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Process for telomerizing noncyclic olefins

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The invention relates to a process for telomerizing noncyclic olefins having at least two conjugated double bonds, in particular to the preparation of 1-octa-2,7-dienyl derivatives, by
5 reacting a 1,3-butadiene-containing hydrocarbon mixture, in particular crack C₄, with nucleophiles.

The telomerization products which are formed from two moles of 1,3-butadiene and one mole of nucleophile (unsaturated amines, unsaturated alcohols and their esters and ethers) are
10 starting materials for organic syntheses. The oxygen-containing derivatives are precursors for the preparation of linear C₈-alcohols and C₈-olefins, in particular 1-octanol and 1-octene. 1-Octanol in turn is used, for example, to obtain plasticizers. 1-Octene is a valuable comonomer for the modification of polyethylene and polypropylene.

15 The telomerization of butadiene with a nucleophile to give octadienyl derivatives is catalyzed by metal complexes, in particular palladium compounds.

Examples of telomerization reactions are described, inter alia, in E. J. Smutny, J. Am. Chem. Soc. 1967, 89, 6793; S. Takahashi, T. Shibano, N. Hagihara, Tetrahedron Lett. 1967, 2451;
20 EP-A-0 561 779, US 3 499 042, US 3 530 187, GB 1 178 812, NL 6 816 008, GB 1 248 593, US 3 670 029, US 3 670 032, US 3 769 352, US 3 887 627, GB 1 354 507, DE 20 40 708, US 4 142 060, US 4 146 738, US 4 196 135, GB 1 535 718, US 4 104 471, DE 21 61 750 and EP-A-0 218 100.

25 The feedstocks used for the preparation of octadienyl derivatives may be pure 1,3-butadiene or 1,3-butadiene-containing hydrocarbon mixtures, for example crack C₄.

Owing to the costly and inconvenient removal process, 1,3-butadiene is a relatively expensive feedstock. It is therefore usually more economically viable to select 1,3-butadiene-containing
30 hydrocarbon mixtures as the feedstock for the telomerization. This is possible since most of the accompanying substances, such as saturated hydrocarbons, for example n-butane or

isobutane, or monoolefins, for example isobutene and linear butenes, behave inertly in the telomerization reaction. Only inhibitors, i.e. substances which reduce the space-time yield or the selectivity or increase the catalytic consumption, should be removed beforehand.

- 5 According to DE 195 23 335, it is advisable, when using the C₄ fraction from naphtha crackers as the 1,3-butadiene-containing raw material, to limit the concentration of acetylenic compounds and of allenes in the reactant for the telomerization. The sum of acetylenically and allenically unsaturated compounds should not exceed 1% by mass based on 1,3-butadiene. For the removal of these troublesome components, reference is made to known processes without
10 mentioning or citing particular processes.

With reference to this patent (DE 195 23 335), DE 101 49 348, DE 102 29 290 and DE 103 29 042 indicate, without specifying concentration limits, that it is favorable to remove acetylenic and allenic compounds before the telomerization.

15

WO 91/09822 states that it is appropriate to remove acetylenically unsaturated compounds by selective hydrogenation from the C₄ mixture obtained in the cracking process of naphtha, gas oil or LPG. The hydrogenation process used is not disclosed. In the examples, a raw material having a total content of acetylenes below 60 ppm is used and does not contain any specified
20 content of allenes.

The acetylenic compounds can be removed by extraction or hydrogenation of these compounds. In the removal of the acetylenic compounds (methylacetylene (propyne), ethylacetylene (butyne), vinylacetylene (butenyne)) by hydrogenation, processes are employed
25 in which the acetylenic compounds are hydrogenated with high selectivity, substantially without hydrogenation of 1,3-butadiene and monoolefins. The catalysts used are hydrogenation catalysts which comprise copper, copper in combination with base metals, copper in combination with noble metals or metal catalysts of metals of transition group VIII of the Periodic Table of the Elements, for example palladium catalysts. Corresponding
30 processes are described, inter alia, in the following patents: US 6 576 588, US 6 417 419, US 6 225 515, US 6 015 933, US 6 194 626, US 6 040 489, US 4 493 906, US 4 440 956,

US 4 101 451, US 3 912 789, US 3 751 508, US 3 541 178, US 3 327 013, US 3 218 268, EP 1 217 060, EP 1 151 790, EP 1 070 695, EP 0 273 900, NL 6 613 942.

The removal of allenes, especially of 1,2-butadiene, by hydrogenation is substantially more difficult than the selective removal of acetylenic compounds. The reactivity of 1,2-butadiene in the hydrogenation is only slightly higher than that of 1,3-butadiene. Therefore, 1,3-butadiene losses are unavoidable in the removal of 1,2-butadiene from 1,3-butadiene-containing hydrocarbon mixtures by hydrogenation.

For example, WO 98/12160 details a process for simultaneously removing acetylenic compounds and 1,2-butadiene from a 1,3-butadiene-containing hydrocarbon stream by hydrogenation over a palladium catalyst in a reactive distillation column. Although the content of acetylenic compounds in the top product had only been reduced by approx. 60% and that of 1,2-butadiene only by 32% in the example 1 reported there, as much as 3% of the 1,3-butadiene had been lost by hydrogenation.

In *Angew. Chem.* **2005**, 117, 2062 - 2065, Jeroen W. Sprengers et al. report that Pd complex catalysts which have N-heterocyclic ligands as ligands are suitable as catalysts for hydrogenation, in particular for the hydrogenation of 1-phenyl-1-propyne to 1-phenyl-1-propene and 1-phenyl-1-propane.

In the preparation of 2,7-octadienyl derivatives from crack C₄ by telomerization according to the prior art, complicated processes, especially with regard to the apparatus complexity, are needed to remove inhibitors such as alkynes from the feedstock mixture. These processes have the disadvantage that a portion of the 1,3-butadiene, especially when it is attempted to get the alkyne content in the feedstock mixture below the detection limit, is lost in the removal of the inhibitors. When 1,3-butadiene losses are avoided by dispensing with a substantially full removal of the inhibitors, a lower space-time yield or selectivity in the telomerization or a higher catalyst consumption has to be accepted.

It is therefore an object of the present invention to provide an alternative telomerization

process which preferably avoids some or all of the disadvantages of the prior art mentioned.

It has now been found that, surprisingly, addition of hydrogen via a hydrogen source into the process step of catalyst recycling can prevent inhibition of the telomerization catalyst, or can
5 reactivate it in the case of inhibition of the catalyst.

The invention accordingly provides a process for telomerizing noncyclic olefins having at least two conjugated double bonds (VI), which are preferably present in a mixture which comprises acetylenically unsaturated compounds, with at least one nucleophile (VII) using a
10 catalyst containing a metal of group 8 to 10 of the Periodic Table of the Elements, wherein at least one catalyst recycling step, in which hydrogen is added via a hydrogen source to the process mixture present in this step, is present in the overall telomerization process.

The present invention likewise provides a mixture comprising 2,7-octadienyl derivatives,
15 prepared by the process according to the invention, and to the use of this mixture for preparing 1-octene.

The process according to the invention has the advantage that a very costly and inconvenient removal of all inhibitors, in particular all alkynes, from the feedstock mixture can be
20 dispensed with. In addition to the reduced apparatus complexity, the process also has the advantage that it is also possible to avoid the use of expensive hydrogenation catalyst.

The process according to the invention also has the advantage that the allenes and cumulenes, i.e. compounds having cumulated double bonds, such as 1,2-butadiene, which constitute an
25 important starting material for organic synthesis, are substantially not destroyed, but rather remain present in the hydrocarbon stream and can be removed after the second process step, that of the telomerization, in the workup of the telomerization product.

The process according to the invention will be described by way of example below, without
30 any intention that the invention, whose scope of protection is evident from the claims and the description, be restricted thereto. The claims themselves also belong to the disclosure content

of the present invention. When ranges, general formulae or compound classes are specified below, these are intended not only to incorporate the corresponding ranges or groups of compounds which are mentioned explicitly, but rather all subranges and subgroups of compounds which can be obtained by omitting individual values (ranges) or compounds.

5

The process according to the invention for telomerizing noncyclic olefins having at least two conjugated double bonds (VI), which are preferably present in a mixture which comprises acetylenically unsaturated compounds, with at least one nucleophile (VII) using a catalyst comprising a metal of group 8, 9 or 10 of the Periodic Table of the Elements has the feature
10 that the process has a catalyst recycling step in which at least a portion of the catalyst present in the reaction mixture is recycled into the telomerization, and that, in the catalyst recycling step, hydrogen is added via a hydrogen source to the process mixture present in the catalyst recycling. The process according to the invention is suitable in particular for telomerizing noncyclic olefins which are present in a feed mixture which comprises acetylenically
15 unsaturated compounds.

The telomerization process according to the invention has at least two steps, firstly the telomerization reaction itself and secondly the catalyst recycling step. Between the two steps, the catalyst is removed at least partly from the reaction mixture. This removal can be effected,
20 for example, by known processes, for example extraction, distillation or membrane separation processes, or by means of a falling-film evaporator. The removal removes preferably at least 95%, more preferably at least 99% and most preferably at least 99.9%, of the catalyst present in the reaction mixture from the reaction mixture, and it is fed to the catalyst recycling. In addition to the catalyst system, any solvents present, telomers of solvents, any excess
25 imidazolium salt and base and unremoved product may also be present in the recycled mixture.

In the catalyst recycling step, preference is given to adding via the hydrogen source sufficient hydrogen that the molar ratio of hydrogen to acetylenically unsaturated compounds (alkynes)
30 in the starting mixture is at least 1:1, preferably from 1:1 to 2:1, more preferably from 1:1 to 1.5:1 and most preferably from 1:1 to 1.1:1. A distinct exceedance of these values leads to

increasing loss of the noncyclic olefins having conjugated double bonds, for example of 1,3-butadiene. The concentration of the alkynes in the feedstock mixture may be determined continuously or at regular intervals, for example by gas chromatography.

