s) and catalyst allowed for subsequent metathesis under otherwise identical conditions. In the case of an azadiene, RCM took place smoothly as previously noted (eq 1). Using an acrylate as partner with olefin **20**, the extent of conversion in 3 M aqueous NaCl remained high and essentially unchanged after eight recycles (eq 2). Likewise, with MVK, in this case using the pH-lowering effect of KHSO₄, 10 recycles did not alter the observed level of conversion to the anticipated enone (eq 3).

CONCLUSIONS

As viewed within the context of transition metal-mediated C–C bond forming reactions, the observations provided herein foreshadow the potential that spontaneously formed nanomicelles in water hold as alternative media to organic solvents. The dynamic nature of these particles, along with their surrounding aqueous environment through which educts and catalysts must traverse, offer rare opportunities to leverage the influence of both aqueous and nonaqueous solutions on cross-coupling reactions. Additives such as simple salts can significantly realign surfactant monomers, thereby perturbing particle size. These subtle changes can be used to great synthetic advantage in synthesis, impacting reaction rates, in particular with respect to Heck couplings. Changes in pH have also been shown to increase rates of olefin metathesis reactions in water as the only medium,

especially when notoriously difficult Type 2 olefins are involved. Several cases demonstrating surfactant recyclability, where work-up procedures involve no increase in aqueous waste streams, also support the inexpensive and environmentally friendly nature of this chemistry.

EXPERIMENTAL SECTION

Typical Procedure for Heck Couplings. Catalyst $(P^tBu_3)_2Pd$ (5.1 mg, 0.01 mmol) and aryl iodide/bromide (0.50 mmol) were added under argon into a 5.0 mL microwave vial equipped with a large stir bar and Teflon lined septum. An aliquot of 3 M NaCl in PTS/(degassed) H_2O (1.0 mL; 5.0% PTS by weight) solution, triethylamine (208 μL , 1.50 mmol), and acrylate/styrene (1.0 mmol) were added by syringe, and the resulting solution was allowed to stir at rt until complete. The homogeneous reaction mixture was then diluted with EtOAc (2 mL), filtered through a bed of silica gel, and the bed further washed (3×5 mL) with EtOAc to collect all of the coupled material. The volatiles were removed *in vacuo* to afford the crude product which was subsequently purified by flash chromatography on silica gel.

(E)-*t*-Butyl 3-(4-methoxyphenyl)acrylate (3). Following the general procedure using 4-methoxyiodobenzene (117 mg, 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 4 h at rt. Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (112 mg, 96%). 1H NMR (400 MHz, $CDCl_3$): δ 7.55 (d, J = 16.0 Hz, 1H), 7.47 (d, J = 8.8 Hz, 2H), 6.90 (d, J = 8.8 Hz, 2H), 6.25 (d, J = 16.0 Hz, 1H), 3.84 (s, 3H), 1.54 (s, 9H).³⁵

(E)-2-Ethylhexyl 3-(4-(3,7,11-trimethyldodecyloxy)phenyl)acrylate. Following the general procedure using 1-iodo-4-(3,7,11-trimethyldodecyloxy)benzene (215 mg, 0.50 mmol) and 2-ethylhexyl acrylate (208 μL , 1.0 mmol), the reaction was stirred for 3 h at rt. Column chromatography on silica gel (eluting with 4% EtOAc/hexanes) afforded the product as a colorless oil (233 mg, 96%). 1H NMR (400 MHz, $CDCl_3$): δ 7.64 (d, J = 16.0 Hz, 1H), 7.48 (d, J = 8.8 Hz, 2H), 6.90 (d, J = 8.8 Hz, 2H), 6.32 (d, J = 16.0 Hz, 1H), 4.14–4.08 (m, 2H), 4.06–3.98 (m, 2H), 1.86–1.80 (m, 1H), 1.70–1.03 (m, 25H), 0.96–0.85 (m, 18H).⁸

(E)-1-(2,4-Dimethylstyryl)-2-methoxynaphthalene. Following the general procedure using 1-iodo-2-methoxynaphthalene (142 mg, 0.5 mmol) and 2,4-dimethylstyrene (147 μL , 1.0 mmol), the reaction was stirred for 3 h at rt. Column chromatography on silica gel (eluting with 5% EtOAc/hexanes) afforded the product as a semisolid (131 mg, 91%). 1H NMR (400 MHz, $CDCl_3$): δ 8.30 (d, J = 8.7 Hz, 1H), 7.81 (t, J = 7.8 Hz, 2H), 7.68 (d, J = 7.8 Hz, 1H), 7.47 (t, J = 7.2 Hz, 1H), 7.40–7.30 (m, 4H), 7.10 (d, J = 8.2 Hz, 1H), 7.05 (s, 1H), 3.98 (s, 3H), 2.40 (s, 3H), 2.37 (s, 3H).⁸

(E)-*t*-Butyl 3-(4-carboethoxyphenyl)acrylate (15). Following the general procedure using ethyl 4-iodobenzoate (84 μL , 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 75 min at rt. Column chromatography on silica gel (eluting with 4% EtOAc/hexanes) afforded the product as a colorless oil (137 mg, 99%). 1H NMR (400 MHz, $CDCl_3$): δ 8.05 (d, J = 8.4 Hz, 2H), 7.60 (d, J = 16.0 Hz, 1H), 7.57 (d, J = 8.4 Hz, 2H), 6.46 (d, J = 16.0 Hz, 1H), 4.39 (q, J = 7.2 Hz, 2H), 1.55 (s, 9H), 1.41 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.1, 165.9, 142.3, 138.9, 131.6, 130.1, 127.9, 122.6, 80.9, 61.3, 28.3, 14.4; ESI-MS m/z : 299 ($M + Na$); HRESIMS calcd for $C_{16}H_{20}O_4Na$ [$M + Na$]⁺ = 299.1259, found 299.1262.

(E)-*t*-Butyl 3-(3,5-dimethylphenyl)acrylate (17). Following the general procedure using 3,5-dimethyl bromobenzene (68 μL , 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 14 h at rt. Column chromatography on silica gel (eluting with 2% EtOAc/hexanes) afforded the product as a colorless oil (110 mg, 95%). IR (neat): 3006, 2978, 2922, 2870, 1707, 1637, 1603, 1455, 1391, 1366, 1330, 1288, 1255, 1151, 1039, 982, 844 cm^{-1} ; 1H NMR (400 MHz,

$CDCl_3$): δ 7.54 (d, J = 16.0 Hz, 1H), 7.14 (s, 2H), 7.01 (s, 1H), 6.35 (d, J = 16.0 Hz, 1H), 2.33 (s, 6H), 1.54 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.6, 144.0, 138.5, 134.7, 131.9, 126.0, 119.9, 80.5, 28.4, 21.4; EI-MS m/z (%): 232 (M^+ , 26), 176 (100), 161 (75); HRMS (EI) calcd for $C_{15}H_{20}O_2$ [M]⁺ = 232.1463, found 232.1464.

