CH_4 conversion in nanosecond pulsed plasma: Is it pyrolysis?

Supplementary Information

S1. Evaluation of performance metrics from gas chromatography data

In this section, we explain the procedure to describe performance metrics of the plasma process, such as CH_4 conversion and energy cost. First, considering that one molecule of CH_4 is converted into multiple gaseous products (H_2 and various hydrocarbons), the gas expands, and this leads to an increased gas flow rate exiting the reactor. If disregarded, this gas expansion leads to an overestimation of conversion and energy efficiency, as reported by Wanten *et al*. [1] Gas expansion is taken into account by introducing a 'flux ratio' or 'gas expansion coefficient', α (Eq. S1), which is the ratio of the total volumetric flow rate at the outlet V_{tot}^{out} (in [L.min^{-1}]) over the total volumetric flow rate at the inlet V_{tot}^{in} (in [L.min^{-1}]). The expansion coefficient was determined using N_2 (99.999 % purity, Air Liquide) as an internal standard, employing the method described by Wanten *et al*. [1]

$$\alpha = V_{tot}^{out}/V_{tot}^{in} \tag{S1}$$

The CH_4 conversion χ_{CH_4} (in [%]) can be calculated by Eq. (S2), where $y_{CH_4}^{in}$ and $y_{CH_4}^{out}$ represent the molar fractions of CH_4 at the inlet and outlet, respectively [1].

$$\chi_{CH_4} = \left(1 - \alpha \cdot \frac{y_{CH_4}^{out}}{y_{CH_4}^{in}}\right) \cdot 100\% \tag{S2}$$

The atom-based (A-based) product selectivity S_j^A of product j is given by Eq. (S3), in which $\mu_{CH_4}^A$ and μ_j^A represent the stoichiometric coefficients, i.e., the number of atoms A, in CH_4 and the specific product, respectively. y_j^{out} is the molar fraction of the specific product at the outlet of the reactor [1].

$$S_j^A = \frac{\mu_j^A \cdot \alpha \cdot y_j^{\mathrm{out}}}{\sum_i \left(\mu_{CH_4}^A \cdot \left(y_{CH_4}^{\mathrm{in}} - \alpha \cdot y_{CH_4}^{\mathrm{out}}\right)\right)} \tag{S3}$$

Another important plasma parameter is the specific energy input *SEI* (in [kJ.mol^{-1}]) (Eq. S4), which is defined as the ratio of the power *P* (in [kW]) deposited into the plasma over the molar inlet flow rate n_{tot}^{in} (in [mol.min^{-1}]), and multiplied by 60 (s.min^{-1}) to obtain the right units. The molar inlet flow rate can be estimated by dividing the volumetric inlet flow rate V_{tot}^{in} (in [L.min^{-1}]) by the molar volume V_m (in [L.mol^{-1}]), see Eq. (S5). The power *P* (in [W]) deposited into the plasma is estimated as the product of the energy deposited into one pulse E_{pulse} (in [J]) and the number of pulses per second [1], i.e. the pulse frequency f_{pulse} (in [s^{-1}]), see Eq. (S6).

$$SEI = \frac{P}{n_{tot}^{in}} \cdot 60 \tag{S4}$$

$$n_{tot}^{in} = \frac{V_{tot}^{in}}{V_m} \tag{S5}$$

$$P = E_{pulse} \cdot f_{pulse} \quad \text{(S6)}$$

The energy cost *EC* (in [kJ.mol^{-1}]), i.e., the amount of energy required to convert 1 mol of reactant [1], can be determined using the *SEI* and conversion as follows:

$$EC = \frac{SEI}{\chi_{CH_4}} \quad \text{(S7)}$$

where the conversion here is not expressed in %, but in fraction (total conversion = 1).

Finally, the effectiveness of the applied energy in forming H_2, or so-called energy efficiency *EE*, is calculated via Eq. (10), with ΔH_R^0 being the reaction enthalpy for complete CH_4 decomposition into H_2 and solid C (Eq. 2) at standard conditions (ΔH_R^0 = 37.4 kJ.mol^{-1} H_2) [1]. Note that this results in a lower *EE* than the *EE* for the conversion of CH_4 (ΔH_R^0 = 74.8 kJ.mol^{-1} CH_4), which also includes the formation of hydrocarbons. However, calculation of the latter *EE* should thus also account for the formation enthalpy and concentrations of these hydrocarbons, as shown by Wanten *et al*. [1], and some of these hydrocarbons could not be measured in our gas chromatography experiments, and thus we considered it to be more correct to focus here on the *EE* for H_2 production.

$$EE = \frac{\chi \cdot \Delta H_R^0}{SEI} \quad \text{(S8)}$$

S2. Model description

A Zero-Dimensional Plasma Kinetics (ZDPlasKin) solver is used to investigate the plasma chemistry. ZDPlasKin is a Fortran 90 module, which follows the evolution of the species densities over time by solving the continuity differential equations for all species included in the model, given by Eq. (S9):

$$\frac{dn_s}{dt} = \sum_r C_{r,s} k_r \prod_q n_q \quad \text{(S9)}$$

with n_s being the number density (in [m^{-3}]) of chemical species s, $C_{r,s}$ the stoichiometric coefficient of species s in reaction r, k_r the reaction rate coefficient of reaction r, and n_q the number density (in [m^{-3}]) of reactant species q. The rate coefficients for reactions without electrons (i.e., so-called heavy particle reactions) are taken from literature (see section S3) and are valid within a given temperature range. However, when electron collisions are involved, the rate coefficient is determined by the BOLSIG+ solver from continuous evaluation of the collisional cross sections and the electron energy distribution function (EEDF). BOLSIG+ works in tandem with ZDPlasKin and calculates the rate coefficients from the mean electron energy, as determined by the EEDF, which is in turn derived from the electric field [2]. The latter is calculated through the local field approximation (Eq. S10):

$$E = \sqrt{P_d/\sigma} \quad \text{(S10)}$$

with *E* being the electric field strength (in [V.m^{-1}]), P_d the power density (in [W.m^{-3}]) and σ the electrical conductivity (in [S.m^{-1}]). The latter is defined by Eq. (S11):

$$\sigma = e \cdot n_e \cdot \mu_e \tag{S11}$$

where e is the elementary charge (in [C]), n_e the electron number density (in [m^{-3}]), and μ_e the electron mobility (in [$m^2.V^{-1}.s^{-1}$]). From the electric field E, the reduced electric field (E/N, in [Td], where 1 Td = 10^{-21} V.m²) can be determined by dividing E by the total number density of gas phase species (N, in [m^{-3}]) (Eq. S12) [2]:

$$\frac{E}{N} = \frac{1}{N}\sqrt{\frac{P_d}{\sigma}} \tag{S12}$$

S3. Gas temperature kinetics

The gas temperature kinetics are estimated by optical emission spectroscopy (OES) of the CH band (λ_0 = 430 nm) and C_2 Swan band (λ_0 = 516 nm) by fitting experimental spectra with simulated spectra using MassiveOES [3-5] and LIFBASE [6] software (Fig. S1). Following the method from Ref. [7], T_{gas} was estimated from the CH spectrum by finding the residual minimum in the slope of peak intensity of the four lines indicated in Fig. S1(a). A temperature of 652 ± 49 K was found in the period of 0 – 50 ns after pulse ignition, when emission from the CH($A^2\Delta$-$X^2\Pi$) transition was observed. Later in the afterglow, i.e., after ca. 500 ns, C_2 Swan emission bands dominated and were used for determining T_{gas} (Fig. S1b). The appearance of Ni emission lines (514.6 and 515.6 nm) and a background emission continuum in the C_2 Swan spectrum means that only the range from 515.7 to 517.0 nm (green shaded area) could be fitted in MassiveOES, as discussed in more detail in Ref. [7]. This region contains ca. 15 rotational lines, sufficient to confidently estimate the rotational temperature. The gas temperature kinetics (Fig S1c) from OES show a relatively low T_{gas} during the pulse and early afterglow (0 – 50 ns), after which T_{gas} rises above 3000 K until at least 5 µs after the pulse. After 5 µs, no emission is observed, meaning that the cooling stage of the gas cannot be assessed via OES.