- 5 In situations in which the starting mixture does not contain any acetylenically unsaturated compounds or contains the acetylenically unsaturated compounds in an unmeasurable concentration, but the activity of the catalyst has declined distinctly in comparison to the starting activity, for example by at least 50%, preferably at least 75%, it may likewise be advantageous to feed hydrogen via a hydrogen source into the catalyst recycling step. In this
- 10 case, the molar ratio of hydrogen (H_2) supplied via the hydrogen source to catalyst metal is at least 1:2, preferably from 1:1 to 2:1, more preferably from 1:1 to 1.5:1 and most preferably from 1:1 to 1.1:1. In this case, the hydrogen source is preferably not fed in continuously, but rather only when the catalyst activity has fallen below the limit mentioned.
- 15 The addition of the hydrogen source to the catalyst recycling has the advantage that the product and also the reactant have been removed very substantially from the catalyst in one preliminary step, and thus the hydrogen added via the hydrogen source does not hydrogenate valuable reactant or product to undesired by-products and the yield is thus not reduced. It may be advantageous when a hydrogen source is added both to the catalyst recycling step and to
- 20 the reaction step. When the hydrogen source is also added to the reaction step, which is especially advantageous when the feedstock mixture comprises alkynes, the hydrogen source preferably feeds sufficient hydrogen to the reaction step that the molar ratio of hydrogen to alkyne is at least 0.5:1, preferably from 0.5:1 to 1.5:1, more preferably from 0.75:1 to 1:1 and most preferably from 0.9:1 to 1:1. A distinct exceedance of these values leads to an increasing
- 25 loss of the noncyclic olefins having conjugated double bonds, for example of 1,3-butadiene. Especially when a hydrogen source is added in both reaction steps, the molar ratio of the sum of the additions of the hydrogen sources to the alkynes present in the feedstock mixture is preferably not greater than 2:1, preferentially not greater than 1.5:1 and more preferably not greater than 1.1:1.

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The hydrogen source used may be a hydrogen-containing gas, in particular hydrogen gas alone

or in a mixture with gases inert to the telomerization, for example nitrogen, methane or noble gas(es), or at least one compound which is capable of releasing hydrogen, for example a compound selected from hydrazine, formic acid, formates or alcohols. The hydrogen source used is more preferably a hydrogen-containing gas or an alcohol, for example isobutanol, isopropanol or methanol. The hydrogen sources added are preferably those compounds which have already been used as the nucleophile in the telomerization step. Particular preference is given to the addition of a hydrogen-containing gas as hydrogen sources. In this way, contamination of the reaction products with extraneous substances, which would not be involved in the reaction without addition of a hydrogen source, can be prevented.

Preference is given to adding the hydrogen source as early as the start of the catalyst recycling. The hydrogen source is preferably fed into the catalyst recycling via an apparatus which is suitable for distributing the hydrogen source in a very fine manner. The hydrogen or the hydrogen source is preferably distributed very homogeneously in the mixture for catalyst recycling. When the hydrogen source is a gas, the apparatus may, for example, be a mixer nozzle. For particularly good homogenization of the gas in the mixture, it may be advantageous when the pressure in the catalyst recycling is at least 2 MPa, preferably at least 4 MPa. When the hydrogen source is present in liquid form, very fine distribution can be achieved, for example, by static mixers.

The feedstocks used may be the pure noncyclic olefins having conjugated double bonds, mixtures of different such olefins or mixtures of one or more of the olefins mentioned with other hydrocarbons. The feedstock used is preferably a mixture of hydrocarbons which comprises one or more noncyclic olefins, preferably one noncyclic olefin, having at least two conjugated double bonds in a mixture with other hydrocarbons.

Particularly preferred feedstocks comprise, as noncyclic olefins having conjugated double bonds, 1,3-butadiene and/or isoprene, in each case as a pure substance, mixture of the pure substances or in a mixture of one or both olefins with other hydrocarbons. The feedstocks used are most preferably mixtures which contain over 90% by mass of C₄ hydrocarbons and preferably 1,3-butadiene.

Suitable feedstocks for the process according to the invention are more preferably 1,3-butadiene-rich hydrocarbon streams. The hydrocarbon stream used may in particular be a C₄ hydrocarbon cut. The hydrocarbon streams may preferably, for example, be mixtures of 1,3-butadiene with other C₄ and C₃ or C₅ hydrocarbons. Such mixtures are obtained, for example, in cracking processes for producing ethylene and propylene, in which refinery gases, naphtha, gas oil, LPG (liquefied petroleum gas), NGL (natural gas liquid), etc. The C₄ cuts obtained as a by-product in the processes may, in addition to 1,3-butadiene, comprise monoolefins (1-butene, cis-but-2-ene, trans-but-2-ene, isobutene), saturated hydrocarbons (n-butane, isobutane), acetylenically unsaturated compounds (ethylacetylene (butyne), vinylacetylene (butenyne), methylacetylene (propyne) and allenically unsaturated compounds (mainly 1,2-butadiene)). In addition, these cuts may comprise small amounts of C₃ and C₅ hydrocarbons. The composition of the C₄ cuts is dependent upon the particular cracking process, the operating parameters and the feedstock. The concentrations of the individual components lie, for steamcrackers for example, typically within the following ranges:

Component	% by mass
1,3- butadiene	25 - 70
1-butene	9 – 25
2-butenes	4 – 20
isobutene	10 – 35
n-butane	0.5 – 8
isobutane	0.5 – 6
Σ acetylenic compounds	0.05 – 4
1,2-butadiene	0.05 - 2

In the process according to the invention, preference is given to using hydrocarbon mixtures having a 1,3-butadiene content of greater than 35% by mass.

The starting hydrocarbons may frequently comprise traces of oxygen compounds, nitrogen compounds, sulfur compounds, halogen compounds, in particular chlorine compounds and

heavy metal compounds, which might be disruptive in the process according to the invention. It is therefore appropriate first to remove these substances. Troublesome compounds may, for example, be carbon dioxide or carbonyl compounds, for example acetone or acetaldehyde.

- 5 These impurities can be removed, for example, by scrubbing, in particular with water or aqueous solutions, or by means of adsorbers.

Water scrubbing can partly or fully remove hydrophilic components, for example nitrogen components, from the hydrocarbon mixture. Examples of nitrogen components are acetonitrile
10 or N-methylpyrrolidone (NMP). Oxygen compounds too can also partly be removed by means of a water scrubbing. The water scrubbing can be carried out directly with water or else with aqueous solutions which may comprise, for example, salts, for example NaHSO_3 (US 3,682,779, US 3,308,201, US 4,125,568, US 3,336,414 or US 5,122,236).

- 15 It may be advantageous when the hydrocarbon mixture, after the water scrubbing, passes through a drying step. The drying may be carried out by processes known in the prior art. In the presence of dissolved water, the drying may be carried out, for example, using a molecular sieve as desiccant or by azeotropic distillation. Free water may be removed by phase separation, for example with a coalescer.

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Adsorbers may be used to remove impurities in the trace region. This may be advantageous especially because noble metal catalysts are used in the telomerization step and react even to traces of impurities with a distinct decline in activity. Often, nitrogen or sulfur compounds are removed by means of upstream adsorbers. Examples of usable adsorbents are aluminas,
25 molecular sieves, zeolites, activated carbon or metal-impregnated clay earths (for example US 4,571,445 or WO 02/53685). Adsorbents are sold by various companies, for example Alcoa under the name Selexsorb[®], by UOP or by Axens, for example in the product series SAS, MS, AA, TG, TGS or CMG.

- 30 Using the process according to the invention, it is possible in particular to use feedstock mixtures which also contain compounds including allenically unsaturated compounds and/or

have a content of greater than or equal to 50% by mass (wppm), preferably greater than or equal to 100 ppm by mass, of acetylenically unsaturated compounds. In the process according to the invention, the feedstocks used may preferably be mixtures which comprise noncyclic olefins having conjugated double bonds and contain up to 5% by mass, preferably up to 3% by mass and more preferably up to 1% by mass, of alkynes or acetylenically unsaturated compounds. As a result of the usability of feedstock mixtures which still comprise small residual amounts of acetylenically unsaturated compounds, it is possible to use numerous hydrocarbon mixtures obtained in industry, especially C₄ or C₅ hydrocarbon mixtures, directly as feedstocks in the process according to the invention for telomerization. Should a distinctly higher content of acetylenically unsaturated compounds be present in a possible feedstock mixture, it may be advantageous to remove at least a portion of the acetylenically unsaturated compounds (alkynes) present from this mixture before use in the telomerization, for example by selective hydrogenation or extraction, so that the feedstock mixture used can then be a mixture which contains from 0 to 5% by mass, preferably from 50 wppm to 3% by mass and more preferably from 100 wppm to 1% by mass, of acetylenically unsaturated compounds. Processes for extraction or selective hydrogenation can be taken from the prior art.

The removal of the acetylenic compounds by extraction has been known for some time and is, as a workup step, an integral part of most plants which obtain 1,3-butadiene from crack C₄. A process for extractively removing acetylenically unsaturated compounds from crack C₄ is described, for example, in *Erdöl und Kohle-Erdgas-Petrochemie vereinigt mit Brennstoffchemie Vol. 34, No. 8, August 1981, page 343–346*. In this process, the polyunsaturated hydrocarbons and the acetylenically unsaturated compounds are removed in a first stage by extractive distillation with aqueous NMP from the monoolefins and saturated hydrocarbons. From the NMP extract, the unsaturated hydrocarbons are removed distillatively. From the hydrocarbon distillate, a second extractive distillation using aqueous NMP removes the acetylenically unsaturated compounds having four carbon atoms. In the workup of crack C₄, two further distillations remove pure 1,3-butadiene, and the by-products obtained are methylacetylene and 1,2-butadiene. In the context of the process according to the invention, the multistage process described here may be carried out as a pretreatment for the

feedstock mixture, in which case the distillative removal of the 1,2-butadiene can be dispensed with.

Optionally, acetylenic compounds can be removed from a 1,3-butadiene-containing stream using one or more ionic liquid(s), for example as an extractant.

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The hydrocarbon streams which are obtained by extraction and contain preferably less than 5% by mass of acetylenic compounds may more preferably be used directly as a feedstock in the process according to the invention.

10 The partial removal of the acetylenically unsaturated compounds from the hydrocarbon stream to be used by selective hydrogenation of the acetylenically unsaturated compounds in the presence of dienes and monoolefins can be carried out, for example, over copper or palladium catalysts, or over mixed catalysts.

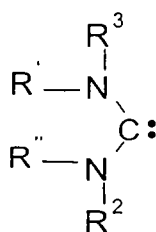
15 If acetylenically unsaturated compounds are present, the feedstocks used in the process according to the invention, especially when C₄ hydrocarbon mixtures comprising 1,3-butadiene are used, comprise acetylenically unsaturated compounds (alkynes) which are preferably selected from vinylacetylene and/or 1-butyne.