(E)-*t*-Butyl 3-(3-methoxyphenyl)acrylate (19). Following the general procedure using 3-methoxy bromobenzene (64 μL , 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 14 h at rt. Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (115 mg, 98%). 1H NMR (400 MHz, $CDCl_3$): δ 7.54 (d, J = 16.0 Hz, 1H), 7.27 (t, J = 8.0 Hz, 1H), 7.09 (d, J = 8.0 Hz, 1H), 7.01 (s, 1H), 6.90 (dd, J = 8.0, 2.4 Hz, 1H), 6.34 (d, J = 16.0 Hz, 1H), 3.81 (s, 3H), 1.52 (s, 9H).³⁶

(E)-*t*-Butyl 3-(4-propylphenyl)acrylate. Following the general procedure using 4-propyl bromobenzene (77 μL , 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 8 h at rt. Column chromatography on silica gel (eluting with 2% EtOAc/hexanes) afforded the product as a colorless oil (106 mg, 86%). IR (neat): 2968, 2872, 1713, 1633, 1609, 1568, 1512, 1456, 1418, 1391, 1367, 1323, 1256, 1210, 1149, 983 cm^{-1} ; 1H NMR (400 MHz, $CDCl_3$): δ 7.59 (d, J = 16.0 Hz, 1H), 7.43 (d, J = 8.0 Hz, 2H), 7.19 (d, J = 8.0 Hz, 2H), 6.35 (d, J = 16.0 Hz, 1H), 2.60 (t, J = 7.6 Hz, 2H), 1.65 (sextet, J = 7.6 Hz, 2H), 1.55 (s, 9H), 0.95 (t, J = 7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.7, 145.2, 143.8, 132.5, 129.1, 128.1, 119.4, 80.5, 38.1, 28.4, 24.5, 13.9; EI-MS m/z (%): 246 (M^+ , 12), 190 (88), 173 (24), 161 (100); HRMS (EI) calcd for $C_{16}H_{22}O_2$ [M]⁺ = 246.1619, found 246.1616.

(E)-*t*-Butyl 3-(3,4,5-trimethoxyphenyl)acrylate. Following the general procedure using 5-bromo-1,2,3-trimethoxybenzene (124 mg, 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 4 h at rt. Column chromatography on silica gel (eluting with 12% EtOAc/hexanes) afforded the product as a white solid (132 mg, 90%). 1H NMR (400 MHz, $CDCl_3$): δ 7.50 (d, J = 16.0 Hz, 1H), 6.74 (s, 2H), 6.28 (d, J = 16.0 Hz, 1H), 3.89 (s, 9H), 1.54 (s, 9H).³⁷

(E)-Ethyl 3-(4-chloro-2-nitrophenyl)acrylate. Following the general procedure using 1-bromo-4-chloro-2-nitrobenzene (118 mg, 0.50 mmol) and ethyl acrylate (109 μL , 1.00 mmol), the reaction was stirred for 14 h at rt. Column chromatography on silica gel (eluting with 5% EtOAc/hexanes) afforded the product as a pale yellow solid (107 mg, 84%). 1H NMR (400 MHz, $CDCl_3$): δ 8.07–8.03 (m, 2H), 7.65–7.59 (m, 2H), 6.37 (d, J = 15.6 Hz, 1H), 4.30 (q, J = 7.2 Hz, 2H), 1.36 (t, J = 7.2 Hz, 2H).³⁸

(E)-*t*-Butyl 3-(2-(3,5-dichlorobenzamido)phenyl)acrylate. Following the general procedure using *N*-(2-bromophenyl)-3,5-dichlorobenzamide (173 mg, 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 14 h at rt. Column chromatography on silica gel (eluting with 10% EtOAc/hexanes) afforded the product as white solid (149 mg, 76%). IR (neat): 3243, 3065, 2979, 2932, 1705, 1682, 1660, 1635, 1587, 1529, 1483, 1455, 1368, 1322, 1253, 1152, 1104, 1050, 981, 911, 869, 760, 734 cm^{-1} . 1H NMR (400 MHz, $CDCl_3$): δ 8.18 (br s, 1H), 7.91 (d, J = 8.0 Hz, 1H), 7.79 (d, J = 16.0 Hz, 1H), 7.74 (d, J = 8.4 Hz, 1H), 7.58 (d, J = 8.0 Hz, 1H), 7.46 (s, 1H), 7.43 (t, J = 8.0 Hz, 1H), 7.33 (d, J = 8.0 Hz, 1H), 7.26 (t, J = 8.0 Hz, 1H), 6.32 (d, J = 16.0 Hz, 1H), 1.51 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.0, 164.1, 138.0, 135.4, 133.3, 131.9, 130.7, 130.3, 128.0, 127.4, 126.6, 125.2, 123.4, 94.6, 81.1, 28.4. ESI-MS m/z : 414 ($M + Na$). HRESI-MS calcd for $C_{20}H_{19}NO_3Cl_2Na$ [$M + Na$]⁺ = 414.0640, found 414.0647.

(E)-*t*-Butyl 3-(2-methoxynaphthalen-1-yl)acrylate. Following the general procedure using 1-bromo-2-methoxynaphthalene (119 mg, 0.50 mmol) and *t*-butyl acrylate (145 μL , 1.00 mmol), the reaction was stirred for 14 h at rt. Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (116 mg, 82%). IR (neat): 3059, 2977, 2935, 2842, 1704, 1622, 1591, 1568, 1513, 1469, 1391, 1367, 1270, 1146, 1102, 1045, 982, 850 cm^{-1} . 1H NMR (400 MHz, $CDCl_3$): δ 8.30 (d, J = 16.0 Hz, 1H), 8.22 (d, J = 8.8

Hz, 1H), 7.84 (d, J = 8.8 Hz, 1H), 7.79 (d, J = 8.4 Hz, 1H), 7.53 (t, J = 8.4 Hz, 1H), 7.38 (t, J = 8.4 Hz, 1H), 7.28 (d, J = 8.4 Hz, 1H), 6.70 (d, J = 16.0 Hz, 1H), 4.00 (s, 3H), 1.61 (s, 9H). ^{13}C NMR (100 MHz, CDCl_3): δ 167.4, 156.6, 136.8, 132.9, 131.4, 129.1, 128.7, 127.4, 125.4, 124.0, 123.5, 117.0, 112.9, 80.4, 56.3, 28.5. EI-MS m/z (%): 284 (M^+ , 28), 228 (67), 211 (23), 183 (100). HRMS(EI) calcd for $\text{C}_{18}\text{H}_{20}\text{O}_3$ [M] $^+$ = 284.1412, found 284.1415.

Typical Procedure for Cross Metathesis. Alkene (0.50 mmol), acrylate (1.00 mmol)/ketone (1.50 mmol) and Grubbs-2 catalyst (0.01–0.02 mmol) were sequentially added into a Teflon-coated-stir-bar-containing Biotage 2–5 mL microwave reactor vial at rt, and then sealed with a septum. An aliquot of 0.02 M of KHSO_4 in $\text{PTS}/\text{H}_2\text{O}$ or $\text{PTS}/\text{H}_2\text{O}$ (1.0 mL; 2.5% PTS by weight; all cross-coupling reactions were conducted at 0.5 M unless stated otherwise) was added, *via* syringe, and the resulting solution was allowed to stir at rt for 4–12 h. The homogeneous reaction mixture was then diluted with EtOAc (2 mL), filtered through a bed of silica gel, and the bed further washed (3 \times 5 mL) with EtOAc to collect all of the cross-coupled material. The volatiles were removed *in vacuo* to afford the crude product that was subsequently purified by flash chromatography on silica gel.