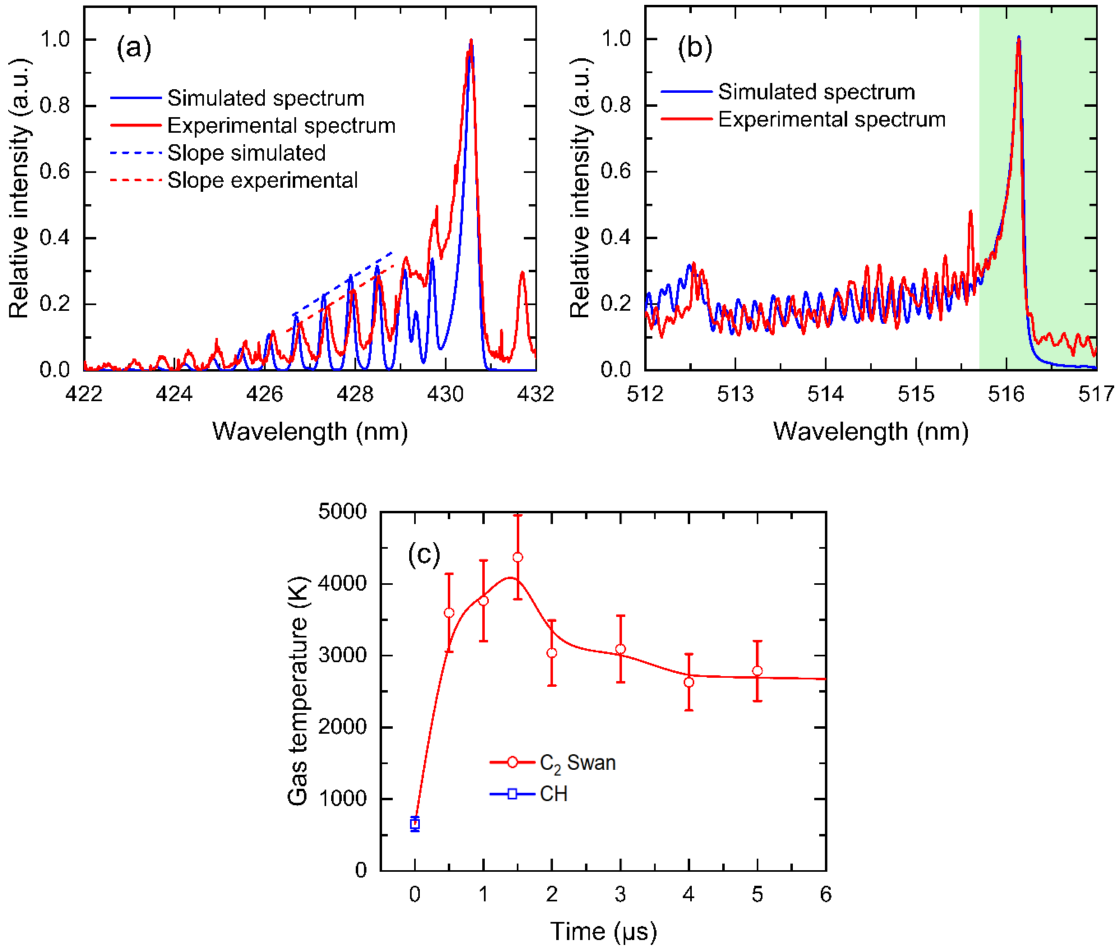

Fig. S1. Experimentally measured (red) and simulated (blue) (a) CH band and (b) C_2 Swan band at 1.1 bar used for estimating the gas temperature evolution shown in (c).

Temporal profiles of the gas temperature in the model were reproduced on the correct timescale by running identical simulations with lower peak power until the self-consistently calculated peak T_{gas} (Eq. S13) matched the experimental peak T_{gas}. The corresponding calculated profile was then introduced in the simulations presented in this work with the actual power density measured experimentally.

$$N \frac{y k_B}{y-1} \frac{dT_{gas}}{dt} = P_{e,el} + \sum_j R_j \cdot \Delta H_j - P_{ext} \qquad \text{(S13)}$$

In this equation, N is the total number density of gas-phase species (in [m^{-3}]), y is the specific heat ratio of the total gas mixture, k_B the Boltzmann constant (in [J.K^{-1}]), T_{gas} the average gas temperature (in [K]), $P_{e,el}$ the gas heating power density due to elastic electron-neutral collisions (in [W.m^{-3}]), R_j the rate of reaction j (in [m^{-3}.s^{-1}]), ΔH_j the reaction enthalpy of reaction j (in [J]), and P_{ext} is the heat loss to the surroundings (in [W.m^{-3}]). The latter is calculated via Eq. (S14),

$$P_{ext} = \frac{8 \cdot \lambda_{CH_4}}{R^2} \left(T_{gas} - T_{edge}\right) \qquad \text{(S14)}$$

Where λ_{CH_4} is the thermal conductivity of CH_4 (1.48×10^{-6} $T_{gas} - 9.92 \times 10^{-5}$ W.m^{-1}.K^{-1}) [8], R is the radius of the plasma zone (in [m]), T_{gas} the average plasma gas temperature (in [K]) and T_{edge} the gas temperature at the edge of the plasma zone, i.e., 293.15 K, as measured in the experiments.

S4. Full chemistry set of the kinetic model

S4.1. CH_4 vibrational excitation

In this model, the lowest energy level of the four degenerate vibrational modes of CH_4 is considered. More specifically, the v_1 symmetric stretch mode (0.362 eV), the v_2 symmetric bend mode (0.190 eV), the v_3 antisymmetric stretch mode (0.374 eV) and the v_4 antisymmetric bend mode (0.162 eV) (see Fig. S2) [9] are included. Rate constants for excitation, deexcitation and relaxation reactions can be found in Table S1. The rate coefficients for reverse reactions were calculated using the detailed balance approach suggested by Menard-Bourcin *et al.* [10]

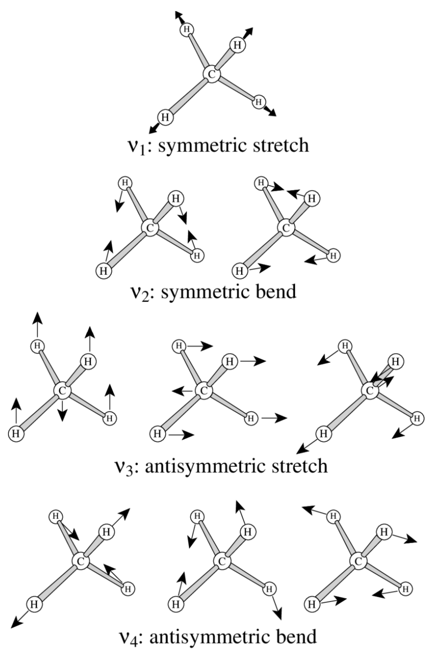

Fig. S2. Visual representation of the CH_4 vibrational modes [11].

Table S1. Excitation, deexcitation and relaxation reactions, with their corresponding rate coefficients, of CH_4 vibrationally excited states through electron impact reactions and neutral-neutral molecular reactions. The rate coefficients for electron impact reactions are evaluated using cross section data *f(σ)*. The rate coefficients for neutral-neutral molecular reactions are given in [cm^3.s^{-1}]. References are shown in the last column. The table can be found in Appendix.

S4.2. H_2 Vibrational excitation

In addition to the ground state H_2, the model includes 14 vibrational levels of H_2 with energy levels ranging from 0 eV to the dissociation limit at 4.48 eV. The energy of each level is calculated using the anharmonic oscillator theory for a diatomic molecule, utilising the vibrational constants $\omega_e = 4401.213$ cm^{-1} and $\omega_e x_e = 121.336$ cm^{-1} of the H_2 molecule [12]. The energy values for the vibrational levels are tabulated in Table S2. Rate constants for excitation, deexcitation and (V-V and V-T) relaxation reactions can be found in Table S3. The rate coefficients for reverse reactions were calculated using detailed balance.

Table S2. Energy values for the ground state and all 14 vibrational levels of H_2.

Energy level	**Energy (eV)**
H_2	0.000
$H_2(v_1)$	0.516
$H_2(v_2)$	1.001
$H_2(v_3)$	1.457
$H_2(v_4)$	1.882
$H_2(v_5)$	2.277
$H_2(v_6)$	2.642
$H_2(v_7)$	2.977
$H_2(v_8)$	3.282
$H_2(v_9)$	3.557
$H_2(v_{10})$	3.802
$H_2(v_{11})$	4.017
$H_2(v_{12})$	4.201
$H_2(v_{13})$	4.356
$H_2(v_{14})$	4.480

Table S3. Excitation, deexcitation and (V-V and V-T) relaxation reactions (with their corresponding rate coefficients) of H_2 vibrationally excited states through electron impact reactions and neutral-neutral molecular reactions. The rate coefficients for electron impact reactions are evaluated using cross section data *f(σ)*. The rate coefficients for neutral-neutral molecular reactions are given in [cm^3.s^{-1}]. References are shown in the last column. The table can be found in Appendix.

S4.3. List of chemical reactions

All other chemical reactions included in the model (not related to vibrational excitation) are listed in the tables below, separated based on the type of reactions. When unavailable in the literature, the rate constants of reverse reactions were calculated via detailed balancing.

Table S4. Elastic collision reactions of electrons with neutral species and their corresponding rate coefficients. The rate coefficients are evaluated using cross section data *f(σ)*. References are shown in the last column. The table can be found in Appendix.

Table S5. Electron impact reactions of electrons with neutral species and their corresponding rate coefficients. The rate coefficients are evaluated using cross section data *f(σ)*. References are shown in the last column. The table can be found in Appendix.

Table S6. Electron impact reactions of electrons with positive and negative ions and their corresponding rate coefficients. The rate coefficients [in $cm^3.s^{-1}$] are evaluated using cross section data *f(σ)* or as a function of T_{gas} [in K], with *R* being the gas constant [in $J.K^{-1}.mol^{-1}$]. References are shown in the last column. The table can be found in Appendix.

Table S7. Neutral-neutral pressure-dependent recombination reactions with low pressure (k_0) and high pressure (k_∞) limit rate coefficients, with T_{gas} being the gas temperature [in K]. The respective rate coefficients [in $cm^3.s^{-1}$] k_0 and k_∞ of each reaction are also given alongside the falloff curve expression (F_C) which incorporates the Troe parameters. k_0, k_∞ and F_C were used to calculate the rate coefficients of pressure dependent reactions (see details in Ref. [13]). References are shown in the last column. The table can be found in Appendix.