20 In the process according to the invention, all catalysts suitable for the telomerization may be used. Preferred catalysts for the telomerization are metal complexes, in particular metal-carbene complexes, of the metals palladium (Pd), iron (Fe), ruthenium (Ru), osmium (Os), cobalt (Co), rhodium (Rh), iridium (Ir), nickel (Ni) or platinum (Pt). The ligands used may, for example, be phosphorus ligands, for example phosphines, phosphinines, phosphinites,
25 phosphonites or phosphites, for example triphenylphosphines or carbene ligands, and it may also be advantageous to use different ligands at the same time.

Preference is given to using palladium compounds, in particular palladium-carbene complexes, as catalysts in the telomerization step. The ligands in the metal complexes used as
30 the catalyst are more preferably trivalent phosphorus compounds or carbenes.

Particular preference is given to using metal complexes as the catalyst which have at least one carbene ligand stabilized by heteroatoms. Examples of such ligands are described, inter alia, in the documents DE 101 28 144, DE 101 49 348, DE 101 48 722, DE 100 62 577, EP 1 308 157 and WO 01/66248. These documents and in particular the ligands described there are included in the disclosure content of the present application. In addition, the active complex may comprise further ligands. The carbene ligands may be open ligands or cyclic ligands.

- 10 The telomerization catalyst used in the process according to the invention is preferably a palladium-carbene complex which has a carbene ligand of the general formula (VIII)



VIII

where R^2 , R'' , R' and R^3 may be the same or different and may each be hydrogen or hydrocarbon groups, where the hydrocarbon groups may be identical or different, linear, branched or cyclic radicals selected from the group of alkyl radicals having from 1 to 50 carbon atoms, alkenyl radicals having from 2 to 50 carbon atoms, alkynyl radicals having from 2 to 50 carbon atoms and aryl radicals having from 6 to 30 carbon atoms, in which at least one hydrogen atom may be replaced by a functional group,

and/or R^2 and R'' and/or R' and R^3 are each part of a cyclic system which is the same or different and has a carbon skeleton having from 2 to 20 carbon atoms and a nitrogen atom according to formula VIII, where the carbon atoms of R^2 and R'' and/or R' and R^3 are not counted and where at least one hydrogen atom in the cyclic system may be replaced by a functional group and/or at least one carbon atom of the cyclic system may be replaced by a

heteroatom selected from the group consisting of S, P, O and N,

and/or R^2 and/or R'' and/or R' and/or R^3 are joined by a bridge composed of from 1 to 20

carbon atoms to a ligand L, where the carbon atoms of the R^2 , R'' , R' and R^3 radicals are not counted,

and L is a further ligand which is an uncharged two-electron donor, part of a cyclic system and/or an anionic ligand, where the functional groups may, for example, be selected from the groups: -CN, -COOH, -COO-alkyl-, -COO-aryl-, -OCO-alkyl-, -OCO-aryl-, -OCOO-alkyl-, -OCOO-aryl-, -CHO, -CO-alkyl-, -CO-aryl-, -O-alkyl-, -O-aryl-, -NH₂, -NH(alkyl)-, -N(alkyl)₂-, -NH(aryl)-, -N(alkyl)₂-, -F, -Cl, -Br, -I, -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H and -PO₃H₂, where the alkyl groups may contain, for example, from 1 to 24 carbon atoms, and the aryl groups, for example, from 5 to 24 carbon atoms. The preparation of such ligands can be taken, for example, from DE 101 48 722.

In the process according to the invention, the telomerization catalyst used is preferably a palladium-carbene complex which has a carbene ligand of the general formula (VIII) where

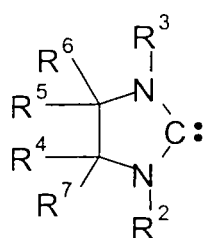
R^2 ; R^3 : are the same or different and are each linear, branched, substituted or unsubstituted, cyclic or alicyclic alkyl groups having from 1 to 24 carbon atoms, or substituted or unsubstituted, mono- or polycyclic aryl groups having from 6 to 24 carbon atoms or

mono- or polycyclic, substituted or unsubstituted heterocycle having from 4 to 24 carbon atoms and at least one heteroatom from the group of N, O, S,

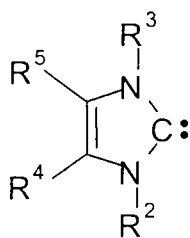
R' , R'' : are the same or different and are each hydrogen, alkyl, aryl, heteroaryl, -CN, -COOH, -COO-alkyl-, -COO-aryl-, -OCO-alkyl-, -OCO-aryl-, -OCOO-alkyl-, -OCOO-aryl-, -CHO, -CO-alkyl-, -CO-aryl-, -O-alkyl-, -O-aryl-, -NH₂, -NH(alkyl)-, -N(alkyl)₂-, -NH(aryl)-, -N(alkyl)₂-, -F, -Cl, -Br, -I, -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H, -PO₃H₂, where the alkyl groups contain 1-24 carbon atoms and the aryl and heteroaryl groups from 5 to 24 carbon atoms, and the R' and R'' radicals may also be part of a bridging aliphatic or aromatic ring.

Very particular preference is given to using carbene ligands which have a 5-membered ring.

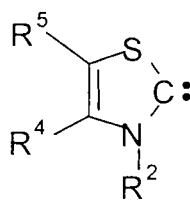
Ligands which have a 5-membered ring and are used with preference in the process according to the invention are, for example, those of the formulae IX, X, XI and XII



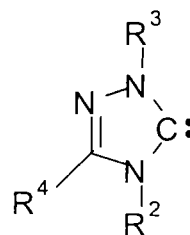
IX



X



XI



XII

where R^2 , R^3 : are the same or different and are each

linear, branched, substituted or unsubstituted, cyclic or alicyclic alkyl groups having from 1 to 24 carbon atoms, or

substituted or unsubstituted, mono- or polycyclic aryl groups having from 6 to 24 carbon atoms or

mono- or polycyclic, substituted or unsubstituted heterocycle having from 4 to 24 carbon atoms and at least one heteroatom from the group of N, O, S,

R^4 , R^5 , R^6 , R^7 : are the same or different and are each

hydrogen, alkyl, aryl, heteroaryl, -CN, -COOH, -COO-alkyl-, -COO-aryl-, -OCO-alkyl-, -OCO-aryl-, -OCOO-alkyl-, -OCOO-aryl-, -CHO, -CO-alkyl-, -CO-aryl-, -O-alkyl-, -O-aryl-, -NH₂, -NH(alkyl)-, -N(alkyl)₂-, -NH(aryl)-, -N(alkyl)₂-, -F, -Cl, -Br, -I, -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H, -PO₃H₂, where the alkyl groups contain 1-24 carbon atoms and the aryl and heteroaryl groups from 5 to 24 carbon atoms, and the R^4 , R^5 , R^6 and R^7 radicals may also be part of a bridging aliphatic or aromatic ring.

Examples of carbene ligands which correspond to the general formulae IX or X and complexes which contain such ligands have already been described in the technical literature (W. A. Herrmann, C. Köcher, *Angew. Chem.* 1997, 109, 2257; *Angew. Chem. Int. Ed. Engl.* 1997, 36, 2162; V.P.W. Böhm, C.W.K. Gstöttmayr, T. Weskamp, W.A. Herrmann, *J. Organomet. Chem.* 2000, 595, 186; DE 44 47 066).

The R^2 and R^3 radicals may in particular be a mono- or polycyclic ring which contains at least one heteroatom selected from the elements nitrogen, oxygen and sulfur, and optionally has further substituents selected from the group of -CN, -COOH, -COO-alkyl-, -COO-aryl-, -OCO-alkyl-, -OCO-aryl-, -OCOO-alkyl-, -OCOO-aryl-, -CHO, -CO-alkyl-, -CO-aryl-, -aryl-,
 5 -alkyl-, -O-alkyl-, -O-aryl-, -NH₂, -NH(alkyl)-, -N(alkyl)₂-, -NH(aryl)-, -N(alkyl)₂-, -F, -Cl, -Br, -I, -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H, -PO₃H₂. The alkyl groups have from 1 to 24 carbon atoms and the aryl groups from 5 to 24 carbon atoms. In the case that Pd is used as the metal of group 8 to 10 of the Periodic Table, one or both R^2 and R^3 ligands preferably has/have these definitions.

10

The R^2 , R^3 , R^4 , R^5 , R^6 and/or R^7 radicals may each be the same or different and have at least one substituent from the group of -H, -CN, -COOH, -COO-alkyl, -COO-aryl, -OCO-alkyl, -OCO-aryl, -OCOO-alkyl, -OCOO-aryl, -CHO, -CO-alkyl, -CO-aryl, -aryl, -alkyl, -alkenyl, -allyl, -O-alkyl, -O-aryl, -NH₂, -NH(alkyl), -N(alkyl)₂, -NH(aryl), -N(alkyl)₂, -F, -Cl, -Br, -I,
 15 -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H, -PO₃H₂, where the alkyl groups contain from 1 to 24, preferably from 1 to 20, carbon atoms, the alkenyl groups from 2 to 24 carbon atoms, the allyl groups from 3 to 24 carbon atoms and the mono- or polycyclic aryl groups from 5 to 24 carbon atoms. The R_4 to R_6 radicals may, for example, be joined covalently to one another via (CH₂) or (CH) groups.

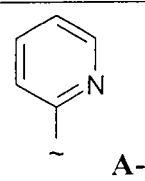
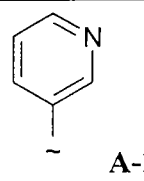
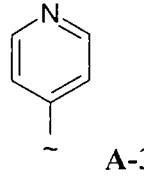
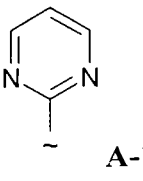
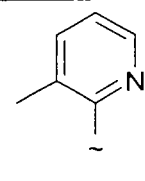
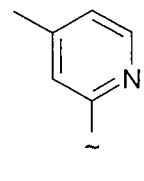
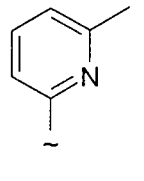
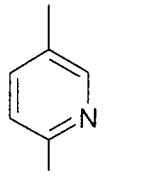
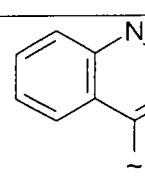
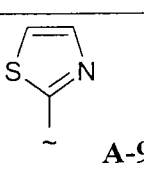
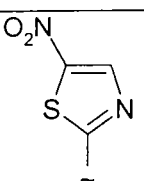
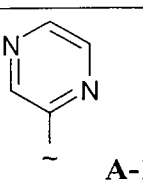
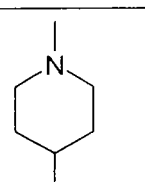
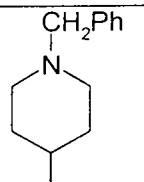
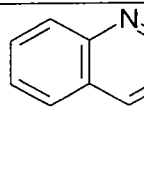
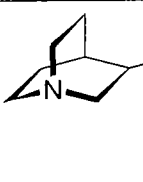
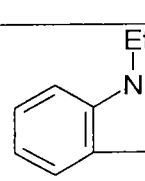
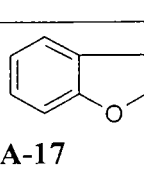
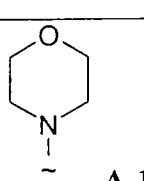
20

In the case of substituents having acidic hydrogen atoms, the protons may be replaced by metal or ammonium ions.