(E)-*t*-Butyl 12-(*t*-butyldimethylsilyloxy)dodec-2-enoate (Table 5, entry 1). The representative procedure above was followed using *t*-butyldimethyl(11-methyldodec-10-en-1-yloxy)silane (156 mg, 0.50 mmol), *t*-butyl acrylate (128 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (177 mg, 92%). ^1H NMR (400 MHz, CDCl_3): δ 6.87 (dt, J = 15.6, 7.2 Hz, 1H), 5.74 (dt, J = 15.6, 1.6 Hz, 1H), 3.60 (t, J = 6.8 Hz, 2H), 2.16 (qd, J = 6.8, 1.6 Hz, 2H), 1.55–1.50 (m, 2H), 1.49 (s, 9H), 1.46–1.40 (m, 2H), 1.33–1.28 (m, 10H), 0.90 (s, 9H), 0.05 (s, 6H).³⁹

(R,E)-*t*-Butyl 12-(2-(Benzyloxycarbonylamino)-3-phenylpropanoyloxy)dodec-2-enoate (Table 5, entry 2). The representative procedure above was followed using (R)-11-methyldodec-10-en-1-yl 2-(benzyloxycarbonylamino)-3-phenylpropanoate (240 mg, 0.50 mmol), *t*-butyl acrylate (128 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (267 mg, 97%). ^1H NMR (400 MHz, CDCl_3): δ 7.38–7.32 (m, 4H), 7.31–7.24 (m, 4H), 7.11 (dd, J = 7.2, 1.2 Hz, 2H), 6.87 (dt, J = 15.6, 6.8 Hz, 1H), 5.74 (dt, J = 15.6, 1.2 Hz, 1H), 5.24 (d, J = 8.4 Hz, 1H), 5.12 (d, J = 12.4 Hz, 1H), 5.08 (d, J = 12.4 Hz, 1H), 4.66 (dt, J = 8.4, 5.6 Hz, 1H), 4.12 (dd, J = 10.8, 6.8 Hz, 1H), 4.06 (dd, J = 10.8, 6.8 Hz, 1H), 3.14 (dd, J = 13.6, 5.6 Hz, 1H), 3.09 (dd, J = 13.6, 5.6 Hz, 1H), 2.17 (qd, J = 7.2, 1.6 Hz, 2H), 1.60–1.55 (m, 2H), 1.49 (s, 9H), 1.46–1.41 (m, 2H), 1.32–1.28 (m, 10H).^{16a}

(E)-4-Phenylbut-2-en-1-yl Acetate (Table 5, entry 3). The representative procedure above was followed using (3-methylbut-2-en-1-yl)benzene (73 mg, 0.50 mmol), (Z)-but-2-ene-1,4-diyl diacetate (172 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (80 mg, 84%). ^1H NMR (400 MHz, CDCl_3): δ 7.33–7.18 (m, 5H), 5.97–5.90 (m, 1H), 5.68–5.61 (m, 1H), 4.55 (d, J = 6.4 Hz, 2H), 3.41 (d, J = 6.4 Hz, 2H), 2.07 (s, 3H).⁴⁰

(E)-*t*-Butyl 4-phenyl-2-butenolate (Table 5, entry 4). The representative procedure above was followed using (3-methylbut-2-en-1-yl)benzene (73 mg, 0.50 mmol), *t*-butyl acrylate (128 mg, 1.00 mmol), and Grubbs second-generation catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 4% EtOAc/hexanes) afforded the product as a colorless oil (96 mg, 88%). ^1H NMR (400 MHz, CDCl_3): δ 7.33 (td, J = 8.4, 1.2 Hz, 2H), 7.25 (t, J = 8.4 Hz, 1H), 7.19 (d, J = 8.4 Hz, 2H), 7.00 (dt, J = 15.6, 6.8 Hz, 1H), 5.74 (dt, J = 15.6, 1.6 Hz, 1H), 3.51 (d, J = 6.8 Hz, 2H), 1.48 (s, 9H).⁴¹

(E)-*t*-Butyl 12-((1-Phenyl-1H-tetrazol-5-yl)thio)dodec-2-enoate (Table 5, entry 5). The representative procedure above

was followed using 5-((11-methyldodec-10-en-1-yl)thio)-1-phenyl-1H-tetrazole (179 mg, 0.50 mmol), *t*-butyl acrylate (128 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (118 mg, 55%). IR (neat): 3053, 2977, 2928, 2855, 1713, 1652, 1598, 1500, 1460, 1389, 1367, 1292, 1246, 1156, 1088, 1074, 1053, 1014, 981, 914, 851, 762 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 7.60–7.52 (m, 5H), 6.85 (dt, J = 15.6, 6.8 Hz, 1H), 5.73 (dt, J = 15.6, 0.8 Hz, 1H), 3.39 (t, J = 7.2 Hz, 2H), 2.15 (qd, J = 6.8, 0.8 Hz, 2H), 1.82 (quint, J = 7.2 Hz, 2H), 1.50–1.43 (m, 4H), 1.48 (s, 9H), 1.32–1.28 (m, 8H). ^{13}C NMR (100 MHz, CDCl_3): δ 166.4, 148.4, 133.9, 130.3, 130.0, 124.0, 123.1, 80.2, 33.5, 32.2, 29.5, 29.3, 29.24, 29.18, 28.8, 28.3, 28.2. EI-MS m/z (%): 430 (M^+ , 8), 357 (19), 329 (14), 118 (76), 57 (100). HRMS(EI) calcd for $\text{C}_{23}\text{H}_{34}\text{O}_2\text{N}_4\text{S}$ [M] $^+$ = 430.2402, found 430.2390.