Table S8. Neutral-neutral molecular recombination reactions and their corresponding rate coefficients [in $cm^3.s^{-1}$ or $cm^6.s^{-1}$], with T_{gas} being the gas temperature [in K] and *R* being the gas constant [in $J.mol^{-1}.K^{-1}$]. References are shown in the last column. The table can be found in Appendix.

Table S9. Negative and positive ion-ion and ion-neutral molecular recombination reactions and respective rate coefficients [in $cm^3.s^{-1}$ or $cm^6.s^{-1}$]. T_{gas} is given in [K]. References are shown in the last column. The table can be found in Appendix.

S5. Model input and pulse characteristics

The physical characteristics of the power pulses introduced in the model, such as the pulse energy, duration and the plasma volume, were measured experimentally [7] in a pressure range between 0.5 and 2.0 bar, and can be found in Table S10.

Table S10. Input pulse characteristics (from experiments [7]) and peak values for the reduced electric field and electron temperature calculated in our model.

Pressure (bar)	Pulse energy (mJ)	Pulse duration (ns)	Plasma volume (mm^3)	Peak E/N (Td)	Peak T_e (eV)
0.5	12.01	13.50	1.00	1131.5	8.23
1.1	12.57	12.50	0.81	770.8	6.23
1.5	11.97	12.00	0.76	671.1	5.73
2.0	10.76	11.50	0.66	586.6	5.31

The description of these parameters enabled the construction of the triangular power pulses seen in Fig. S3(a), which were implemented in the simulations as power density profiles, similar to the works of Morais *et al*. [14, 15] In this study, we have simulated one power pulse and the following afterglow, focusing on (i) the electron impact ionisation, excitation and dissociation mechanisms within the pulse, and thereafter (ii) the thermal kinetic pathways when the gas temperature rises and drops in the afterglow.

The application of a power pulse gives rise to a characteristic E/N (as described in Eq. (S12)) and T_e, which are shown in Fig. S3(b). Their peaks are reached at the very beginning of the pulse, when n_e is still relatively low (8×10^{10} cm^{-3}). As a result, σ is also low (Eq. S11), which enhances the electrical field E (Eq. S10), and E/N. Within 0.5 ns, both E/N and T_e reach intermediate values (ca. 200 Td and 4 eV, respectively) which are maintained during the pulse. Once the pulse ends, E/N and T_e quickly drop to negligible values due to the absence of an electric field. The peaks in E/N and T_e reached during the pulse are also shown in Table S10. Their falling trend upon rising pressure can be explained considering that at elevated pressure, the total particle density, N, increases. The lower E/N results in less electrical energy being coupled to the free electrons, which directly impacts the peak T_e, as the latter is calculated from the EEDF by BOLSIG+.

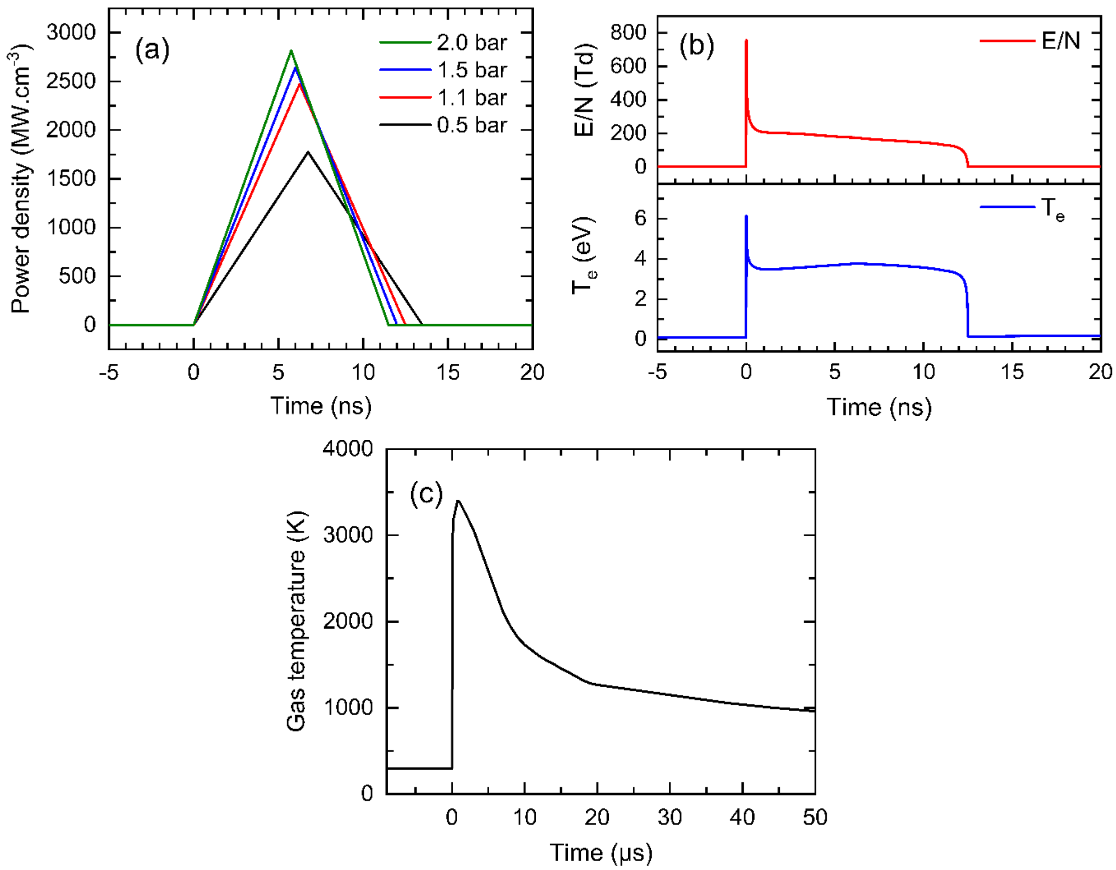

Fig. S3. (a) Symmetrical triangular power density pulses at different pressures, matching the experimentally measured pulse energy, duration and plasma volume. (b) Calculated *E/N* and T_e profiles as a function of time at 1.1 bar. (c) Calculated T_{gas} profile used as input in the model at 1.1 bar, matching the experimental temperatures measured by OES at the same pressure.

As previously explained, experimentally validated gas temperature profiles (example shown in Fig. S3(c)) were introduced in the model. As seen in Fig. S3(c), gas heating starts during the pulse, reaching ca. 800 K by the end of the pulse. Heating continues in the early afterglow until ca. 700 ns, when the peak temperature of 3400 K is reached. After ca. 1.1 µs, T_{gas} starts to decrease and reaches below 500 K after ca. 90 µs. The mechanism behind this temperature profile is discussed in multiple papers [7, 14-17]. Briefly, heating happens due to elastic and inelastic electron-molecule collisions, dissociative excitation and V-T relaxation. After reaching the peak T_{gas}, cooling takes place due to heat loss to the surroundings and endothermic reactions.

S6. Comparison of electron density in the model and experiments

The calculated values of the electron density (n_e) and ionisation degree (*ID*) are compared with the corresponding experimental data reported in Ref. [7], and they are shown in solid and dotted lines, respectively, in Fig. S4. It is clear that the model significantly underestimates the absolute values of n_e and consequently *ID*. This can be explained because nanosecond pulses create steep, localised fields that concentrate ionisation in space and time, which are averaged out due to the uniformity approximation in the 0D model [18]. The relatively large difference can thus be attributed to the absence of spatial dimensions in the model, rather than potential inaccuracies in the implementation of electron impact processes, which are generally well established with validated input cross sections [19-21]. Consequently, the chemical pathways predicted by the model are expected to be fairly realistic, despite the underestimation of n_e and thus *ID*. The calculated n_e remains around 2 x 10^{16} cm^{-3}, while *ID* drops from 0.176 % at 0.5 bar to 0.038 % at 2.0 bar. This is attributed to the weaker reduced electric fields reached upon increasing pressure, resulting in a lower ionisation rate, which is confirmed in this work (see Table S10 above). The same relationship between n_e and pressure was also observed by Morais *et al*. [14, 15]

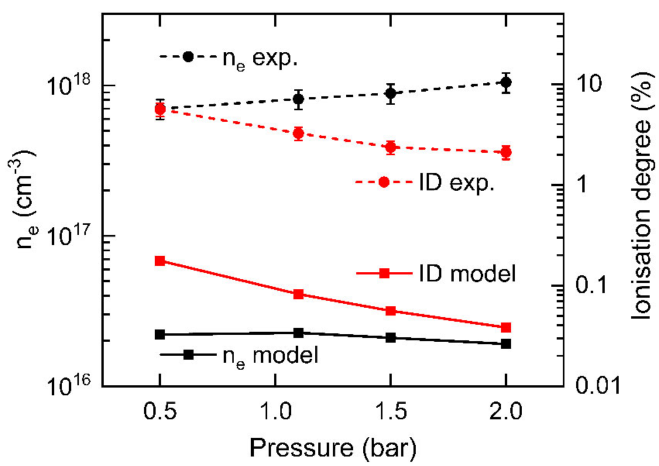

Fig. S4. Electron density (n_e, black) and ionisation degree (*ID*, red) calculated in the model (full line) and measured experimentally (dotted line) at different pressures.