The R^2 and R^3 radicals may more preferably be radicals which derive from five- and six-
 25 membered heteroalkanes, heteroalkenes and heteroaromatics, such as 1,4-dioxane, morpholine, γ -pyran, pyridine, pyrimidine, pyrazine, pyrrole, furan, thiophene, pyrazole, imidazole, thiazole and oxazole. The table 1 which follows reproduces specific examples of such R^2 and R^3 radicals. In this table, ~ indicates in each case the point of attachment to the five-membered heterocyclic ring or to the compound of the formula VIII.

30

Table 1: Examples of possible R² or R³ radicals

 A-1	 A-2	 A-3	 A-19
 A-4	 A-5	 A-6	 A-7
 A-8	 A-9	 A-10	 A-11
 A-12	 A-13	 A-14	 A-15
 A-16	 A-17	 A-18	

In the context of this invention, carbene ligands are understood to mean both free carbenes which can function as a ligand and carbenes coordinated to metal.

5

The catalyst metal, in particular the palladium used as the catalyst metal, from which the active catalyst is formed under reaction conditions can be introduced into the process in different ways.

10 The metal (palladium) can be introduced into the process

a) as a metal-carbene complex (palladium-carbene complex), in which case the metal

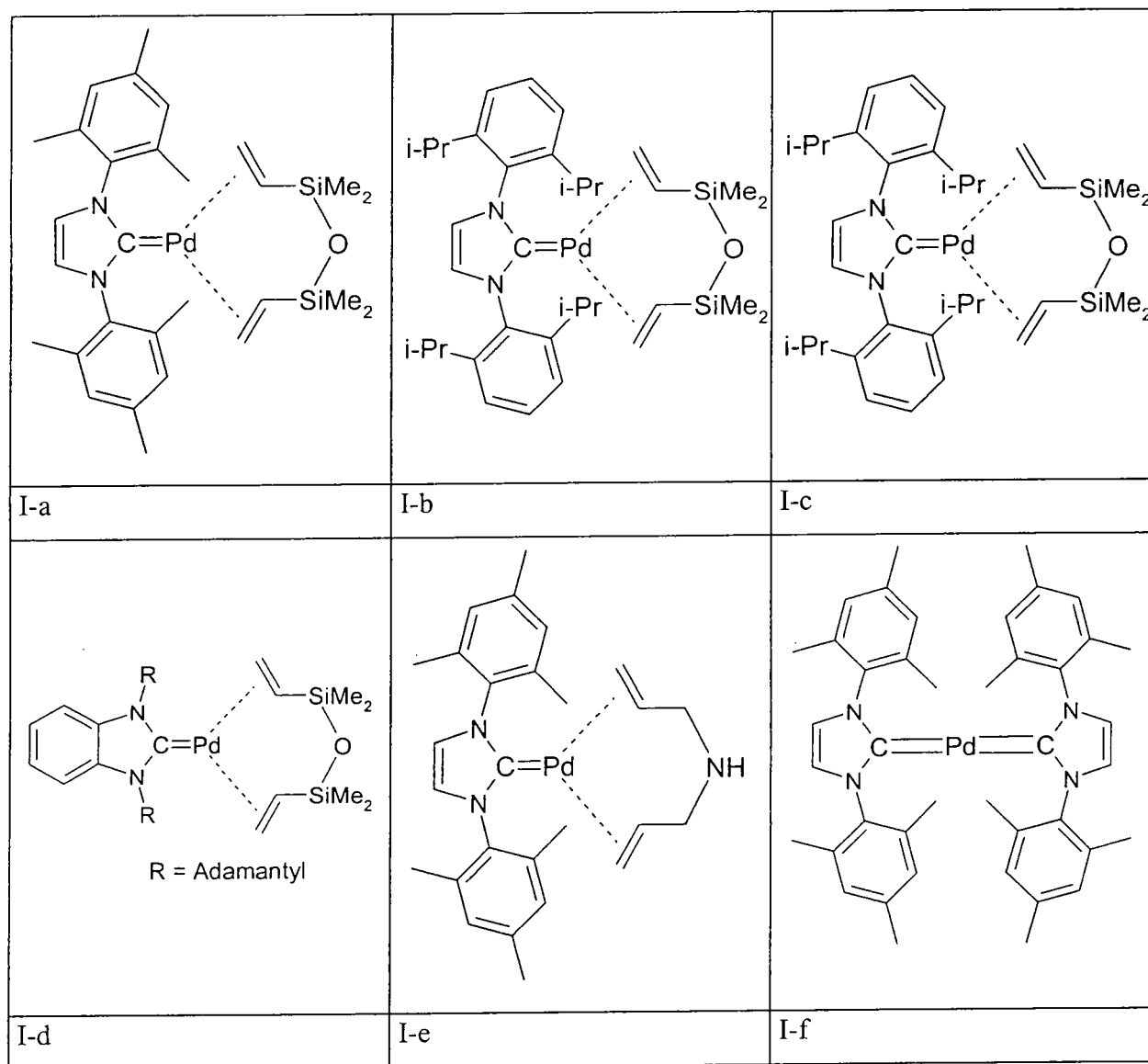
(palladium) is preferably in the (II) or (0) oxidation states, or

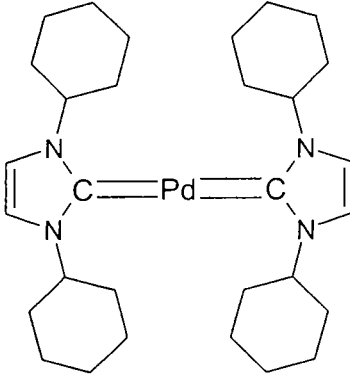
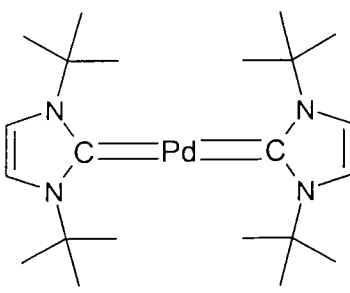
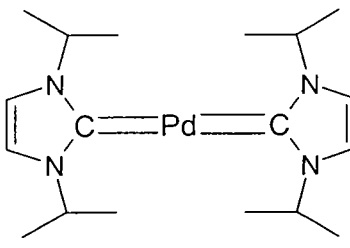
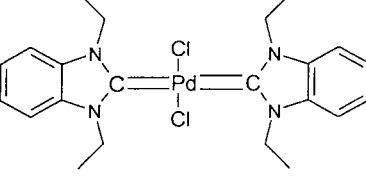
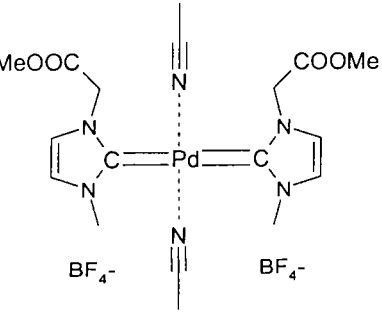
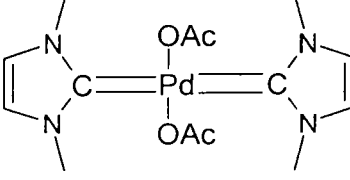
b) in the form of metal precursors (palladium precursors) from which the catalysts are formed in situ.

5 a)

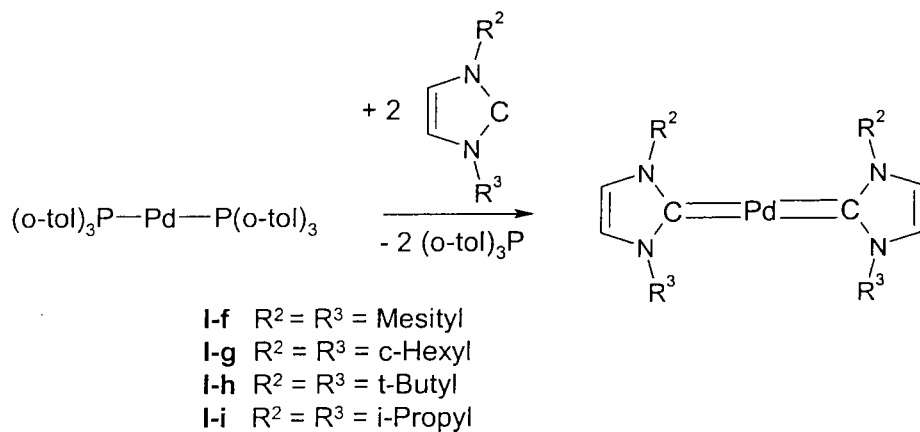
Examples are palladium(0)-carbene-olefin complexes, palladium(0)-dicarbene complexes and palladium(II)-dicarbene complexes, palladium(0)-carbene-1,6-diene complexes. The 1,6-diene may, for example, be diallylamine, 1,1'-divinyldimethylsiloxane, 2,7-octadienyl ethers or 2,7-octadienyl amines. Further examples are shown by the following formulae I-a to I-e.

10



		
I-g	I-h	I-i
		
I-j	I-k	I-l

The carbene complexes of palladium can be prepared in a wide variety of ways. A simple route is, for example, the addition of carbene ligands or the exchange of ligands on palladium complexes for carbene ligands. For example, the complexes I-f to I-i are obtainable by
 5 exchange of the phosphorus ligands of the bis(tri-*o*-tolylphosphine)palladium(0) complex (T. Weskamp, W.A. Herrmann, *J. Organomet. Chem.* 2000, 595, 186).