(E)-2-Ethylhexyl 4-phenyl-2-butenolate (Table 5, entry 6). The representative procedure was followed using (3-methylbut-2-en-1-yl)benzene (73 mg, 0.50 mmol), 2-ethylhexyl acrylate (184 mg, 1.00 mmol), and Grubbs second-generation catalyst (23.4 mg, 0.0275 mmol). Column chromatography on silica gel (eluting with 5% EtOAc/hexanes) afforded the product as a colorless oil (121 mg, 88%). ^1H NMR (400 MHz, CDCl_3): δ 7.33 (t, J = 7.2 Hz, 2H), 7.25 (t, J = 7.2, 1.2 Hz, 1H), 7.19 (dd, J = 7.2, 1.2 Hz, 2H), 7.10 (dt, J = 15.6, 6.8 Hz, 1H), 5.84 (dt, J = 15.6, 1.6 Hz, 1H), 4.06 (dd, J = 14.4, 6.0 Hz, 1H), 4.03 (dd, J = 14.4, 6.0 Hz, 1H), 3.54 (dd, J = 6.8, 1.6 Hz, 2H), 1.60 (septet, J = 6.4 Hz, 1H), 1.42–1.26 (m, 8H), 0.90 (t, J = 7.2 Hz, 6H).^{16a}

(E)-Ethyl 3-(3-(*t*-Butoxy)-3-oxoprop-1-en-1-yl)-2,2-dimethylcyclopropanecarboxylate (Table 5, entry 7). The representative procedure above was followed using ethyl chrysanthemate (135 mg, 0.50 mmol, mixture of *cis* and *trans* isomers), *t*-butyl acrylate (128 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 2% EtOAc/hexanes) afforded the mixture of *cis* and *trans* isomers as a colorless oil (143 mg, 84%). For *cis* isomer: IR (neat): 2979, 1727, 1713, 1643, 1455, 1415, 1391, 1368, 1309, 1270, 1189, 1157, 1135, 1086, 985 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 7.24–7.15 (m, 1H), 5.90 (d, J = 15.2 Hz, 1H), 4.13 (q, J = 7.2 Hz, 2H), 1.87 (d, J = 5.2 Hz, 1H), 1.86 (d, J = 5.2 Hz, 1H), 1.48 (s, 9H), 1.35 (s, 3H), 1.27 (t, J = 7.2 Hz, 3H), 1.23 (s, 3H). ^{13}C NMR (100 MHz, CDCl_3): δ 170.5, 165.7, 143.5, 124.5, 80.2, 60.5, 35.3, 34.0, 28.9, 28.8, 28.4, 15.2, 14.5. ESI-MS m/z : 307 ($\text{M} + \text{K}$), 291 ($\text{M} + \text{Na}$). HRESI-MS calcd for $\text{C}_{15}\text{H}_{24}\text{O}_4\text{Na}$ [$\text{M} + \text{Na}$] $^+$ = 291.1572, found 291.1559. For *trans* isomer: IR (neat): 2979, 2933, 1728, 1714, 1645, 1457, 1427, 1392, 1381, 1367, 1313, 1281, 1232, 1197, 1155, 1137, 1114, 982 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 6.57 (dd, J = 15.2, 10.0 Hz, 1H), 5.91 (d, J = 15.2 Hz, 1H), 4.19–4.07 (m, 2H), 2.14 (dd, J = 10.0, 5.2 Hz, 1H), 1.76 (d, J = 5.2 Hz, 1H), 1.47 (s, 9H), 1.28 (s, 3H), 1.27 (t, J = 7.2 Hz, 3H), 1.24 (s, 3H). ^{13}C NMR (100 MHz, CDCl_3): δ 171.3, 165.9, 145.3, 124.4, 80.4, 60.8, 35.7, 35.5, 30.4, 28.3, 22.4, 20.5, 14.5; ESI-MS m/z : 291 ($\text{M} + \text{Na}$). HRESI-MS calcd for $\text{C}_{15}\text{H}_{24}\text{O}_4\text{Na}$ [$\text{M} + \text{Na}$] $^+$ = 291.1572, found 291.1558.

(E)-*t*-Butyl 8-(*tert*-Butyldimethylsilyloxy)-6-methyloct-2-enoate (Table 5, entry 8, R = ^tBu). The representative procedure above was followed using *t*-butyl(3,7-dimethyloct-6-en-1-yloxy)dimethylsilane⁴² (135 mg, 0.50 mmol), *t*-butyl acrylate (128 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 2% EtOAc/hexanes) afforded the product as a colorless oil (143 mg, 84%). IR (neat): 2956, 2929, 2858, 1717, 1654, 1472, 1462, 1390, 1366, 1289, 1255, 1156, 1096, 983, 897, 836, 775 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 6.86 (dt, J = 15.6 Hz, 1H), 5.74 (dt, J = 15.6, 1.6 Hz, 1H), 3.69–3.59 (m, 2H), 2.26–2.10 (m, 2H), 1.65–1.41 (m, 3H), 1.48 (s, 9H), 1.38–1.23 (m, 2H), 0.89 (s, 9H), 0.892 (d, J = 6.4 Hz, 3H), 0.05 (s, 6H). ^{13}C NMR (100 MHz, CDCl_3): δ 166.4, 148.4, 123.0, 80.2, 61.4, 39.9, 35.5, 29.8, 29.2, 28.4, 26.2, 19.6, 18.5, –5.1. MS (CI) m/z (%): 343 ($\text{M} + \text{H}$, 100), 287 (89), 269 (83), 229 (65), 109 (29), 59 (76). HRMS (CI) calcd for $\text{C}_{19}\text{H}_{39}\text{O}_3\text{Si}$ [$\text{M} + \text{H}$] $^+$ = 343.2668, found 343.2669.

(E)-Ethyl 8-(*t*-Butyldimethylsilyloxy)-6-methyloct-2-enoate (Table 5, entry 8, R = Et). The representative procedure above was followed using *t*-butyl(3,7-dimethyloct-6-en-1-yloxy)dimethylsilane⁴² (135 mg, 0.50 mmol), ethyl acrylate (0.11 mL, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 50% CH₂Cl₂/hexanes) afforded the product as a colorless oil (129 mg, 82%). IR (neat): 2957, 2856, 1725, 1656, 1464, 1388, 1367, 1308, 1257, 1198, 1171, 1094, 1048, 984, 939, 897, 836, 776 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 6.96 (dt, *J* = 15.6, 1H), 5.82 (dt, *J* = 15.6, 1.6 Hz, 1H), 4.18 (q, *J* = 7.2 Hz, 2H), 3.69–3.58 (m, 2H), 2.29–2.13 (m, 2H), 1.66–1.43 (m, 3H), 1.38–1.24 (m, 2H), 1.28 (t, *J* = 7.2 Hz, 3H), 0.895 (s, 9H), 0.894 (d, *J* = 6.4 Hz, 3H), 0.45 (s, 6H). ¹³C NMR (100 MHz, CDCl₃): δ 167.0, 149.7, 121.4, 61.4, 60.3, 39.9, 35.4, 29.9, 29.2, 26.2, 19.6, 18.5, 14.5, –5.1. EI-MS *m/z* (%): 299 (M – CH₃, 3), 257 (M – C₄H₉, 100), 211 (16). HRMS (EI) calcd for C₁₃H₂₅O₃Si [M – C₄H₉]⁺ = 257.1573, found 257.1580.

(E)-*t*-Butyl 8-acetoxy-6-methyloct-2-enoate (Table 5, entry 9, R = ^tBu). The representative procedure above was followed using 3,7-dimethyloct-6-en-1-yl acetate⁴³ (99 mg, 0.50 mmol), *t*-butyl acrylate (128 mg, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 6% EtOAc/hexanes) afforded the product as a colorless oil (108 mg, 80%). IR (neat): 2973, 2931, 2874, 1740, 1715, 1653, 1458, 1391, 1367, 1290, 1236, 1157, 1125, 1049, 984, 851 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 6.82 (dt, *J* = 15.6, 6.8 Hz, 1H), 5.72 (dt, *J* = 15.9, 1.6 Hz, 1H), 4.13–4.02 (m, 2H), 2.25–2.08 (m, 2H), 2.02 (s, 3H), 1.69–1.38 (m, 3H), 1.45 (s, 9H), 1.36–1.23 (m, 2H), 0.90 (d, *J* = 6.4 Hz, 3H). ¹³C NMR (100 MHz, CDCl₃): δ 171.3, 166.2, 147.9, 123.2, 80.2, 62.8, 35.4, 35.2, 29.6, 29.5, 28.3, 21.2, 19.3. ESI-MS *m/z*: 293 (M + Na). HRESI-MS calcd for C₁₅H₂₆O₄Na [M + Na]⁺ = 293.1723, found 293.1730.