S7. Product selectivity from GC experiments

As seen in Fig. S5(a) and (b), the assumptions and approximations in the model cause some selectivity discrepancies with the experimental data. Interestingly, the model predicts a higher selectivity towards the main products than observed in the experiments, i.e., C_2H_2 (ca. 78 % calculated vs. ca. 48 % in the experiment) and H_2 (ca. 77 % calculated vs. ca. 65 % in the experiment). Conversely, the formation of the other C_2 and C_3 hydrocarbon products is underestimated in the model. The main reason for these observations can be found in the size of the chemistry set, which is limited to C_4 hydrocarbons. As a result, the most important reaction type in soot formation by the HACA mechanism, i.e., addition of C_2H_2 to larger hydrocarbons [22], is not included. The absence of C_2H_2 consumption reactions leads to an overestimation of its selectivity and consequently an underestimation of the selectivity of all other C_xH_y. Besides, one needs to consider that instead of the uniform volume-element assumed by the model, in reality the reactor consists of the hot plasma centre surrounded by a hot reactive volume, as well as the colder unreactive volume created due to the low T_{gas}. Previous research has shown that temperatures above 1600 K favour the formation of more unsaturated hydrocarbons (C_2H_2 > C_2H_4 > C_2H_6) and H_2 (via sequential de-hydrogenation reactions leading to C_2H_2) [23]. Thus, the absence of a surrounding cold region in the model to slow down H abstraction contributes to why the C_2H_2 and H_2 products become dominant in the model above saturated hydrocarbons, whereas in the experiments, higher production of C_2H_4 and C_2H_6 takes place in the colder regions of the reactor (as opposed to C_2H_2). The same principle holds true for the production of C_3 hydrocarbons, hence the underestimation of H_2CCCH_2, CH_2CHCH_3 and $CH_3CH_2CH_3$ selectivity can be attributed to both the absence of C_2H_2 addition reactions to larger C_xH_y, and the absence of different temperature zones in the model, as discussed above. Furthermore, high temperatures enable further conversion into C_4 (and higher) hydrocarbons [23], which explains the relatively high selectivity for HCCCCH and $HCCCHCH_2$ (ca. 8 % and ca. 1 %, respectively) in the model (Fig. S5c). However, this prediction could not be confirmed by the experiments, as no C_4 molecules were detected in the GC, likely due to further reactions into larger molecules, which eventually become soot.

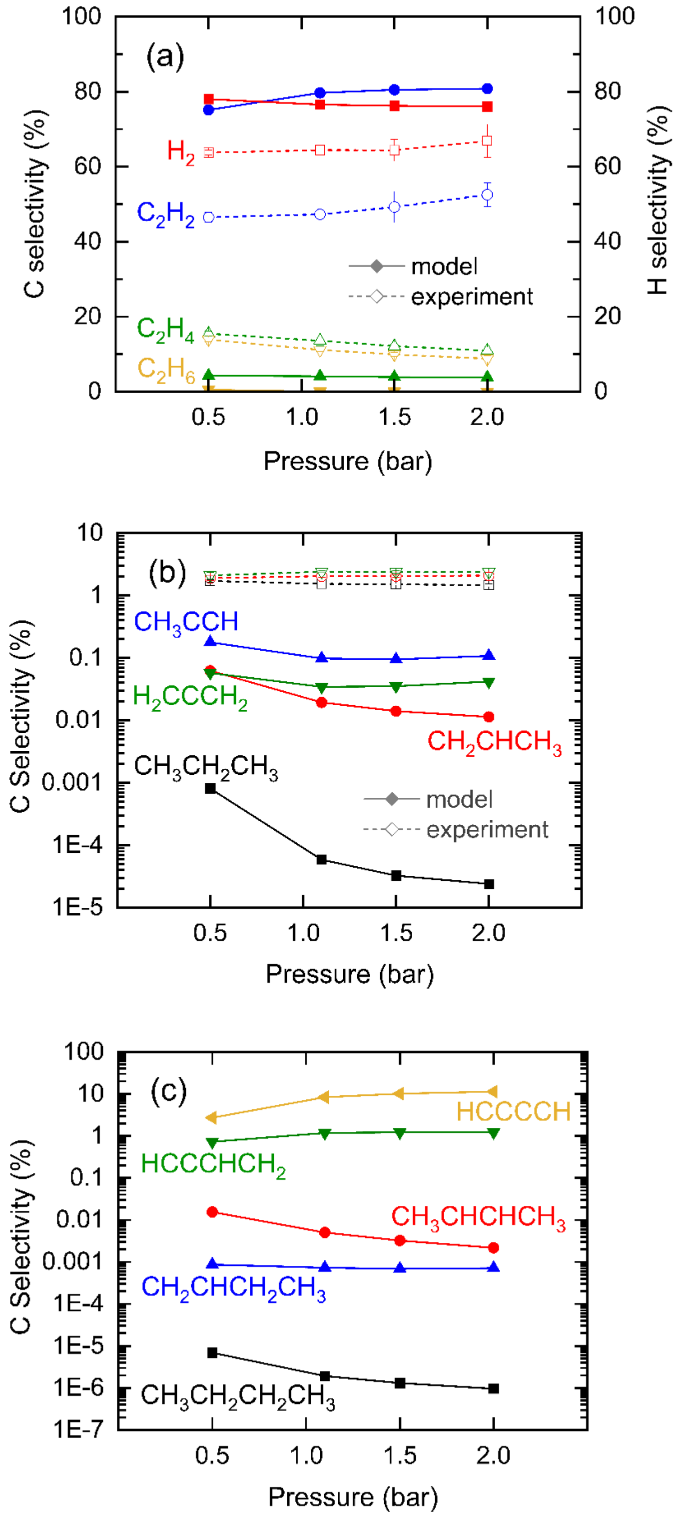

Fig. S5. Product selectivity into (a) H_2 and C_2-, (b) C_3-, and (c) C_4-hydrocarbons, in the model (full lines) and experiments (dotted lines) as a function of the applied pressure.

S8. CH_4 conversion calibration factor

A calibration factor (*CF*) for the modelled CH_4 conversion is defined to account for gas not passing through the plasma region. This was estimated from Rayleigh scattering profiles in Ref. [7]. Rayleigh scattering shows the radial T_{gas} profile, calculated from the ratio of the scattered laser light intensity (I_{ref}) corresponding to the known reference temperature (T_{ref}) and the laser scattered intensity when it passes through the plasma (I_{plasma}) (Eq. S15), which are indicated in Fig. S6(a).

$$T_{gas} = \frac{I_{ref}}{I_{plasma}} \cdot T_{ref} \tag{S15}$$

In these profiles, a plasma core and column can be defined. The core, which corresponds to the region simulated by the 0D model, is defined as the section where T_{gas} is highest, using a threshold of 13.5 % (or $1/e^2$) deviation from the peak temperature (Fig. S3b). In addition, the plasma column is defined as the region within the full width at half maximum (FWHM) of the Rayleigh scattering profile (Fig. S6b) and is characteristic for the plasma edge with a steep T_{gas} gradient. The volume ratio, i.e. *CF*, between both equals 0.211, meaning that ca. 21 % of the gas passes through the plasma core. The calibrated CH_4 conversion can then be calculated from the conversion in the model $\chi_{CH_4,(mod)}$ by:

$$\chi_{CH_4,(cal)} = CF \cdot \chi_{CH_4,(mod)} \tag{S16}$$

It is worth to mention that a more accurate estimation of this calibration factor can be obtained from a multidimensional model, which couples flow fields, gas mixing, diffusion, etc. However, this comes at the cost of a limited reaction set size. Moreover, such multidimensional modelling of nanosecond pulsed plasmas in molecular gases, such as CH_4, brings extra challenges due to a rapid dissociation, gas heating and conversion (to gas and solid products, i.e., soot formation), resulting in large pressure variations. In addition, the pulsed plasma nature creates a tight coupling between the interacting dynamics, such as electron impact dissociation, excitation, cathode spot formation, species recombination, Ohmic heating, gas expansion, secondary species formation, and pressure changes. All these effects strongly impact the plasma properties, posing great challenges to couple in a multidimensional nanosecond pulsed CH_4 model. Therefore, we believe the method used here is a more feasible and sufficiently accurate alternative for this 0D modelling study.

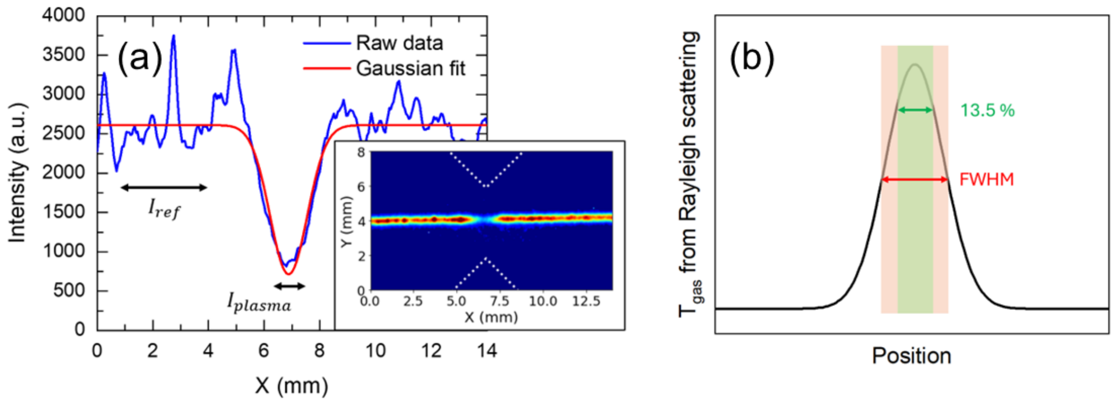

Fig. S6. (a) Rayleigh scattering intensity profile (blue) and Gaussian fit (red) along the laser beam at 1.5 bar and a time delay of 3 µs after the plasma pulse, taken from Ref. [7]. The inset shows the corresponding ICCD image where the white dotted lines indicate the electrode pins. (b) Gaussian fit with indication of the plasma core (green) and plasma column (red) regions.