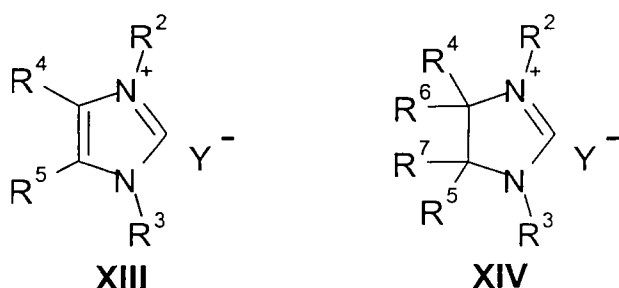


b)

The palladium precursors used may, for example, be: palladium(II) acetate, palladium(II) chloride, palladium(II) bromide, lithium tetrachloropalladate, palladium(II) acetylacetonate, palladium(0)-dibenzylideneacetone complexes, palladium(II) propionate, bisacetonitrile-
 5 palladium(II) chloride, bistriphenylphosphinepalladium(II) dichloride, bisbenzonitrile-palladium(II) chloride, bis(tri-*o*-tolylphosphine)palladium(0) and further palladium(0) and palladium(II) complexes.

The carbenes of the general formulae IX and X may be used in the form of free carbenes or as
 10 metal complexes, or are obtained in situ from carbene precursors.

Suitable carbene precursors are, for example, salts of the carbenes of the general formulae XIII and XIV,



where R^2 , R^3 , R^4 , R^5 , R^6 , R^7 are each as defined in formulae IX and X, and Y is a singly charged anionic group or, in accordance with the stoichiometry, a fraction of a multiply charged anionic group.

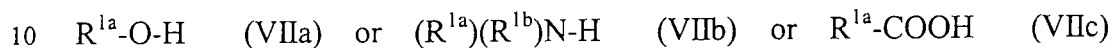
Examples of Y are halides, hydrogensulfate, sulfate, alkylsulfates, arylsulfates, borates, hydrogencarbonate, carbonate, alkylcarboxylates, arylcarboxylates.

The corresponding carbenes can be released from the salts of the carbenes, for example, by
 25 reacting with a base.

The concentration of the catalyst, reported formally in ppm (by mass) of palladium metal

based on the total mass, in the process according to the invention is preferably from 0.01 ppm to 1000 ppm, preferably from 0.5 to 100 ppm, more preferably from 1 to 50 ppm. The ratio [mol/mol] of ligand, preferably carbene, to metal, preferably of carbene to Pd, in the reaction mixture is preferably from 0.01:1 to 250:1, preferably from 1:1 to 100:1, more preferably from 1:1 to 50:1. In addition to the carbene ligands, further ligands, for example phosphorus ligands, e.g. triphenylphosphine, may be present in the reaction mixture.

The nucleophiles (VII) used are preferably compounds of the general formulae



in which R^{1a} and R^{1b} are each independently selected from hydrogen, a linear, branched or cyclic C_1 to C_{22} -alkyl group, -alkenyl group or -alkynyl group, a C_5 to C_{18} -aryl group or a -CO-alkyl- (C_1-C_8) group or a -CO-aryl- (C_5-C_{10}) group, where these groups may contain
 15 substituents selected from the group of -CN, -COOH, -COO-alkyl- (C_1-C_8) , -CO-alkyl- (C_1-C_8) , -aryl- (C_5-C_{10}) , -COO-aryl- (C_6-C_{10}) , -CO-aryl- (C_6-C_{10}) , -O-alkyl- (C_1-C_8) , -O-CO-alkyl- (C_1-C_8) , -N-alkyl₂- (C_1-C_8) , -CHO, -SO₃H, -NH₂, -F, -Cl, -OH, -CF₃ and -NO₂, and where the R^{1a} and R^{1b} radicals may be joined together via covalent bonds. The nucleophiles used are preferably compounds in which the R^{1a} and optionally R^{1b} radicals are each hydrogen, methyl,
 20 ethyl, n-propyl, isopropyl, tert-butyl, n-butyl, sec-butyl, pentyl, hexyl, heptyl, octyl, octenyl, octadienyl, isononyl, 2-ethylhexyl, n-nonyl, phenyl, m-, o- or p-methylphenyl, naphthyl, 2,4-di-tert-butylphenyl, 2,6-di-tert-butylmethylphenyl, hydrogencarbonyl, methylcarbonyl, ethylcarbonyl, propylcarbonyl or phenylcarbonyl.

25 The nucleophiles (VII) used are more preferably water, alcohols, phenols, polyols, carboxylic acids, ammonia and/or primary or secondary amines. These are especially:

- water, ammonia,
- monoalcohols and phenols, for example methanol, ethanol, n-propanol, isopropanol, allyl alcohol, n-butanol, i-butanol, octanol, 2-ethylhexanol, isononanol, benzyl alcohol,
 30 cyclohexanol, cyclopentanol or 2,7-octadien-1-ol, phenol,
- dialcohols, for example ethylene glycol, 1,2-propanediol, 1,3-propanediol,

- 1,4-butanediol, 1,2-butanediol, 2,3-butanediol and 1,3-butanediol,
- hydroxyl compounds, for example α -hydroxyacetic esters,
 - primary amines, for example methylamine, ethylamine, propylamine, butylamine, octylamine, 2,7-octadienylamine, dodecylamine, ethylenediamine or hexamethylene-
5 diamine,
 - secondary amines such as dimethylamine, diethylamine, N-methylaniline, bis(2,7-octadienyl)amine, dicyclohexylamine, methylcyclohexylamine, pyrrolidine, piperidine, morpholine, piperazine or hexamethyleneimine or
 - carboxylic acids such as formic acid, acetic acid, propanoic acid, butenoic acid,
10 isobutenoic acid, benzoic acid, 1,2-benzenedicarboxylic acid (phthalic acid).

The nucleophiles (VII) used in the telomerization step are most preferably methanol, ethanol, 2-ethylhexanol, octanol, octenol, octadienol, isopropanol, n-propanol, isobutanol, n-butanol, isononanol, formic acid, acetic acid, propionic acid, n-butanoic acid, isobutanoic acid, benzoic
15 acid, phthalic acid, phenol, dimethylamine, methylamine, ammonia and/or water. Advantageously, the nucleophile used is methanol.

Nucleophiles which can themselves be obtained via a telomerization reaction can be used directly or else formed in situ. For example, 2,7-octadien-1-ol can be formed in situ from
20 water and butadiene in the presence of the telomerization catalyst, 2,7-octadienylamine from ammonia and 1,3-butadiene, etc.

For the ratio of nucleophile to the starting olefin having at least two conjugated double bonds in the telomerization reaction, the number of active hydrogen atoms in the telogen has to be
25 taken into account. For example, methanol has one active hydrogen atom, ethylene glycol has two, methylamine has two, etc.

Per mole of active hydrogen atom of the nucleophile which can react with the starting olefin, preference is given to using from 0.001 mol to 10 mol of starting olefin in the telomerization
30 reaction. In a reaction with a liquid phase, particular preference is given to a ratio of from 0.1 mol to 2 mol of starting olefin per mole of active hydrogen.

It may be advantageous when the process according to the invention is carried out in the presence of a solvent. The solvents used for the telomerization reaction may be the nucleophile used when it is present in liquid form under reaction conditions, and/or inert organic solvents. Preference is given to the addition of solvents when nucleophiles are used which are present in the form of solids under reaction conditions, or in the case of products that would be obtained in the form of solids under the reaction conditions. Suitable solvents include aliphatic, cycloaliphatic and aromatic hydrocarbons, for example C₃–C₂₀-alkanes, mixtures of lower alkanes (C₃–C₂₀), cyclohexane, cyclooctane, ethylcyclohexane, alkenes and polyenes, vinylcyclohexene, 1,3,7-octatriene, the C₄ hydrocarbons from crack C₄ cuts, benzene, toluene and xylene; polar solvents, for example tertiary and secondary alcohols, amides, for example acetamide, dimethylacetamide and dimethylformamide, nitriles, for example acetonitrile and benzonitrile, ketones, for example acetone, methyl isobutyl ketone and diethyl ketone, carboxylic esters, for example ethyl acetate, ethers, for example dipropyl ether, diethyl ether, dimethyl ether, methyl octyl ether, methyl tert-butyl ether, ethyl tert-butyl ether, 3-methoxyoctane, dioxane, tetrahydrofuran, anisole, alkyl and aryl ethers of ethylene glycol, diethylene glycol, triethylene glycol, tetraethylene glycol, polyethylene glycol, propylene glycol, dipropylene glycol, tripropylene glycol and polypropylene glycol, and other polar solvents, for example sulfolane, dimethyl sulfoxide, ethylene carbonate, propylene carbonate and water. It is also possible to use ionic liquids, for example imidazolium or pyridinium salts, as solvents. The solvents may be used alone or as mixtures of different solvents.

The temperature at which the telomerization reaction is performed is preferably in the range from 10 to 180°C, preferably in the range from 30 to 120°C and more preferably in the range from 40 to 100°C. The reaction pressure is preferably from 1 to 300 bar, preferably from 1 to 120 bar, more preferably from 1 to 64 bar and most preferably from 1 to 20 bar.

It is often advantageous to carry out the telomerization reaction in the presence of bases. Preference is given to using basic components having a pK_b of less than 7, in particular compounds selected from the group of the amines, alkoxides, phenoxides, alkali metal salts

or alkaline earth metal salts.

Suitable basic components are, for example, amines such as trialkylamines which may be alicyclic or/and open-chain, amides, alkali metal or/and alkaline earth metal salts of aliphatic
 5 or/and aromatic carboxylic acids, such as acetates, propionates, benzoates or corresponding carbonates, hydrogencarbonates, alkoxides of alkali elements and/or alkaline earth elements, phosphates, hydrogenphosphates or/and hydroxides, preferably of lithium, sodium, potassium, calcium, magnesium, cesium, ammonium and phosphonium compounds. Preference is given as an additive to hydroxides of alkali metal and alkaline earth metal elements and to metal
 10 salts of the nucleophile according to the general formulae III, IV or V.

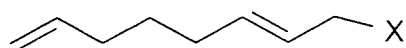
Preference is given to using from 0.01 mol% to 10 mol% of the basic components (based on the starting olefin), preferably from 0.1 mol% to 5 mol% and most preferably from 0.2 mol% to 1 mol%.

15

The telomerization may be operated continuously or batchwise and is not restricted to the use of particular reactor types. Examples of reactors in which the reaction can be carried out are stirred tank reactor, stirred tank batteries, flow tubes and loop reactors. Combinations of different reactors are also possible, for example a stirred tank reactor with downstream flow
 20 tube.