(E)-2-Ethylhexyl 8-Acetoxy-6-methyloct-2-enoate (Table 5, entry 9, R = 2-Ethylhexyl). The representative procedure above was followed using 3,7-dimethyloct-6-en-1-yl acetate⁴³ (99 mg, 0.50 mmol), 2-ethylhexyl acrylate (0.21 mL, 1.00 mmol) and Grubbs-2 catalyst (12.8 mg, 0.015 mmol). Column chromatography on silica gel (eluting with 6% EtOAc/hexanes) afforded the product as a colorless oil (127 mg, 78%). IR (neat): 2959, 2930, 2873, 2861, 1741, 1721, 1655, 1462, 1382, 1366, 1309, 1239, 1171, 1125, 1047, 985 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 6.92 (dt, *J* = 15.6, 6.8 Hz, 1H), 5.81 (dt, *J* = 15.9, 1.6 Hz, 1H), 4.13–4.04 (m, 2H), 4.03–3.98 (m, 2H), 2.27–2.12 (m, 2H), 2.02 (s, 3H), 1.70–1.27 (m, 14H), 0.92–0.86 (m, 9H). ¹³C NMR (100 MHz, CDCl₃): δ 171.3, 167.0, 149.1, 121.6, 66.8, 62.8, 38.9, 35.4, 35.2, 30.6, 29.7, 29.5, 29.1, 24.0, 23.1, 21.2, 19.3, 14.2, 11.2. ESI-MS *m/z*: 349 (M + Na), 327 (M + H). HRESI-MS calcd for C₁₉H₃₄O₄Na [M + Na]⁺ = 349.2349, found 349.2354.

(E)-12-(1,3-Dioxolan-2-yl)dodec-3-en-2-one. The representative procedure above was followed using 2-(dec-9-en-1-yl)-1,3-dioxolane (22) (106 mg, 0.50 mmol), methyl vinyl ketone (106 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (114 mg, 90%). IR (neat): 2926, 2855, 1697, 1675, 1626, 1465, 1434, 1361, 1253, 1139, 1036, 980 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 6.78 (dt, *J* = 16.0, 7.2 Hz, 1H), 6.04 (dt, *J* = 16.0, 1.2 Hz, 1H), 4.81 (t, *J* = 4.8 Hz, 1H), 3.98–3.90 (m, 2H), 3.87–3.78 (m, 2H), 2.22 (s, 3H), 2.19 (qd, *J* = 7.2, 1.2 Hz, 2H), 1.63 (td, *J* = 7.2, 4.8 Hz, 2H), 1.46–1.28 (m, 12H). ¹³C NMR (100 MHz, CDCl₃): δ 198.8, 148.7, 131.4, 104.8, 65.0, 34.0, 32.6, 29.6, 29.5, 29.4, 29.3, 28.2, 27.0, 24.2. ESI-MS *m/z*: 393 (M + K), 277 (M + Na). HRESI-MS calcd for C₁₅H₂₆O₃Na [M + Na]⁺ = 277.1780, found 277.1774.

(E)-6-(2-(*t*-Butyldimethylsilyloxy)phenyl)hex-4-en-3-one (23). The representative procedure above was followed using *t*-butyl (2-allylphenoxy)dimethylsilane⁴⁴ (20) (124 mg, 0.50 mmol), ethyl vinyl ketone (126 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes)

afforded the product as a colorless oil (134 mg, 88%). IR (neat): 3063, 3035, 2956, 2897, 2857, 1697, 1682, 1632, 1599, 1583, 1495, 1454, 1451, 1361, 1258, 1201, 1123, 1107, 1043, 982, 934, 838, 781, 756, 704, 663 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 7.14 (td, *J* = 7.6, 1.6 Hz, 1H), 7.10 (dd, *J* = 7.2, 1.6 Hz, 1H), 6.98 (dt, *J* = 16.0, 6.8 Hz, 1H), 6.91 (td, *J* = 7.2, 1.2 Hz, 1H), 6.83 (d, *J* = 7.6 Hz, 1H), 6.05 (dt, *J* = 16.0, 1.6 Hz, 1H), 3.53 (dd, *J* = 6.8, 1.6 Hz, 2H), 2.56 (q, *J* = 7.6 Hz, 2H), 1.09 (t, *J* = 7.6 Hz, 3H), 1.01 (s, 9H), 0.25 (s, 6H). ¹³C NMR (100 MHz, CDCl₃): δ 201.2, 153.7, 145.3, 130.9, 130.7, 128.6, 128.0, 121.4, 118.6, 33.6, 33.2, 26.0, 18.4, 8.3, –3.9. ESI-MS *m/z*: 327 (M + Na), 305 (M + H). HRESI-MS calcd for C₁₈H₂₈O₂SiNa [M + Na]⁺ = 327.1756, found 327.1758.

(E)-6-(2-(*t*-Butyldimethylsilyloxy)phenyl)-1-phenylhex-4-en-3-one (24). The representative procedure above was followed using *t*-butyl(2-allylphenoxy)dimethylsilane⁴⁴ (20) (124 mg, 0.50 mmol), 5-phenylpent-1-en-3-one (240 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (154 mg, 81%). IR (neat): 3062, 3028, 2955, 2929, 2896, 2858, 1697, 1674, 1628, 1600, 1582, 1492, 1453, 1362, 1256, 1105, 981, 928, 839, 781, 756, 699 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 7.30–7.26 (m, 2H), 7.20–7.18 (m, 3H), 7.14 (td, *J* = 7.2, 1.2 Hz, 1H), 7.08 (dd, *J* = 7.2, 1.2 Hz, 1H), 6.98 (dt, *J* = 16.0, 6.4 Hz, 1H), 6.91 (t, *J* = 7.2 Hz, 1H), 6.83 (d, *J* = 8.0 Hz, 1H), 6.05 (d, *J* = 16.0 Hz, 1H), 3.52 (d, *J* = 6.4 Hz, 2H), 2.96–2.92 (m, 2H), 2.88–2.84 (m, 2H), 1.00 (s, 9H), 0.25 (s, 6H). ¹³C NMR (100 MHz, CDCl₃): δ 199.7, 153.7, 146.0, 141.5, 131.1, 130.7, 128.7, 128.54, 128.49, 128.1, 126.2, 121.5, 118.7, 41.7, 33.6, 30.2, 26.0, 18.4, –3.9. ESI-MS *m/z*: 403 (M + Na), 381 (M + H); HRESI-MS calcd for C₂₄H₃₂O₂SiNa [M + Na]⁺ = 403.2069, found 403.2078.