S9. Interplay of vibrational CH_4 modes

In this section, we present the interplay of the four vibrational modes in the first vibrational excitation level of CH_4. More specifically, the model includes the ground state of CH_4, with (v1, v2, v3, v4) = (0, 0, 0, 0), the symmetric stretch mode CH_4(v1) = (1, 0, 0, 0), symmetric bend mode CH_4(v2) = (0, 1, 0, 0), antisymmetric stretch mode CH_4(v3) = (0, 0, 1, 0), and antisymmetric bend mode CH_4(v4) = (0, 0, 0, 1). Vibrational excitation to higher levels can take place within the same mode, e.g. (0, 3, 0, 0), and as a mixed excitation of different modes, e.g. (1, 3, 0, 5). However, these higher vibrational levels are not included in the model due to the high complexity and computational cost, lack of data, and their fast V-V and V-T relaxation times (< 1 ns) [24].

High populations in the four vibrational modes are predicted by the model near the end of the pulse, as can be seen in Fig. S7. In the CH_4 plasma studied here, the order of abundance is CH_4(v4) > CH_4(v2) > CH_4(v3) > CH_4(v1), which is also observed by Butterworth *et al.* [16] Some vibrational modes (CH_4(v2) and CH_4(v4)) can even become more abundant than the ground level for several tens of ns, during the last phase of the pulse (5 ns towards the end of the pulse) and the beginning of the afterglow stage.

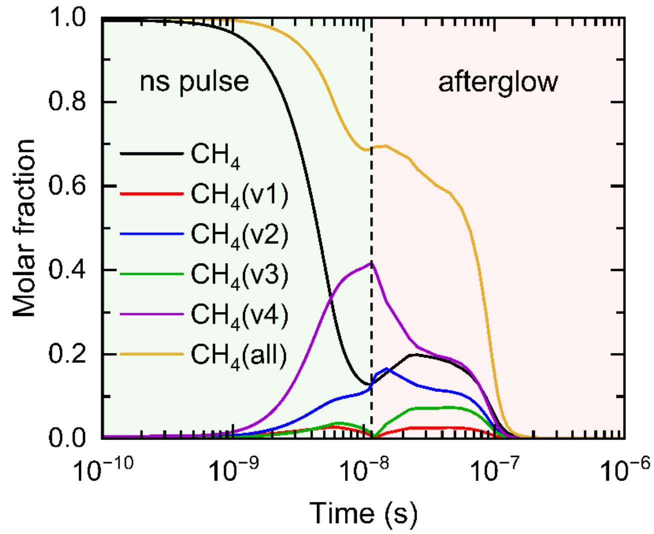

Fig. S7. Calculated molar fractions of the four vibrational modes of CH_4 at 2.0 bar, as well as of ground-state CH_4 and the sum of all levels, as a function of time. The black dotted line indicates the end of the nanosecond pulse.

Theoretically, these high populations may enable an alternative pathway for CH_4 conversion via energy barrier reduction thanks to vibrational excitation. Therefore, we wanted to evaluate whether this effectively occurs at the conditions under study, using a reaction pathway scheme (see Fig. S8) focused on CH_4, the major ions and radicals and the vibrational modes, CH_4(v1, v2, v3, v4), as revealed by our model. As can be seen in the figure, electron impact processes mostly excite CH_4 to CH_4(v1) (48 %) and CH_4(v2) (38 %), with excitation to CH_4(v3) and CH_4(v4) contributing less than 0.5 %. More prominent than the latter is dissociation to CH_3 (5.4 %) and other radicals (5.7 % in total, not shown for readability of the figure). Ionisation only accounts for 0.3 % of all CH_4 loss processes over the whole simulation and mostly leads to the formation of CH_5^+, which is the dominant ion in CH_4 plasmas. Reverse reactions to regenerate CH_4 are less prominent, which is also why near-complete depletion of CH_4 is observed in the model (see Fig. 2(a) in the main paper). These are mostly recombination of CH_3 and H (55 %), and deexcitation of CH_4(v1) (14 %) and CH_4(v2) (23 %). Upon formation, CH_4(v1) and CH_4(v2) are converted into CH_4(v3) and CH_4(v4) via thermal V-V relaxation reactions, with the most important processes being V-V transfer reactions between CH_4(v2) and CH_4(v4), at the conditions under study. The latter explains why CH_4(v4) is the dominant vibrational level in Fig. S7.

At the same time, our model reveals that the vibrationally excited levels do not contribute for a large extent to CH_4 conversion into H_2 or higher hydrocarbons (because their energy barriers are much lower than the CH_4 dissociation barrier, as explained in the main paper). Instead, the vibrationally excited levels are the main driver of gas heating in the afterglow due to V-T relaxation.

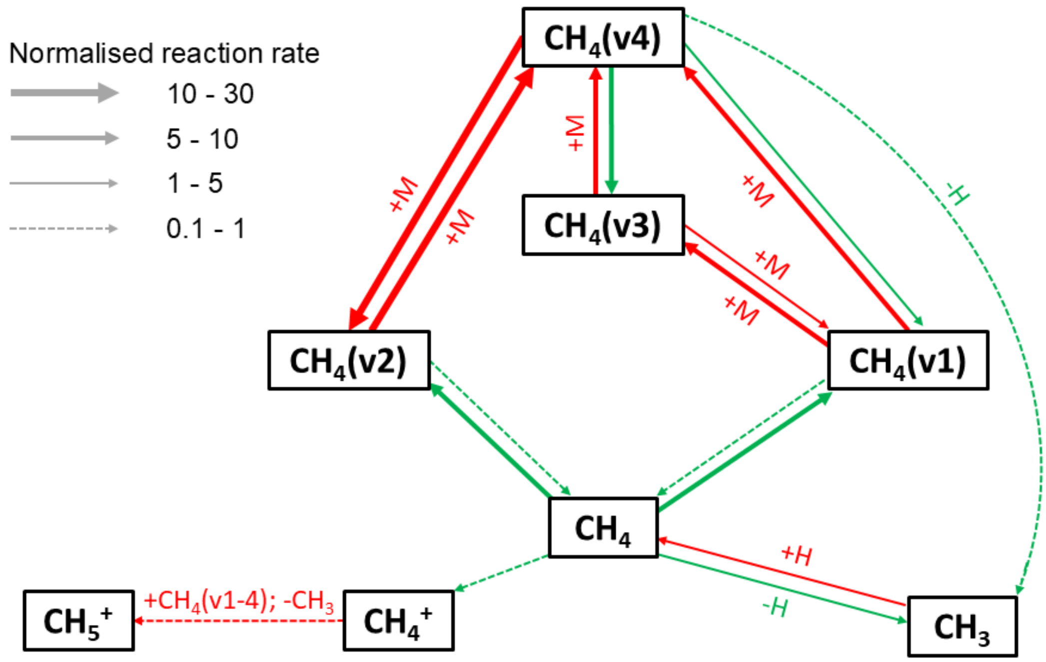

Fig. S8. Reaction pathway from CH_4 to the vibrationally excited states at 2.0 bar. Green arrows represent electron impact reactions and red arrows are reactions induced by heavy particle collisions. The arrow's thickness is a measure for the rate of the pathway, normalised to the reaction $e^- + CH_4 \rightarrow e^- + CH_3 + H$. Each reaction shows the other reactants ('+') and by-products ('-'). Note that only reactions with a contribution of at least 10 % for a given species are shown. As is clear from this figure, the vibrationally excited levels are mainly "transferred into each other" and to the ground state, only minimally contributing to dissociation (see only the green dashed line from CH_4(v4)). Hence, their main role is fast gas heating in the afterglow upon V-T relaxation.

S10. Study on improving ethylene (C_2H_4) production

C_2H_4 is the most valuable hydrocarbon product in CH_4 reforming [25], but only minor fractions are formed in the current process. More specifically, the outlet gas mixture contains ca. 1 % of C_2H_4 in the experiments and ca. 4 % in the model. Therefore, we conducted a theoretical computational study aiming to find temperature conditions that improve the C_2H_4 yield and can serve as a guide to optimise the development of pulsed plasma reactors. Since the most critical parameter affecting the final gas composition is T_{gas}, besides the pressure (which is already discussed in the manuscript), new T_{gas} profiles were introduced to the model at 2.0 bar. These profiles keep the same temporal dependency as the original profile (Fig. S9a), but reach lower peak temperatures of 1000, 1500, 2000 and 2500 K, being coupled to pulse energies of 3, 5, 7 and 9 mJ, respectively. The latter parameter was also changed because the pulse energy is the driver for gas heating via (vibrational) excitation, followed by V-T relaxation (see section 3.4). As shown in Fig. S9(b), high C_2H_4 selectivity can be achieved at lower gas temperatures than those measured in this study. In the cases of 1000, 1500 K, and 2000 K, C_2H_4 would be the most abundant hydrocarbon product, with a C-based selectivity exceeding 55 %, and it can even reach ca. 75 % at 2000 K. However, at higher temperatures (2500 and 3400 K), C_2H_4

undergoes dehydrogenation and C_2H_2 becomes the dominant product. The selectivity alone is not a sufficient metric to guide process improvement because the CH_4 conversion in the simulations with 1000 and 1500 K as peak T_{gas} is relatively low (4.8 and 10.5 %, respectively), in turn resulting in a low C_2H_4 yield (<6 %). Thus, this analysis indicates that suitable conditions for C_2H_4 production can only be found in the simulation with assumed peak T_{gas} of 2000 K, reaching a C_2H_4 yield of 15 % at 20 % CH_4 conversion. Ideally, simulations that make use of T_{gas} profiles should be coupled with experimental input data and have their predictions verified by products quantification techniques. Nonetheless, our model shows that the current experimental system generates too much heat (leading to excessive temperatures) for efficient C_2H_4 formation and that weaker pulses, with a corresponding cooler afterglow, could be more favourable.