In order to obtain a high space-time yield, the telomerization may preferably not be carried out up to the full conversion of the starting olefin. This is the case especially when the starting olefin is 1,3-butadiene. In this case, preference is given to restricting the conversion to not
 25 more than 95%, more preferably to 88%.

The process according to the invention may be used in particular for preparing, from a 1,3-butadiene-containing hydrocarbon stream, a compound of the formula II

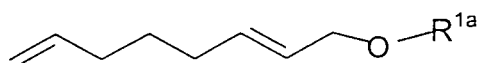


II

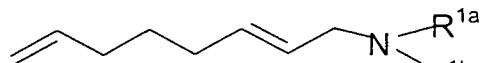
30 in which X is an OR^{1a} or $NR^{1a}R^{1b}$ radical, where R^{1a} and R^{1b} are each independently selected

from hydrogen, a linear, branched or cyclic C_1 to C_{22} -alkyl group, an alkenyl group, an alkynyl group, a C_5 to C_{18} aryl group or a $-\text{CO-alkyl-(}C_1\text{-}C_8\text{)}$ group or a $-\text{CO-aryl-(}C_5\text{-}C_{10}\text{)}$ group, where these groups may contain substituents selected from the group of $-\text{CN}$, $-\text{COOH}$, $-\text{COO-alkyl-(}C_1\text{-}C_8\text{)}$, $-\text{CO-alkyl-(}C_1\text{-}C_8\text{)}$, $-\text{aryl-(}C_5\text{-}C_{10}\text{)}$, $-\text{COO-aryl-(}C_6\text{-}C_{10}\text{)}$, $-\text{CO-aryl-(}C_6\text{-}C_{10}\text{)}$, $-\text{O-alkyl-(}C_1\text{-}C_8\text{)}$, $-\text{O-CO-alkyl-(}C_1\text{-}C_8\text{)}$, $-\text{N-alkyl}_2\text{-(}C_1\text{-}C_8\text{)}$, $-\text{CHO}$, $-\text{SO}_3\text{H}$, $-\text{NH}_2$, $-\text{F}$, $-\text{Cl}$, $-\text{OH}$, $-\text{CF}_3$, $-\text{NO}_2$, and where the R^{1a} and R^{1b} radicals may be joined together via covalent bonds.

Using the process according to the invention, it is possible in particular to prepare compounds of the formulae IIIa or IIIb,



IIIa



IIIb

by reacting 1,3-butadiene with a nucleophile (VII) of the formulae VIIa, VIIb or VIIc



where R^{1a} and R^{1b} are each as defined above.

Particular preference is given to using the process according to the invention to prepare compounds of the formula II in which X is OR^{1a} or $\text{NR}^{1a}\text{R}^{1b}$, where

R^{1a} is H, methyl, ethyl, n-propyl, isopropyl, tert-butyl, n-butyl, sec-butyl, pentyl, hexyl, heptyl, octyl, octenyl, octadienyl, isononyl, 2-ethylhexyl, n-nonyl, phenyl, m-, o- or p-methylphenyl, naphthyl, 2,4-di-tert-butylphenyl, 2,6-di-tert-butylmethylphenyl, hydrogencarbonyl, methylcarbonyl, ethylcarbonyl, propylcarbonyl or phenylcarbonyl

and/or

R^{1b} is H, methyl, ethyl, n-propyl, isopropyl, tert-butyl, n-butyl, sec-butyl, pentyl, hexyl, heptyl, octyl, octenyl, octadienyl, isononyl, 2-ethylhexyl, n-nonyl, phenyl, m-, o- or p-methylphenyl, naphthyl, 2,4-di-tert-butylphenyl, 2,6-di-tert-butylmethylphenyl, hydrogencarbonyl, methylcarbonyl, ethylcarbonyl, propylcarbonyl or phenylcarbonyl. Very particular preference is given to using the process according to the invention to prepare a compound of the formula

IIIa where R^{1a} = hydrogen, methyl, ethyl, phenyl or methylcarbonyl. The compounds of the

formulae IIIa and IIIb may be present either in the cis or in the trans form.

The effluent from the telomerization reaction step may, for example, comprise mainly the telomerization product, by-products, "inert hydrocarbons", residual amounts of starting olefin, residual amounts of nucleophile and catalyst system (catalyst metal, ligands and optionally bases, etc.) or subsequent products thereof and any added solvents, or consist thereof. The effluent from the telomerization reaction step may be separated quite generally by known industrial processes, in particular by thermal separating processes, for example distillation or extraction. For example, a distillative separation can be effected into the following fractions:

- 10 - a C₄ fraction which comprises n-butane, isobutane, 1-butene, 2-butenes, isobutene, 1,3-butadiene, 1,2-butadiene and, if appropriate, all or some of the nucleophile,
- a fraction comprising the target product (2,7-octadienyl derivative),
- a fraction comprising the by-product and/or
- a fraction comprising the catalyst and
- 15 - if appropriate, a fraction comprising the nucleophile and/or
- if appropriate, a solvent fraction.

The fraction comprising the nucleophile, the fraction comprising the solvent and the fraction comprising the catalyst may each be recycled fully or partly, together or separately into the reaction step, or else, with the exception of the fraction comprising the catalyst, be fed to a workup. Preference is given to recycling the fractions into the reaction step.

However, the separation may also be carried out in such a way that only two fractions are obtained. In this case, one fraction comprises the substantial portion of the target product and the second fraction comprises the substantial portion of the catalyst used. The catalyst-containing fraction is in turn recycled fully or partly into the reaction step.

The recycled catalyst fraction may, in addition to the catalyst system, also comprise any solvent present, telomers of the solvent, any excess imidazolium salt and base, and unremoved product, and also any stabilizers present for the 1,3-butadiene, for example tert-butylpyrocatechol.

The target product is used as such or serves as a precursor for other substances. For example, 1-octene can be prepared from the 1-methoxyoctadi-2,7-ene target product by hydrogenating the two double bonds and subsequently eliminating methanol. By means of the process according to the invention, it is thus possible to prepare mixtures comprising 1-methoxyoctadi-2,7-ene. These mixtures can then be used to prepare 1-octene.

When the nucleophile used in the telomerization is methanol or ethanol, the use of C₄ hydrocarbon streams as the starting stream (1,3-butadiene as the starting olefin) gives rise to the option of not removing the nucleophile from the reaction product. Instead, the effluent of the hydrogenation of the target product (e.g. 1-methoxyoctadi-2,7-ene) can be sent directly to an etherification in which the alcohol used as a nucleophile is reacted with the isobutene present in the C₄ stream to give methyl tert-butyl ether or ethyl tert-butyl ether. This reaction too is effected by processes known in industry, usually under catalysis of ion exchangers. For full conversion of the isobutene, alcohol has to be added additionally in some cases.

The invention is illustrated in detail with reference to the figure Fig. 1, without any intention that the invention be restricted to the embodiment shown in Fig. 1. Fig. 1 is a schematic illustration of one possible embodiment of the process according to the invention. The overall telomerization process shown here has three steps: one telomerization reaction step (Telo), one removal step (A) and one catalyst recycling step (KR). In the reaction step (Telo), a reactant stream is conducted together with the catalyst recycle stream (KR) and optionally a hydrogen source (WQ1). The reaction mixture obtained as the reaction product (P1) is conducted into the following step (A), in which the catalyst and optionally a solvent are removed from the remaining constituents of the reaction mixture. The product mixture (P2) freed of catalyst may be sent to a further workup. The removed catalyst is sent back to the reactant stream via the catalyst recycling (KR). In the catalyst recycling, a hydrogen source (WQ2) is added to the catalyst stream. When the process according to the invention is carried out, it is possible for a hydrogen source to be fed into one or more steps of the overall telomerization process either only via WQ2 or else WQ1 and WQ2. It is self-evident that, when the process is carried out, it is possible that further apparatus, for example pumps and valves, etc. or means, for example, of discharging a portion of the used catalyst and/or of

adding fresh catalyst, may be or have to be present, but are not shown in this scheme in Fig. 1.

The examples which follow are intended to illustrate the invention in detail without restricting the scope of protection which is evident from the description and the claims.

5

Examples

Example 1: Telomerization in the absence of alkynes

In a 100 ml Schlenk tube, 55.9 mg (0.18 mmol) of palladium acetylacetonate and 0.390 g (0.75 mmol) of 1,3-bis(2,4,6-trimethylphenyl)imidazolium *o*-cresoxide-*o*-cresol were dissolved under protective gas in 51.2 g (1.59 mol) of methanol. In a 3-liter autoclave from Büchi, 6.72 g (0.06 mol) of *o*-cresol, heated to 40°C in a water vat, and 3.47 g (0.06 mol) of sodium methoxide were dissolved in 115 g (3.59 mol) of methanol and in 100 g (0.52 mol) of tripropylene glycol. Subsequently, with the aid of a pressurized gas canister, 536 g of a C₄ hydrocarbon mixture were injected into the autoclave (determination of amounts by a loss of mass in the C₄ supply bottle). The autoclave was heated to reaction temperature (80°C) with stirring, the palladium-containing solution was introduced in one portion into the autoclave contents and the reaction was monitored with the aid of an online gas chromatograph. The reaction time was 14 h. The hydrocarbon mixture obtained was an alkyne-free C₄ hydrocarbon mixture having 42.61% by mass of 1,3-butadiene, 1.77% by mass of isobutane, 7.05% by mass of *n*-butane, 5.14% by mass of trans-butene, 15.05% by mass of 1-butene, 24.80% by mass of isobutene, 3.8% by mass of cis-butene (no alkynes were detectable).

GC-analysis:

GC (1st column: DB-WAX/Al₂O₃, 2nd column: DB-Wax/HP-5MS; starting temperature: 50°C, maximum temperature: 200°C, starting time: 1 min, equilibration time: 3 min; temperature program: from 50°C at 15°C min⁻¹ to 200°C, run time: 11 min; inj.: 220°C, const. flow rate). Retention time [t_R](C₄ hydrocarbons) = 2762 min, t_R(methanol) = 3152 min, t_R(1,7-octadiene) = 3866 min, t_R(trans-1,6-octadiene) = 3958 min, t_R(cis-1,6-octadiene) = 4030 min, t_R(cis-1,3,7-octatriene) = 4291 min, t_R(trans-1,3,7-octatriene) = 4292 min, t_R(vinylcyclohexene) = 4448 min, t_R(*i*-butane) = 4552 min, t_R(*n*-butane) = 4822 min, t_R(3-MODE) = 5523 min, t_R(trans-butene) = 6116 min, t_R(1-butene) =

6240 min, $t_R(\text{i-butene}) = 6412$ min, $t_R(\text{cis-butene}) = 6616$ min, $t_R(1\text{-MODE}) = 6650$ min,
 $t_R(1,2\text{-butadiene}) = 6900$ min, $t_R(1,3\text{-butadiene}) = 7526$ min.