(E)-5-(2-(*t*-Butyldimethylsilyloxy)phenyl)pent-3-en-2-one (Table 7, entry 1). The representative procedure above was followed using *t*-butyl(2-allylphenoxy)dimethylsilane⁴⁴ (20) (124 mg, 0.50 mmol), methyl vinyl ketone (106 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (132 mg, 91%). IR (neat): 3062, 3034, 2932, 2894, 2859, 1699, 1676, 1626, 1599, 1582, 1492, 1472, 1452, 1422, 1390, 1361, 1254, 1182, 1108, 1043, 982, 929 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 7.15 (td, *J* = 7.6, 1.6 Hz, 1H), 7.11 (dd, *J* = 7.6, 1.6 Hz, 1H), 6.95 (dt, *J* = 16.0, 6.4 Hz, 1H), 6.92 (td, *J* = 7.6, 1.2 Hz, 1H), 6.84 (dd, *J* = 7.6, 1.2 Hz, 1H), 6.03 (dt, *J* = 16.0, 1.6 Hz, 1H), 3.54 (dd, *J* = 6.4, 1.6 Hz, 2H), 2.24 (s, 3H), 1.01 (s, 9H), 0.26 (s, 6H). ¹³C NMR (100 MHz, CDCl₃): δ 198.8, 153.7, 146.8, 132.0, 130.7, 128.4, 128.1, 121.4, 118.6, 33.7, 26.9, 25.9, 18.4, –4.0. EI-MS *m/z* (%): 275 (M – CH₃⁺, 2), 233 (M – C₄H₉⁺, 100), 215 (20), 151 (8), 75 (42). HRMS (EI) calcd for C₁₃H₁₇O₂Si [M – C₄H₉]⁺ = 233.0998, found 233.1006.

4-(2-(*t*-Butyldimethylsilyloxy)phenyl)but-2-enenitrile (Table 7, entry 2). The representative procedure above was followed using *t*-butyl(2-allylphenoxy)dimethylsilane⁴⁴ (20) (124 mg, 0.50 mmol), acrylonitrile (80 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (41 mg, 30%). IR (neat): 3067, 3035, 2956, 2931, 2896, 2859, 2222, 1683, 1620, 1599, 1583, 1492, 1472, 1454, 1390, 1362, 1258, 1184, 1109, 1045, 1108, 928, 838 cm⁻¹. ¹H NMR (400 MHz, CDCl₃): δ 7.17–7.14 (m, 2H), 6.93 (t, *J* = 7.6 Hz, 1H), 6.84 (d, *J* = 7.6 Hz, 1H), 6.65 (dt, *J* = 11.2, 7.2 Hz, 1H), 5.38 (d, *J* = 11.2 Hz, 1H), 3.74 (d, *J* = 7.2 Hz, 2H), 1.03 (s, 9H), 0.27 (s, 6H). ¹³C NMR (100 MHz, CDCl₃): δ 153.3, 130.8, 130.4, 128.6, 128.4, 121.6, 118.7, 116.3, 99.7, 34.4, 33.2, 26.0, –3.9. FI-MS *m/z*: 273 (M), 216 (M – C₄H₉). HRFI-MS calcd for C₁₆H₂₃NOSi [M]⁺ = 273.1549, found 273.1557.

(E)-4-(2-(*t*-Butyldimethylsilyloxy)phenyl)but-2-enal (Table 7, entry 3). The representative procedure above was followed using *t*-butyl (2-allylphenoxy)dimethylsilane⁴⁴ (20) (124 mg, 0.50 mmol), acrolein (84 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column

chromatography on silica gel (eluting with 3% EtOAc/hexanes) afforded the product as a colorless oil (97 mg, 70%). IR (neat): 3365, 3064, 3035, 2932, 2895, 2859, 2810, 2739, 1686, 1635, 1599, 1582, 1491, 1471, 1452, 1413, 1390, 1361, 1254, 1183, 1128, 1095, 1043, 1008, 978, 927, 838, 782, 757, 734, 704 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 9.53 (d, $J = 7.6$ Hz, 1H), 7.16 (td, $J = 7.6, 1.6$ Hz, 1H), 7.11 (dd, $J = 7.6, 1.6$ Hz, 1H), 6.99 (dt, $J = 15.6, 6.4$ Hz, 1H), 6.93 (td, $J = 7.6, 1.6$ Hz, 1H), 6.84 (dd, $J = 7.6, 1.6$ Hz, 1H), 6.07 (ddt, $J = 15.6, 7.6, 1.6$ Hz, 1H), 3.64 (dd, $J = 6.4, 1.6$ Hz, 2H), 1.00 (s, 9H), 0.26 (s, 6H). ^{13}C NMR (100 MHz, CDCl_3): δ 194.1, 157.1, 153.7, 133.5, 130.7, 128.4, 127.9, 121.6, 118.7, 34.0, 26.0, 18.4, -3.9 . ESI-MS m/z : 315 ($M + K$), 299 ($M + Na$). HRESI-MS calcd for $\text{C}_{16}\text{H}_{24}\text{O}_2\text{SiNa}$ [$M + Na$] $^+ = 299.1443$, found 299.1445.

(E)-Diethyl (3-(2-(*t*-Butyldimethylsilyloxy)phenyl)prop-1-en-1-yl)phosphonate (Table 7, entry 4). The representative procedure above was followed using *t*-butyl(2-allylphenoxy)dimethylsilane⁴⁴ (**20**) (124 mg, 0.50 mmol), diethyl vinylphosphonate (164 mg, 1.00 mmol) and Grubbs-2 catalyst (17 mg, 0.02 mmol). Column chromatography on silica gel (eluting with 25% EtOAc/hexanes) afforded the product as a colorless oil (125 mg, 65%). IR (neat): 3063, 2931, 2900, 2859, 1631, 1599, 1583, 1493, 1472, 1453, 1391, 1362, 1250, 1164, 1104, 1023, 964 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 7.12 (td, $J = 7.6, 1.6$ Hz, 1H), 7.08 (dd, $J = 7.6, 1.6$ Hz, 1H), 6.94 (dt, $J = 17.2, 6.0$ Hz, 1H), 6.92–6.85 (m, 1H), 6.80 (d, $J = 8.0$ Hz, 1H), 5.59–5.49 (m, 1H), 4.08–3.99 (m, 4H), 3.53–3.51 (m, 2H), 1.29 (t, $J = 7.2$ Hz, 6H), 0.99 (s, 9H), 0.22 (s, 6H). ^{13}C NMR (100 MHz, CDCl_3): δ 153.7, 151.83, 151.78, 130.8, 128.2, 128.0, 121.4, 118.6, 116.7, 61.73, 61.67, 35.1, 34.9, 25.9, 18.4, 16.54, 16.47, -4.0 . ESI-MS m/z : 407 ($M + Na$), 385 ($M + H$). HRESI-MS calcd for $\text{C}_{19}\text{H}_{33}\text{O}_4\text{SiPNa}$ [$M + Na$] $^+ = 407.1783$, found 407.1783.