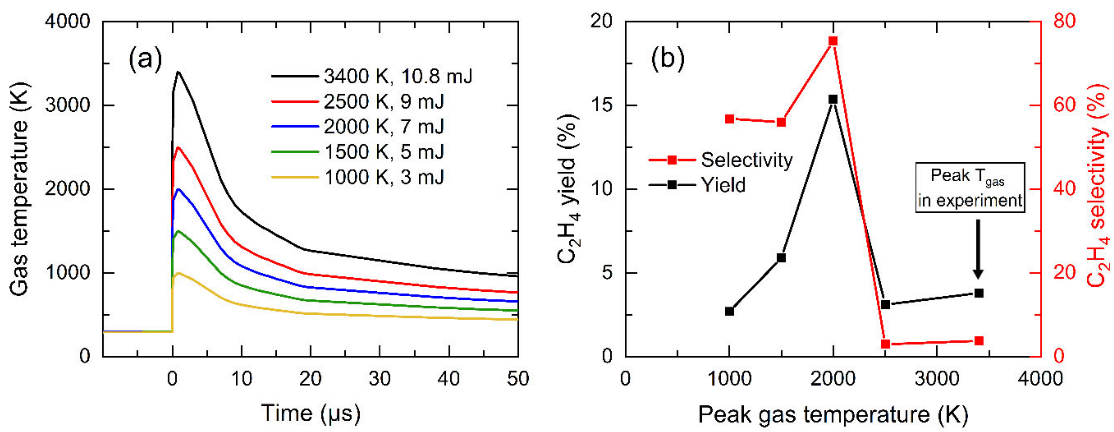

Fig. S9. (a) T_{gas} profiles used as input in the model at 2.0 bar, and (b) C-based yield and selectivity of C_2H_4 as a function of peak T_{gas}.

S11. Plasma versus thermal CH_4 reforming: product selectivity

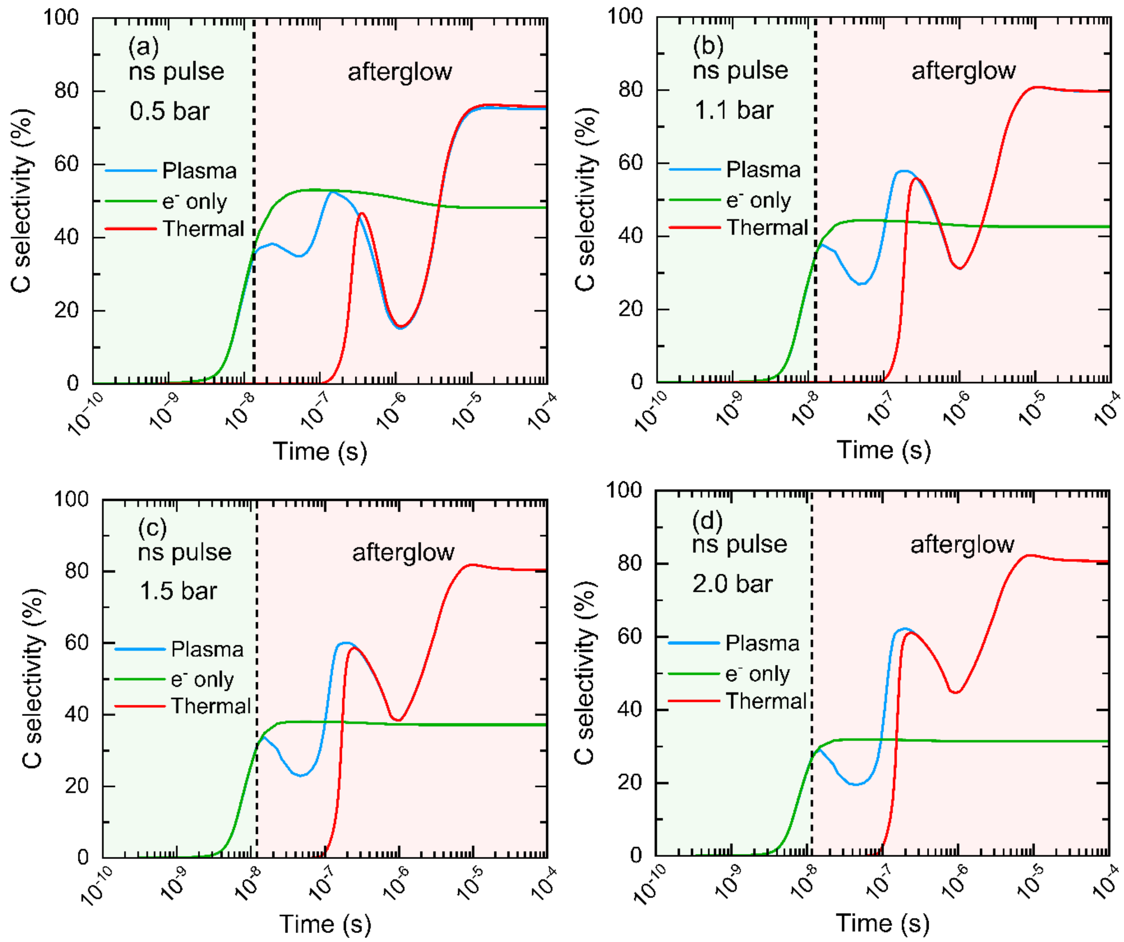

Fig. S10. C_2H_2 selectivity as a function of time for simulations with only power density profiles, thus solely considering the effects of electron impact reactions (e- only; green), only gas temperature profiles (red) and both (blue) at (a) 0.5 bar, (b) 1.1 bar, (c) 1.5 bar, and (d) 2.0 bar. The black dotted line indicates the end of the nanosecond pulse.

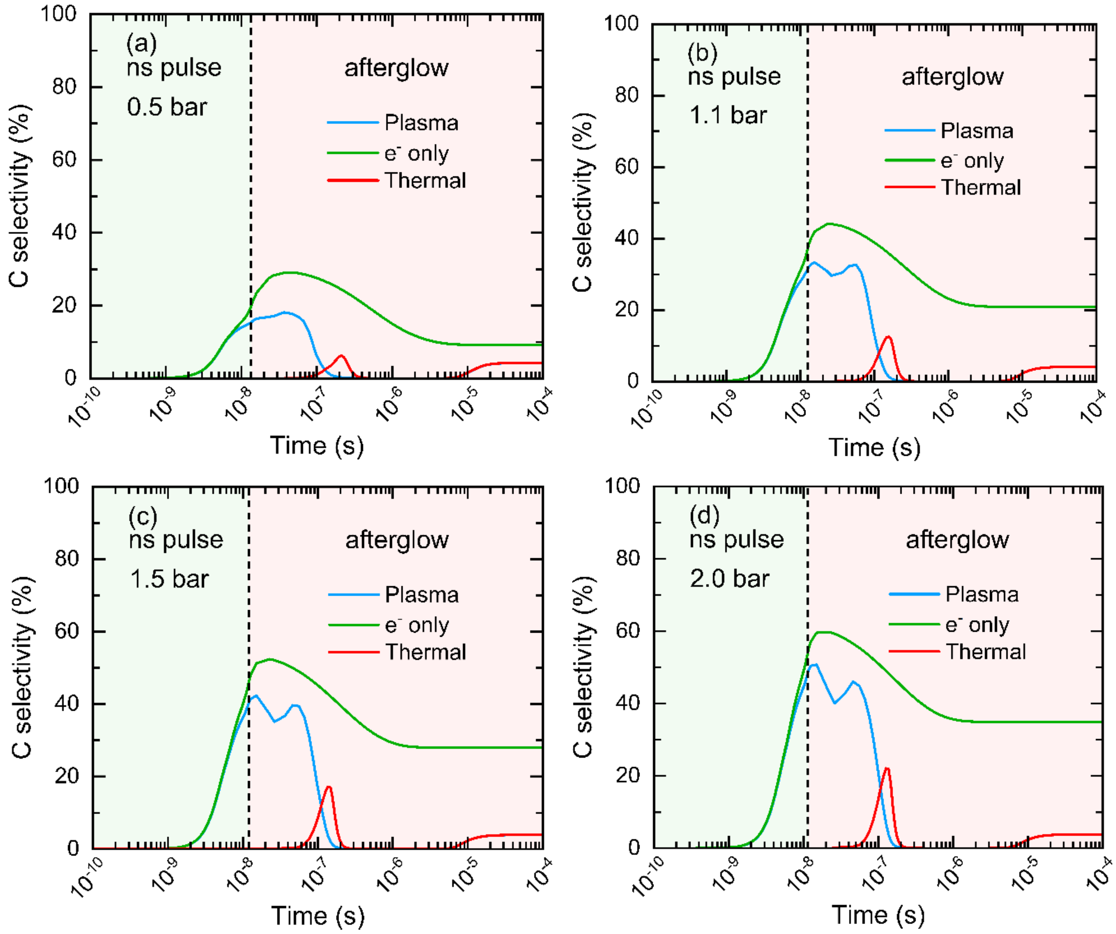

Fig. S11. C_2H_4 selectivity as a function of time for simulations with only power density profiles, thus solely considering the effects of electron impact reactions (e- only; green), only gas temperature profiles (red) and both (blue) at (a) 0.5 bar, (b) 1.1 bar, (c) 1.5 bar, and (d) 2.0 bar. The black dotted line indicates the end of the nanosecond pulse.