2,7-octadien-1-yl methyl ether (= 1-MODE)

1,7-octadien-3-yl methyl ether (= 3-MODE)

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Example 2: Telomerization in the presence of 2273 ppm by mass of alkynes (comparative experiments)

In a 100 ml Schlenk tube, 56.2 mg (0.18 mmol) of palladium acetylacetonate and 0.395 g (0.76 mmol) of 1,3-bis(2,4,6-trimethylphenyl)imidazolium *o*-cresoxide-*o*-cresol were dissolved under protective gas in 51.2 g (1.59 mol) of methanol. In a 3-liter autoclave from Büchi, 6.80 g (0.062 mol) of *o*-cresol, heated to 40°C in a water vat, and 3.80 g (0.07 mol) of sodium methoxide were dissolved in 115.1 g (3.59 mol) of methanol and in 101.1 g (0.52 mol) of tripropylene glycol. Subsequently, with the aid of a pressurized gas canister, 573 g of a C₄ hydrocarbon mixture were injected into the autoclave (determination of amounts by a loss of mass in the C₄ supply bottle). The autoclave was heated to reaction temperature (80°C) with stirring, the palladium-containing solution was introduced into the autoclave contents and the reaction was monitored with the aid of an online gas chromatograph. The reaction time was 14 h.

GC (1st column: DB-WAX/Al₂O₃, 2nd column: DB-Wax/HP-5MS; starting temperature: 50°C, maximum temperature: 200°C, starting time: 1 min, equilibration time: 3 min; temperature program: from 50°C at 15°C min⁻¹ to 200°C, run time: 11 min; inj.: 220°C, const. flow rate), $t_R(\text{C}_4 \text{ hydrocarbons}) = 2762$ min, $t_R(\text{methanol}) = 3152$ min, $t_R(1,7\text{-octadiene}) = 3866$ min, $t_R(\text{trans-1,6-octadiene}) = 3958$ min, $t_R(\text{cis-1,6-octadiene}) = 4030$ min, $t_R(\text{cis-1,3,7-octatriene}) = 4291$ min, $t_R(\text{trans-1,3,7-octatriene}) = 4292$ min, $t_R(\text{vinylcyclohexene}) = 4448$ min, $t_R(\text{i-butane}) = 4552$ min, $t_R(\text{n-butane}) = 4822$ min, $t_R(3\text{-MODE}) = 5523$ min, $t_R(\text{trans-butene}) = 6116$ min, $t_R(1\text{-butene}) = 6240$ min, $t_R(\text{i-butene}) = 6412$ min, $t_R(\text{cis-butene}) = 6616$ min, $t_R(1\text{-MODE}) = 6650$ min, $t_R(1,2\text{-butadiene}) = 6900$ min, $t_R(1,3\text{-butadiene}) = 7526$ min.

2,7-octadien-1-yl methyl ether (= 1-MODE)

1,7-octadien-3-yl methyl ether (= 3-MODE)

30

In the inventive example, a C₄ hydrocarbon mixture having 45.39% by mass of 1,3-butadiene, 1.46% by mass of isobutane, 4.61% by mass of n-butane, 5.20% by mass of trans-butene, 15.22% by mass of 1-butene, 23.85% by mass of cis-butene, 0.1866% by mass of vinylacetylene and 0.0407% by mass of 1-butyne was used.

Example 3: Telomerization with addition of water (in accordance with the invention):

In a 100 ml Schlenk tube, 55 mg (0.181 mmol) of palladium acetylacetonate and 0.384 g (0.96 mmol) of 1,3-bis(2,4,6-trimethylphenyl)imidazolium *o*-cresoxide-*o*-cresol were dissolved under protective gas in 50.2 g (1.57 mol) of methanol. In a 3-liter autoclave from Büchi, 6.98 g (0.064 mol) of *o*-cresol, heated to 40°C in a water vat, and 3.95 g (0.070 mol) of sodium methoxide were dissolved in 115.2 g (3.59 mol) of methanol and in 100.7 g (0.52 mol) of tripropylene glycol. Subsequently, with the aid of a pressurized gas canister, 526 g of a C₄ hydrocarbon mixture were injected into the autoclave (determination of amounts by a loss of mass in the C₄ supply bottle). Without heating the reaction mixture, in each case 0.1 MPa of hydrogen was injected after 1 min, 3 h 2 min, 22 h 35 min, 25 h 10 min, 27 h 11 min, 29 h 50 min and 49 h 10 min, and the concentration of the alkynes in the gaseous C₄ sample was measured by means of GC. After 52 h 45 min, the autoclave was heated to reaction temperature (80°C) with stirring. The reaction time at 80°C was 8.5 h.

20

GC (1st column: DB-WAX/Al₂O₃, 2nd column: DB-Wax/HP-5MS; starting temperature: 50°C, maximum temperature: 200°C, starting time: 1 min, equilibration time: 3 min; temperature program: from 50°C at 15°C min⁻¹ to 200°C, run time: 11 min; inj.: 220°C, const. flow rate), tR(C₄ hydrocarbons) = 2762 min, tR(methanol) = 3152 min, tR(1,7-octadiene) = 3866 min, tR(trans-1,6-octadiene) = 3958 min, tR(cis-1,6-octadiene) = 4030 min, tR(cis-1,3,7-octatriene) = 4291 min, tR(trans-1,3,7-octatriene) = 4292 min, tR(vinylcyclohexene) = 4448 min, tR(i-butane) = 4552 min, tR(n-butane) = 4822 min, tR(3-MODE) = 5523 min, tR(trans-butene) = 6116 min, tR(1-butene) = 6240 min, tR(i-butene) = 6412 min, tR(cis-butene) = 6616 min, tR(1-MODE) = 6650 min, tR(1,2-butadiene) = 6900 min, tR(1,3-butadiene) = 7526 min.

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2,7-octadien-1-yl methyl ether (= 1-MODE)

1,7-octadien-3-yl methyl ether (= 3-MODE)

In the inventive example, a C₄ hydrocarbon mixture comprising 43.48% by mass of 1,3-butadiene, 3.58% by mass of isobutane, 5.69% by mass of n-butane, 4.00% by mass of trans-butene, 14.78% by mass of 1-butene, 24.9% by mass of isobutene, 2.56% by mass of cis-butene and 0.005% by mass of propyne, 0.6299% by mass of vinylacetylene and 0.1058% by mass of 1-butyne (7407 ppm by mass of alkynes) was used.

Example 4: Telomerization with addition of water (in accordance with the invention):

10 In a 100 ml Schlenk tube, 57.6 mg (0.189 mmol) of palladium acetylacetonate and 0.399 g (0.76 mmol) of 1,3-bis(2,4,6-trimethylphenyl)imidazolium *o*-cresoxide-*o*-cresol were dissolved under protective gas in 51.3 g (1.60 mol) of methanol. In a 3-liter autoclave from Büchi, 6.90 g (0.064 mol) of *o*-cresol, heated to 40°C in a water vat, and 3.80 g (0.070 mol) of sodium methoxide were dissolved in 115.1 g (3.59 mol) of methanol and in 102 g (0.53 mol) of tripropylene glycol. Subsequently, with the aid of a pressurized gas canister, 495 g of a C₄ hydrocarbon mixture were injected into the autoclave (determination of amounts by a loss of mass in the C₄ supply bottle). The autoclave was heated to reaction temperature (80°C) with stirring and the palladium-containing solution was introduced into the autoclave contents. Next, 1.4 MPa of hydrogen were injected. The reaction was monitored with the aid of an online gas chromatograph. The reaction time was 14 h.

GC (1st column: DB-WAX/Al₂O₃, 2nd column: DB-Wax/HP-5MS; starting temperature: 50°C, maximum temperature: 200°C, starting time: 1 min, equilibration time: 3 min; temperature program: from 50°C at 15°C min⁻¹ to 200°C, run time: 11 min; inj.: 220°C, const. flow rate, tR(C₄ hydrocarbons) = 2762 min, tR(methanol) = 3152 min, tR(1,7-octadiene) = 3866 min, tR(trans-1,6-octadiene) = 3958 min, tR(cis-1,6-octadiene) = 4030 min, tR(cis-1,3,7-octatriene) = 4291 min, tR(trans-1,3,7-octatriene) = 4292 min, tR(vinylcyclohexene) = 4448 min, tR(i-butane) = 4552 min, tR(n-butane) = 4822 min, tR(3-MODE) = 5523 min, tR(trans-butene) = 6116 min, tR(1-butene) = 6240 min, tR(i-butene) = 6412 min, tR(cis-butene) = 6616 min, tR(1-MODE) = 6650 min, tR(1,2-butadiene) = 6900 min, tR(1,3-butadiene) = 7526 min.

2,7-octadien-1-yl methyl ether (= 1-MODE)

1,7-octadien-3-yl methyl ether (= 3-MODE)

In the inventive example, a C₄ hydrocarbon mixture comprising 44.69% by mass of 1,3-butadiene, 2.56% by mass of isobutane, 4.82% by mass of n-butane, 3.96% by mass of trans-
5 butene, 15.50% by mass of 1-butene, 24.68% by mass of isobutene, 2.76% by mass of cis-butene and 0.0415% by mass of propyne, 0.4609% by mass of vinylacetylene and 0.2328% by mass of 1-butyne (7350 ppm by mass of alkynes).