1-Tosyl-2,3,4,7-tetrahydro-1H-azepine (Table 8). The representative procedure above was followed using *N*-allyl-4-methyl-*N*-(pent-4-en-1-yl)benzenesulfonamide⁴⁵ (56 mg, 0.20 mmol) and Grubbs-2 catalyst (3.4 mg, 0.004 mmol). Column chromatography on silica gel (eluting with 4% EtOAc/hexanes) afforded the product as a colorless oil (46 mg, 92%). ^1H NMR (400 MHz, CDCl_3): δ 7.67 (d, $J = 8.0$ Hz, 2H), 7.28 (d, $J = 8.0$ Hz, 2H), 5.79–5.74 (m, 1H), 5.67–5.62 (m, 1H), 3.83–3.82 (m, 2H), 3.38 (t, $J = 6.0$ Hz, 2H), 2.42 (s, 3H), 2.20–2.15 (m, 2H), 1.82–1.76 (m, 2H).⁴⁵

(E)-*t*-Butyl 6-(1-Phenyl-1H-tetrazol-5-ylthio)-2-hexenoate (Table 12, entry 1). The representative procedure above was followed using 5-(pent-4-en-1-ylthio)-1-phenyl-1H-tetrazole^{16a} (123 mg, 0.50 mmol), *t*-butyl acrylate (217 μL , 1.50 mmol), CuI (7.2 mg, 0.038 mmol) and Grubbs-2 catalyst (21.2 mg, 0.025 mmol). Column chromatography on silica gel (eluting with 10% EtOAc/hexanes) afforded the product as colorless oil (138 mg, 80%). ^1H NMR (400 MHz, CDCl_3): δ 7.59–7.55 (m, 5H), 6.82 (dt, $J = 15.6, 7.2$ Hz, 1H), 5.79 (dt, $J = 15.6, 1.6$ Hz, 1H), 3.41 (t, $J = 7.2$ Hz, 2H), 2.36 (qd, $J = 7.2, 1.6$ Hz, 2H), 2.03 (quintet, $J = 7.2$ Hz, 2H), 1.48 (s, 9H).^{16a}

(E)-*t*-Butyl 3-(2,4-Dimethylphenyl)-2-propenoate (Table 12, entry 3). The representative procedure above was followed using 2,4-dimethylstyrene (74 μL , 0.50 mmol), *t*-butyl acrylate (145 μL , 1.00 mmol), CuI (2.9 mg, 0.015 mmol) and Grubbs second-generation catalyst (8.5 mg, 0.010 mmol). Column chromatography on silica gel (eluting with 2% EtOAc/hexanes) afforded the product as colorless oil (94 mg, 81%). ^1H NMR (400 MHz, CDCl_3): δ 7.88 (d, $J = 15.6$ Hz, 1H), 7.46 (d, $J = 8.4$ Hz, 1H), 7.02–7.00 (m, 2H), 6.28 (d, $J = 15.6$ Hz, 1H), 2.40 (s, 3H), 2.33 (s, 3H), 1.55 (s, 9H).^{16a}

(E)-7-(4-Nitrophenoxy)-7-phenylhept-4-en-3-one (26). The representative procedure above was followed using 1-nitro-4-(1-phenylbut-3-en-1-yloxy)benzene (**25**)^{21a} (135 mg, 0.50 mmol), ethyl vinyl ketone (126 mg, 1.50 mmol) and Grubbs-2 catalyst (8.5 mg, 0.01 mmol). Column chromatography on silica gel (eluting with 15% EtOAc/hexanes) afforded the product as a pale yellow liquid (122 mg, 75%). ^1H NMR (400 MHz, CDCl_3): δ 8.07 (d, $J = 9.2$ Hz, 2H), 7.38–7.27 (m, 5H), 6.89 (d, $J = 9.2$ Hz, 2H), 6.83 (dt, $J = 16.0, 7.2$ Hz, 1H), 6.17 (d, $J = 16.0$ Hz, 1H), 5.34 (dd,

$J = 7.6, 4.8$ Hz, 1H), 2.97–2.89 (m, 1H), 2.83–2.76 (m, 1H), 2.54 (q, $J = 7.2$ Hz, 2H), 1.07 (t, $J = 7.2$ Hz, 3H).^{21a}

***t*-Butyldimethyl(11-methyldodec-10-en-1-yloxy)silane.**

TBSCl (0.29 g, 1.92 mmol) and imidazole (0.17 g, 2.50 mmol) were dissolved in dry CH_2Cl_2 (6 mL) in a round-bottom flask. 11-methyldodec-10-en-1-ol⁴⁶ (0.25 g, 1.26 mmol) was then added dropwise and the resulting solution was allowed to warm to rt and left to stir for another 12 h, after which it was quenched with water. The aqueous layer was extracted with CH_2Cl_2 and the organic extracts were washed with water and dried over Na_2SO_4 . The volatiles were removed *in vacuo* to afford the crude product which was subsequently purified by column chromatography on silica gel (eluting with 5% EtOAc/hexanes) to yield the product (0.38 g, 96%) as a colorless oil. IR (neat): 2851, 1464, 1386, 1361, 1253, 1100, 1007, 984, 938, 840, 775 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 5.12 (t, $J = 7.2$ Hz, 1H), 3.60 (t, $J = 6.8$ Hz, 2H), 1.96 (q, $J = 6.8$ Hz, 2H), 1.69 (s, 3H), 1.61 (s, 3H), 1.51 (quint, $J = 6.8$ Hz, 2H), 1.28 (br s, 12H), 0.91 (s, 9H), 0.06 (s, 6H). ^{13}C NMR (100 MHz, CDCl_3): δ 131.3, 125.2, 63.6, 33.1, 30.1, 29.9, 29.8, 29.7, 29.6, 28.3, 26.2, 26.0, 18.6, 17.9, -5.0 . EI-MS m/z (%): 255 ($M - \text{C}_4\text{H}_9$, 70), 75 (100). HRMS (EI) calcd for $\text{C}_{15}\text{H}_{31}\text{OSi}$ [$M - \text{C}_4\text{H}_9$] $^+ = 255.2144$, found 255.2146.