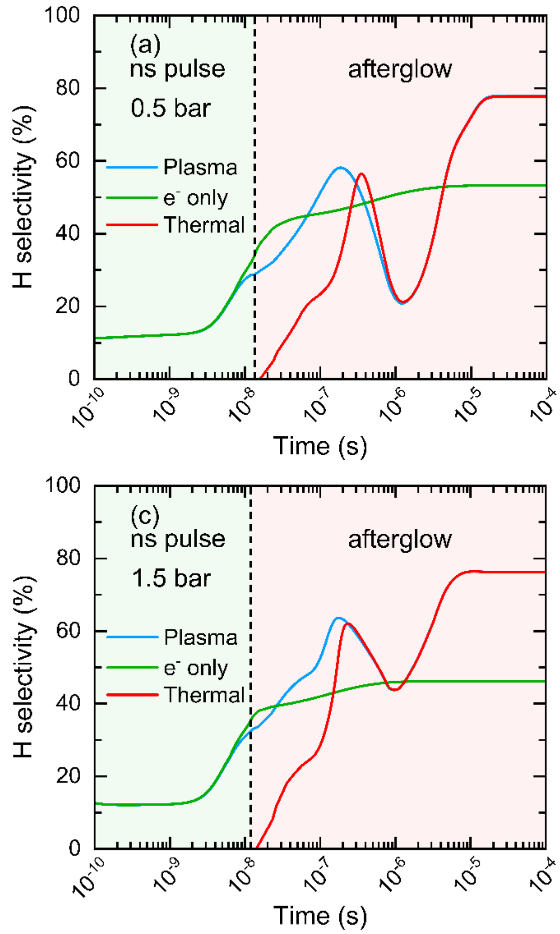

Fig. S12. H_2 selectivity as a function of time for simulations with only power density profiles, thus solely considering the effects of electron impact reactions (e- only; green), only gas temperature profiles (red) and both (blue) at (a) 0.5 bar, (b) 1.1 bar, (c) 1.5 bar, and (d) 2.0 bar. The black dotted line indicates the end of the nanosecond pulse.

Appendix

Table S1. Excitation, deexcitation and relaxation reactions, with their corresponding rate coefficients, of CH_4 vibrationally excited states through electron impact reactions and neutral-neutral molecular reactions. The rate coefficients for electron impact reactions are evaluated using cross section data *f(σ)*. The rate coefficients for neutral-neutral molecular reactions are given in [$cm^3.s^{-1}$]. References are shown in the last column. The table can be found in Appendix.

Reaction	Rate constant	Ref.
$e^- + CH_4 \leftrightarrow e^- + CH_4(v_1 - v_4)$	f(σ)	[26]
$e^- + CH_4(v1 - v4) \leftrightarrow e^- + CH_4(v1 - v4)$	f(σ)	[26]
$CH_4 + M \rightarrow CH_4(v_2) + M$ $M =$ any neutral molecule	$\gamma * T_{gas} * \exp\left(-30.65 - 40.0 * T_{gas}^{\left(-\frac{1}{3}\right)}\right) * 2 * \exp\left(\frac{-0.190 * 11604.5885}{T_{gas}}\right)$ M is any hydrocarbon: $\gamma = 1.0$ M is H or H_2: $\gamma = 1.2$	[27]
$CH_4 + M \rightarrow CH_4(v_4) + M$ $M =$ any neutral molecule	$\gamma * T_{gas} * \exp\left(-30.65 - 40.0 * T_{gas}^{\left(-\frac{1}{3}\right)}\right) * 3 * \exp\left(\frac{-0.162 * 11604.5885}{T_{gas}}\right)$ M is any hydrocarbon: $\gamma = 1.0$ M is H or H_2: $\gamma = 1.2$	[27]
$CH_4(v_2, v_4) + M \rightarrow CH_4 + M$ $M =$ any neutral molecule	$\gamma * T_{gas} * \exp\left(-30.65 - 40.0 * T_{gas}^{\left(-\frac{1}{3}\right)}\right)$ C_1-hydrocarbon: $\gamma = 1.0$ C_2, C_3, C_4-hydrocarbon: $\gamma = 2.468$ H or H_2: $\gamma = 2.111$	[27, 28]
$CH_4(v_1, v_3) + M \rightarrow CH_4(v_4) + M$ $M =$ any neutral hydrocarbon	$\exp\left(-10.661954 * T_{gas}^{\left(-\frac{1}{3}\right)} + 10.661854 - 193.0^{\left(-\frac{1}{3}\right)}\right) * 3.6 \times 10^{-11}$	[10]
$CH_4(v_1, v_3) + M \rightarrow CH_4(v_4) + M$ $M = H$ or H_2	$\exp\left(-34.41848157 * T_{gas}^{\left(-\frac{1}{3}\right)} + 34.41848157 - 193.0^{\left(-\frac{1}{3}\right)}\right) * 1.6 \times 10^{-11}$	[10]
$CH_4(v_4) + M \rightarrow CH_4(v_1, v_3) + M$ $M =$ any neutral hydrocarbon	$\exp\left(-10.661954 * T_{gas}^{\left(-\frac{1}{3}\right)} + 10.661854 - 193.0^{\left(-\frac{1}{3}\right)}\right) * 3.6 \times 10^{-11} * \gamma$ $CH_4(v_1)$: $\gamma = \frac{1}{3}\exp\left(-\frac{0.20 * 11604.5885}{T_{gas}}\right)$	[10]

	$CH_4(v_3): \gamma = \exp\left(-\frac{0.212 * 11604.5885}{T_{gas}}\right)$	
$CH_4(v_4) + M \rightarrow CH_4(v_1, v_3) + M$ $M = H$ or H_2	$\exp\left(-34.41848157 * T_{gas}^{\left(-\frac{1}{3}\right)} + 34.41848157 - 193.0^{\left(-\frac{1}{3}\right)}\right) * 1.6 \times 10^{-11} * \gamma$ $CH_4(v_1): \gamma = \frac{1}{3}\exp\left(-\frac{0.20 * 11604.5885}{T_{gas}}\right)$ $CH_4(v_3): \gamma = \exp\left(-\frac{0.212 * 11604.5885}{T_{gas}}\right)$	[10]
$CH_4(v_1) + M \rightarrow CH_4(v_3) + M$ $M =$ any hydrocarbon	$\exp\left(-11.28303275 * T_{gas}^{\left(-\frac{1}{3}\right)} + 11.28303275 - 193.0^{\left(-\frac{1}{3}\right)}\right) * \gamma * 3.0 * \exp\left(-\frac{0.012 * 11604.5885}{T_{gas}}\right)$ M is any hydrocarbon: $\gamma = 2.6 \times 10^{-11}$ M is H or H_2: $\gamma = 1.8 \times 10^{-11}$	[10]
$CH_4(v_3) + M \rightarrow CH_4(v_1) + M$ $M =$ any neutral molecule	$\exp\left(-11.28303275 * T_{gas}^{\left(-\frac{1}{3}\right)} + 11.28303275 - 193.0^{\left(-\frac{1}{3}\right)}\right) * \gamma$ M is any hydrocarbon: $\gamma = 2.6 \times 10^{-11}$ M is H or H_2: $\gamma = 1.8 \times 10^{-11}$	[10]
$CH_4(v_2) + M \rightarrow CH_4(v_4) + M$ $M =$ any neutral molecule	$\exp\left(-14.82909243 * T_{gas}^{\left(-\frac{1}{3}\right)} + 14.82909243 - 193.0^{\left(-\frac{1}{3}\right)}\right) * \gamma$ M is any hydrocarbon: $\gamma = 4.8 \times 10^{-11}$ M is H or H_2: $\gamma = 2.8 \times 10^{-11}$	[10]
$CH_4(v_4) + M \rightarrow CH_4(v_2) + M$ $M =$ any neutral molecule	$\exp\left(-14.82909243 * T_{gas}^{\left(-\frac{1}{3}\right)} + 14.82909243 - 193.0^{\left(-\frac{1}{3}\right)}\right) * \gamma * \frac{2}{3} * \exp\left(-\frac{0.028 * 11604.5885}{T_{gas}}\right)$ M is any hydrocarbon: $\gamma = 4.8 \times 10^{-11}$ M is H or H_2: $\gamma = 2.8 \times 10^{-11}$	[10]

Table S3. Excitation, deexcitation and (V-V and V-T) relaxation reactions (with their corresponding rate coefficients) of H_2 vibrationally excited states through electron impact reactions and neutral-neutral molecular reactions. The rate coefficients for electron impact reactions are evaluated using cross section data *f(σ)*. The rate coefficients for neutral-neutral molecular reactions are given in [$cm^3.s^{-1}$]. References are shown in the last column. The table can be found in Appendix.