Table 2: Comparison of the results of examples 1 to 4

Example 1				Example 2				Example 3				Example 4			
Time min	Conversion %	Sel. MODE %*	Yield % MODE	Time min	Conversion %	Sel. MODE %*	Yield % MODE	Time min	Conversion %	Sel. MODE %*	Yield % MODE	Time min	Conversion %	Sel. MODE %*	Yield % MODE
0	0.67	100	0.5	0	2.6	100	2.6	0	3.62	100	3.2	0	2.57	96.80	2.6
140	65.22	96.53	62.0	140	1.53	90.48	1.4	140	84.07	96.59	75.3	140	37.45	96.42	26.0
350	97.71	96.37	93.3	380	1.75	82.18	1.4	330	98.0	96.27	88.3	350	96.22	96.83	74.8
710	99.33	95.89	94.4	800	2.18	72.13	1.6	510	98.64	95.82	89.1	770	99.06	95.76	76.1

* Sel. MODE = Selectivity for MODE among C₈ products5 Yield % MODE = mol of MODE (from GC) per mole of butadiene in the reactant $\times 2 \times 100\%$

As can be seen readily by the comparison of examples 1 and 2, the presence of alkynes in the C₄ hydrocarbon mixture used leads to inhibition of the catalyst, so that telomerization does not take place under otherwise identical conditions. In example 3, the starting material is a C₄ hydrocarbon mixture which has an even greater proportion of acetylenes. Hydrogen is added regularly to the reaction mixture. After approx. 37 hours, a slow start to the reaction can be observed even at low temperature. After a subsequent temperature increase, in spite of the presence of alkynes in the starting C₄ hydrocarbon mixture, telomerization can be observed. The inventive addition of a hydrogen source to the reaction mixture was able to reactivate the inhibited catalyst.

Example 4 also demonstrates that presence of hydrogen in the telomerization reaction can neutralize the inhibiting action of the alkynes. In example 4, the hydrogen is metered in shortly before the start of the reaction and the mixture is immediately heated to 80°C. In spite of the higher amount of alkyne compared to example 2, a high degree of product formation can be observed in the presence of hydrogen, even though it was not possible to fully restore the reaction rate of example 1. A side reaction observed is hydrogenation of butadiene to the butenes.

It is suspected that the particularly high conversion at the start of the reaction in example 3 in comparison to examples 1 and 4 can be attributed to the alkynes which deactivate the catalyst already having been removed fully by hydrogenation before the start of the actual reaction in the presence of the telomerization catalyst and any deactivated catalyst having been reactivated. It is suspected that the reason for the greater yield of MODE in example 3 in comparison to example 4 is that the single addition of hydrogen according to example 4 has resulted in the presence of such a great excess of hydrogen in the reaction mixture that the hydrogenation of butadiene to butenes proceeds to an increased extent as a competing reaction to the hydrogenation of the alkynes. A further reason for the amount of MODE being greater in example 3 for comparable residence time/reaction time might be that the regeneration does not proceed very rapidly, but the hydrogenation and telomerization do proceed in parallel, so that a smaller amount of active catalyst is available. The advantage of the embodiments of the process according to the invention according to example 4 lies in the possibility of dispensing

with a time-consuming step of prehydrogenation or preregeneration as carried out in example 3.

What is claimed is:

1. A process for telomerizing noncyclic olefins having at least two conjugated double bonds (VI) with at least one nucleophile (VII) using a catalyst containing a metal of group 8, 9
5 or 10 of the Periodic Table of the Elements,
characterized in that
the process has a process step for catalyst recycling, in which at least a portion of the catalyst present in the reaction mixture is recycled into the telomerization, and in that, in
the catalyst recycling step, hydrogen is added via a hydrogen source to the process
10 mixture present in the catalyst recycling, when the activity of the catalyst has declined significantly in comparison to the starting activity or the acyclic olefins having at least two conjugated double bonds (VI) are present in a mixture which comprises acetylenically unsaturated compounds.
- 15 2. The process as claimed in claim 1,
characterized in that
the hydrogen source used is a hydrogen-containing gas, formic acid, formates, alcohols or hydrazine.
- 20 3. The process as claimed in claim 1 or 2,
characterized in that
the feedstock used is a mixture of hydrocarbons which comprises the noncyclic olefins having at least two conjugated double bonds in a mixture with other hydrocarbons.
- 25 4. The process as claimed in claim 3,
characterized in that
the mixture contains up to 5% by mass of alkynes.
5. The process as claimed in claim 3 or 4,
30 characterized in that
the mixture comprises alkynes selected from vinylacetylene and 1-butyne.

6. The process as claimed in claim 4 or 5,
characterized in that
a portion of the alkynes present is hydrogenated selectively before use in the
telomerization.

5

7. The process as claimed in at least one of claims 1 to 6,
characterized in that
the hydrogen source feeds sufficient hydrogen into the catalyst recycling step that the
molar ratio of hydrogen to catalyst metal is at least 1 to 1.

10

8. The process as claimed in at least one of claims 1 to 7,
characterized in that
the feedstock used is a mixture which contains over 90% by mass of C₄ hydrocarbons.

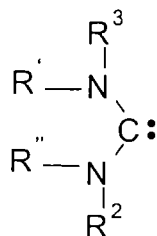
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9. The process as claimed in at least one of claims 1 to 8,
characterized in that
the noncyclic olefins used are 1,3-butadiene or isoprene.

10. The process as claimed in at least one of claims 1 to 9,

20

- characterized in that
the telomerization catalyst used is a palladium-carbene complex which contains a carbene
ligand of the general formula VIII:



VIII

where R²; R³: are the same or different and are each

25

- a) linear, branched, substituted or unsubstituted, cyclic or alicyclic alkyl
groups having from 1 to 24 carbon atoms, or

b) substituted or unsubstituted, mono- or polycyclic aryl groups having from 6 to 24 carbon atoms or

c) mono- or polycyclic, substituted or unsubstituted heterocycle having from 4 to 24 carbon atoms and at least one heteroatom from the group of N, O and S, and

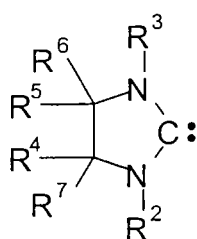
R' , R'' :

are the same or different and are each

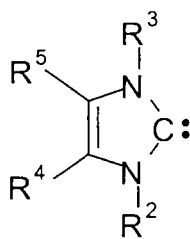
hydrogen, alkyl, aryl, heteroaryl, -CN, -COOH, -COO-alkyl-, -COO-aryl-, -OCO-alkyl-, -OCO-aryl-, -OCOO-alkyl-, -OCOO-aryl-, -CHO, -CO-alkyl-, -CO-aryl-, -O-alkyl-, -O-aryl-, -NH₂, -NH(alkyl)-, -N(alkyl)₂-, -NH(aryl)-, -N(alkyl)₂-, -F, -Cl, -Br, -I, -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H, -PO₃H₂, where the alkyl groups contain 1-24 carbon atoms and the aryl and heteroaryl groups from 5 to 24 carbon atoms, and the R' and R'' radicals may also be part of a bridging aliphatic or aromatic ring.

11. The process as claimed in at least one of claims 1 to 9, characterized in that

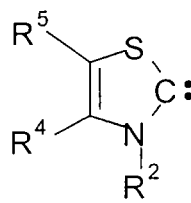
the telomerization catalyst used is a palladium-carbene complex which contains a carbene ligand of the general formula IX, X, XI or XII:



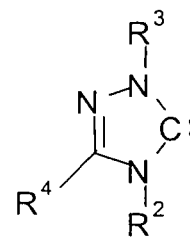
IX



X



XI



XII

where R^2 , R^3 : are the same or different and are each

a) linear, branched, substituted or unsubstituted, cyclic or alicyclic alkyl groups having from 1 to 24 carbon atoms, or

b) substituted or unsubstituted, mono- or polycyclic aryl groups having from 6 to 24 carbon atoms or

c) mono- or polycyclic, substituted or unsubstituted heterocycle having from 4 to 24 carbon atoms and at least one heteroatom from the group of N, O and S, and

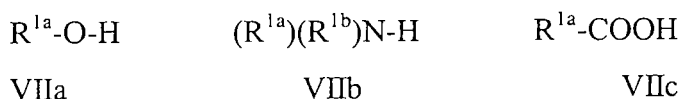
R^4, R^5, R^6, R^7 : are the same or different and are each hydrogen, alkyl, aryl, heteroaryl, -CN, -COOH, -COO-alkyl-, -COO-aryl-, -OCO-alkyl-, -OCO-aryl-, -OCOO-alkyl-, -OCOO-aryl-, -CHO, -CO-alkyl-, -CO-aryl-, -O-alkyl-, -O-aryl-, -NH₂, -NH(alkyl)-, -N(alkyl)₂-, -NH(aryl)-, -N(alkyl)₂-, -F, -Cl, -Br, -I, -OH, -CF₃, -NO₂, -ferrocenyl, -SO₃H, -PO₃H₂, where the alkyl groups contain 1-24 carbon atoms and the aryl and heteroaryl groups from 5 to 24 carbon atoms, and the R^4, R^5, R^6 and R^7 radicals may also be part of a bridging aliphatic or aromatic ring.

12. The process as claimed in one of claims 10 or 11, characterized in that

the ratio of ligand to metal [mol/mol] in the reaction mixture is from 0.01:1 to 250:1.

13. The process as claimed in one of claims 1 to 12, characterized in that

the nucleophiles VII used are compounds of the general formulae VIIa, VIIb or VIIc



in which R^{1a} and R^{1b} are each independently selected from hydrogen, a linear, branched or cyclic C₁ to C₂₂-alkyl group, -alkenyl group or -alkynyl group, a C₅ to C₁₈-aryl group or a -CO-alkyl-(C₁-C₈) group or a -CO-aryl-(C₅-C₁₀) group, where these groups may contain substituents selected from the group of -CN, -COOH, -COO-alkyl-(C₁-C₈), -CO-alkyl-(C₁-C₈), -aryl-(C₅-C₁₀), -COO-aryl-(C₆-C₁₀), -CO-aryl-(C₆-C₁₀), -O-alkyl-(C₁-C₈), -O-

CO-alkyl-(C₁-C₈), -N-alkyl₂-(C₁-C₈), -CHO, -SO₃H, -NH₂, -F, -Cl, -OH, -CF₃ and -NO₂, and where the R^{1a} and R^{1b} radicals may be joined together via covalent bonds.

14. The process as claimed in claim 13,

5 characterized in that

the nucleophile (VII) used is water, alcohols, phenols, polyols, carboxylic acids, ammonia and/or primary or secondary amines.

15. The process as claimed in one of claims 1 to 14,

10 characterized in that

the telomerization is carried out in the presence of a solvent.

16. The process as claimed in one of claims 1 to 15,

characterized in that

15 the telomerization is carried out in the presence of a solvent and the solvent used is the nucleophile (VII) and/or inert organic solvent.

17. The process as claimed in one of claims 1 to 16,

characterized in that

20 a hydrogen source is added additionally in the reaction step to the overall telomerization process.

18. A mixture comprising 2,7-octadienyl derivatives which is obtainable by a process as claimed in one of claims 1 to 17.

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19. The use of the mixture comprising 2,7-octadienyl derivatives as claimed in claim 18 for preparing 1-octene.