(R)-11-Methyldodec-10-en-1-yl 2-(benzyloxycarbonylamino)-3-phenylpropanoate. To a 50 mL round-bottomed-flask containing a stir bar, was added CH_2Cl_2 (12 mL) which was cooled to 0 $^\circ\text{C}$. *N*-carbobenzyloxy-L-phenylalanine (0.45 g, 1.51 mmol), 11-methyldodec-10-en-1-ol⁴⁶ (0.25 g, 1.26 mmol), 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (0.33 g, 2.14 mmol), and 4-dimethylaminopyridine (0.015 g, 0.13 mmol) were then added. The resulting solution was allowed to warm to rt over a 20 h period, after which it was quenched by the addition of H_2O . The reaction mixture was extracted with CH_2Cl_2 , and the organic layer washed with aqueous NaHCO_3 , water and dried over anhydrous Na_2SO_4 . Removal of the volatiles *in vacuo* afforded the crude residue, which was purified by column chromatography on silica gel (eluting with 10% EtOAc/hexanes) to yield the product (0.58 g, 96%) as a colorless liquid. IR (neat): 3348, 3087, 3063, 3031, 2925, 2854, 1720, 1604, 1499, 1455, 1395, 1376, 1346, 1254, 1208, 1081, 1057, 1029 cm^{-1} . ^1H NMR (400 MHz, CDCl_3): δ 7.39–7.22 (m, 8H), 7.11 (dd, $J = 7.6, 1.6$ Hz, 2H), 5.25 (d, $J = 8.4$ Hz, 1H), 5.14–5.07 (m, 3H), 4.66 (dt, $J = 8.4, 5.6$ Hz, 1H), 4.15–4.05 (m, 2H), 3.14 (dd, $J = 13.6, 5.6$ Hz, 1H), 3.10 (dd, $J = 13.6, 5.6$ Hz, 1H), 1.99–1.95 (m, 2H), 1.70 (s, 3H), 1.61 (s, 3H), 1.60–1.58 (m, 2H), 1.28 (br s, 12H). ^{13}C NMR (100 MHz, CDCl_3): δ 171.6, 155.7, 136.4, 135.9, 131.2, 129.4, 128.61, 128.58, 128.2, 128.1, 127.1, 125.0, 67.0, 65.8, 55.0, 38.5, 30.1, 29.68, 29.65, 29.5, 29.4, 28.6, 28.2, 26.0, 25.9, 17.9. ESI-MS m/z : 502 ($M + Na$). HRESI-MS calcd for $\text{C}_{30}\text{H}_{41}\text{NO}_4\text{Na}$ [$M + Na$] $^+ = 502.2933$, found 502.2909.

5-((11-Methyldodec-10-en-1-yl)thio)-1-phenyl-1H-tetrazole. A solution of DCAD (0.51 g, 1.39 mmol) in CH_2Cl_2 (10 mL) was slowly added at rt via cannula to a solution of PPh_3 (0.37 g, 1.39 mmol), 1-phenyl-1H-tetrazole-5-thiol (0.25 g, 1.39 mmol) and the 11-methyldodec-10-en-1-ol⁴⁶ (0.25 g, 1.26 mmol) in CH_2Cl_2 (5 mL). The resulting cloudy solution was stirred at rt for 12 h. Filtration of the reaction mixture was then carried out to afford reduced DCAD as a white powder. The filtrate was removed *in vacuo* to afford the crude product, which was purified by column chromatography on silica gel (eluting with 10% EtOAc/hexanes) to yield the product (0.23 g, 51%) as a colorless liquid. IR (neat): 2925, 2853, 1598, 1499, 1462, 1411, 1386, 1278, 1243, 1087, 1074, 1053, 1014, 979, 912, 761, 694 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3): 7.60–7.52 (m, 5H), 5.13–5.09 (m, 1H), 3.39 (t, $J = 7.2$ Hz, 2H), 1.97–1.92 (m, 2H), 1.81 (quint, $J = 7.2$ Hz, 2H), 1.68 (s, 3H), 1.59 (s, 3H), 1.44 (quint, $J = 7.2$ Hz, 2H), 1.31–1.27 (m, 10H); ^{13}C NMR (100 MHz, CDCl_3): 154.7, 133.9, 131.3, 130.2, 129.9, 125.0, 124.0, 33.5, 30.0, 29.62, 29.59, 29.4, 29.22, 29.19, 28.8, 28.2, 25.9, 17.8; ESI-MS

m/z : 381 ($M + Na$), 359 ($M + H$); HRESIMS calcd for $C_{20}H_{30}N_4SNa$ [$M + Na$] $^+ = 381.2089$, found 381.2072.

2-(Dec-9-en-1-yl)-1,3-dioxolane (22). A round-bottom flask, equipped with a stirrer bar and a Dean–Stark apparatus, was charged with Undec-10-enal (1.34 g, 8.00 mmol), ethylene glycol (2.7 mL, 48.00 mmol), $pTSA \cdot H_2O$ (0.06 g, 0.32 mmol), and benzene (15 mL) and the reaction mixture heated at reflux for 8 h. After usual workup the pure acetal (1.52 g, 90%) was obtained by distillation *in vacuo* as a colorless oil. IR (neat): 3076, 2976, 2926, 2855, 1640, 1465, 1438, 1411, 1361, 1212, 1142, 1037, 993, 944, 910 cm^{-1} . 1H NMR (400 MHz, $CDCl_3$): δ 5.87–5.76 (m, 1H), 5.02–4.92 (m, 2H), 4.85 (t, $J = 4.8$ Hz, 1H), 4.01–3.93 (m, 2H), 3.90–3.81 (m, 2H), 2.04 (q, $J = 7.2$ Hz, 2H), 1.68–1.63 (m, 2H), 1.45–1.29 (m, 12H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 139.3, 114.2, 104.8, 65.0, 34.1, 34.0, 29.8, 29.7, 29.6, 29.3, 29.1, 24.3. EI-MS m/z (%): 211 ($M - H$, 2), 73 (100). HRMS (EI) calcd for $C_{13}H_{23}O_2$ [$M - H$] $^+ = 211.1698$, found 211.1693.

Recycling of PTS. N,N' -Diallyl-4-methylbenzenesulfonamide (25 mg, 0.10 mmol) and Grubbs-2 catalyst (1.7 mg, 0.002 mmol) were both added into a Teflon-coated-stir-bar-containing Biotage 5 mL microwave reactor vial at rt, and sealed with a septum. An aliquot of PTS/ H_2O (1.0 mL; 2.5% PTS by weight) was added, *via* syringe, and the resulting solution was allowed to stir at rt for 2 h. Et_2O (3 mL) was then added to the reaction mixture and stirred for 10 s. The reaction mixture was then allowed to separate and the upper (Et_2O) layer was removed by pipet. The aqueous layer was successively washed with Et_2O (3×3 mL). The combined Et_2O extracts layers were evaporated *in vacuo* to afford the crude product, which was examined by 400 MHz 1H NMR spectroscopy to reveal complete conversion of diene and clean formation of the corresponding cyclized product. 1H NMR (400 MHz, $CDCl_3$): δ 7.72 (d, $J = 8.0$ Hz, 2H), 7.32 (d, $J = 8.0$ Hz, 2H), 5.65 (t, $J = 4.4$ Hz, 2H), 4.11 (t, $J = 4.4$ Hz, 2H), 2.42 (s, 3H).⁴⁷ For the second run, the diene (25 mg, 0.10 mmol) and Grubbs-2 catalyst (1.7 mg, 0.002 mmol) were both added again to the same reaction vessel and stirred at rt for another 2 h. The workup was conducted in exactly the same way as described for the first cycle. This reaction was repeated eight more times, each using the above diene (25 mg, 0.10 mmol) and Grubbs-2 catalyst (1.7 mg, 0.002 mmol).

■ ASSOCIATED CONTENT

S Supporting Information. Synthesis of starting materials and copies of 1H and ^{13}C NMR spectra of all new compounds and copies of 1H NMR spectra of all known compounds. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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