Reaction	**Rate coefficient**	**Ref.**
$e^- + H_2(X, v_1 - v_{14}) \leftrightarrow e^- + H_2(X, v_1 - v_{14})$	f(σ)	[29]
$e^- + H_2(X, v_1 - v_{14}) \rightarrow H_2^* \rightarrow e^- + H_2(X, v_1 - v_{14})$	f(σ)	[30]
$H_2(v+1) + H_2(w) \leftrightarrow H_2(v) + H_2(w+1)$	$4.23 \times 10^{-15} \left(\frac{300}{T_{gas}}\right)^{\frac{1}{3}} (v+1)(w+1)$ $\left[\frac{3}{2} - \frac{1}{2}\exp(-\delta\,(w-v))\right]$ $\exp[\Delta_1(w-v) - \Delta_2(w-v)^2]$ With $w > v$ $\delta = 0.21\sqrt{\left(\frac{T_{gas}}{300}\right)}$ $\Delta_1 = 0.236\left(\frac{Tgas}{300}\right)^{\frac{1}{4}}$ $\Delta_2 = 0.0572\left(\frac{300}{T_{gas}}\right)^{\frac{1}{3}}$	[31]
$H_2(v) + M \leftrightarrow H_2(v-1) + M$ $M =$ any neutral molecule, except H	$k_{1,0}\, v \exp\left[0.97\left(\frac{300}{T_{gas}}\right)^{\frac{1}{3}} (v-1)\right]$ $k_{1,0} = 7.47 \times 10^{-12}\sqrt{T_{gas}}\exp\left(-93.87\, T_{gas}^{-\frac{1}{3}}\right)$ $\left[1 - \exp\left(-\frac{5983.2\,K}{T_{gas}}\right)\right]^{-1}$	[31, 32]
$H_2(v) + H \rightarrow H_2(v-1) + H$	$A_{nr}\exp\left(-\frac{E_{a,nr}}{T_{gas}}\right) + A_r\exp\left(-\frac{E_{a,r}}{T_{gas}}\right)$ $A_{nr}, A_r, E_{a,nr}$ and $E_{a,r}$: see reference	[33]

Table S4. Elastic collision reactions of electrons with neutral species and their corresponding rate coefficients. The rate coefficients are evaluated using cross section data *f(σ)*. References are shown in the last column. The table can be found in Appendix.

Reaction	Rate coefficient	Ref.
$e^- + CH_4 \rightarrow e^- + CH_4$	f(σ)	[26]
$e^- + CH_4(v1 - v4) \leftrightarrow e^- + CH_4(v1 - v4)$	f(σ)	[34]
$e^- + CH_3 \rightarrow e^- + CH_3$	f(σ)	IST Lisbon database – Lxcat net
$e^- + CH_2 \rightarrow e^- + CH_2$	f(σ)	IST Lisbon database – Lxcat net
$e^- + CH \rightarrow e^- + CH$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C \rightarrow e^- + C$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_s \rightarrow e^- + C_s$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_2H_6 \rightarrow e^- + C_2H_6$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_2H_5 \rightarrow e^- + C_2H_5$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_2H_4 \rightarrow e^- + C_2H_4$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_2H_3 \rightarrow e^- + C_2H_3$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_2H_2 \rightarrow e^- + C_2H_2$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C_2H \rightarrow e^- + C_2H$	f(σ)	IST Lisbon database – Lxcat net
$e^- + H \rightarrow e^- + H$	f(σ)	IST Lisbon database – Lxcat net
$e^- + H_2 \rightarrow e^- + H_2$	f(σ)	IST Lisbon database – Lxcat net
$e^- + H_2(v1 - 14) \leftrightarrow e^- + H_2(v1 - 14)$	f(σ)	[29]
$e^- + H^* \rightarrow e^- + H^*$	f(σ)	CCC database – Lxcat net

Table S5. Electron impact reactions of electrons with neutral species and their corresponding rate coefficients. The rate coefficients are evaluated using cross section data *f(σ)*. References are shown in the last column. The table can be found in Appendix.

Reaction	Rate coefficient	Ref.
$e^- + H \leftrightarrow e^- + H^*$	f(σ)	Morgan database – Lxcat net
$e^- + CH_4 \rightarrow e^- + e^- + CH_4^+$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + CH_3^+ + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + CH_2^+ + H_2$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + CH_2^+ + H + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + CH_3 + H^+$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + CH_2 + H_2^+$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + CH^+ + H + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + e^- + C^+ + H + H + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + CH_3 + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + CH_2 + H_2$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + CH_2 + H + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + CH + H_2 + H$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + C + H_2 + H_2$	f(σ)	[35]
$e^- + CH_4 \rightarrow e^- + C + H_2 + H + H$	f(σ)	[35]

$e^- + CH_3 \rightarrow e^- + e^- + CH_3^+$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + e^- + CH_2^+ + H$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + e^- + CH_2 + H^+$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + e^- + CH^+ + H_2$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + e^- + CH^+ + H + H$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + e^- + C^+ + H_2 + H$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + CH_2 + H$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + CH + H_2$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + C + H_2 + H$	f(σ)	[35]
$e^- + CH_3 \rightarrow e^- + CH + H + H$	f(σ)	[35]
$e^- + CH_2 \rightarrow e^- + e^- + CH_2^+$	f(σ)	[35]
$e^- + CH_2 \rightarrow e^- + CH + H$	f(σ)	[35]
$e^- + CH_2 \rightarrow e^- + C + H_2$	f(σ)	[35]
$e^- + CH_2 \rightarrow e^- + C + H + H$	f(σ)	[35]
$e^- + CH_2 \rightarrow e^- + e^- + C^+ + H_2$	f(σ)	[35, 36]
$e^- + CH_2 \rightarrow e^- + e^- + C^+ + H + H$	f(σ)	[35, 36]
$e^- + CH_2 \rightarrow e^- + e^- + CH^+ + H$	f(σ)	[35, 36]
$e^- + CH_2 \rightarrow e^- + e^- + C + H_2^+$	f(σ)	[35, 36]
$e^- + CH_2 \rightarrow e^- + e^- + CH + H^+$	f(σ)	[35, 36]
$e^- + CH \rightarrow e^- + e^- + CH^+$	f(σ)	[35]
$e^- + CH \rightarrow e^- + C + H$	f(σ)	[35]
$e^- + CH \rightarrow e^- + e^- + C^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_6^+$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + e^- + C_2H_5^+$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + e^- + C_2H_4^+$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + e^- + C_2H_3^+$	f(σ)	[35]
$e^- + C_2H_2 \rightarrow e^- + e^- + C_2H_2^+$	f(σ)	[35]
$e^- + C_2H \rightarrow e^- + e^- + C_2H^+$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_5^+ + H$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_4^+ + H_2$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_4 + H_2^+$	f(σ)	[35, 36]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_3^+ + H_2 + H$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_2^+ + 2\,H_2$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + e^- + C_2H_2^+ + H_2 + H + H$	f(σ)	[35, 36]
$e^- + C_2H_6 \rightarrow e^- + e^- + CH_3^+ + CH_3$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + e^- + C_2H_4^+ + H$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + e^- + C_2H_3^+ + H_2$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + e^- + C_2H_3^+ + H + H$	f(σ)	[35, 36]
$e^- + C_2H_5 \rightarrow e^- + e^- + C_2H_2^+ + H_2 + H$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + e^- + C_2H^+ + 2H_2$	f(σ)	[35, 36]

$e^- + C_2H_5 \rightarrow e^- + e^- + C^+ + CH_3 + H_2$	f(σ)	[35, 36]
$e^- + C_2H_5 \rightarrow e^- + e^- + C^+ + CH_4 + H$	f(σ)	[35, 36]
$e^- + C_2H_5 \rightarrow e^- + e^- + CH_2^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_5 \rightarrow e^- + e^- + CH_3^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_5 \rightarrow e^- + e^- + CH^+ + CH_4$	f(σ)	[35, 36]
$e^- + C_2H_4 \rightarrow e^- + e^- + C_2H_3^+ + H$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + e^- + C_2H_2^+ + H_2$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + e^- + C_2H_2^+ + 2H$	f(σ)	[35, 36]
$e^- + C_2H_4 \rightarrow e^- + e^- + C_2H^+ + 3H$	f(σ)	[35, 36]
$e^- + C_2H_4 \rightarrow e^- + e^- + C^+ + CH_4$	f(σ)	[35, 36]
$e^- + C_2H_4 \rightarrow e^- + e^- + CH_2^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_4 \rightarrow e^- + e^- + CH_3^+ + CH$	f(σ)	[35, 36]
$e^- + C_2H_4 \rightarrow e^- + e^- + CH^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + C_2H_2^+ + H$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + e^- + C_2H^+ + H_2$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + C_2H^+ + H + H$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + C^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + C_2^+ + H_2 + H$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + CH_2^+ + CH$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + CH^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_3 \rightarrow e^- + e^- + H^+ + C_2H_2$	f(σ)	[35, 36]
$e^- + C_2H_2 \rightarrow e^- + e^- + C_2H^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_2 \rightarrow e^- + e^- + H^+ + C_2H$	f(σ)	[35, 36]
$e^- + C_2H_2 \rightarrow e^- + e^- + C_2^+ + H_2$	f(σ)	[35, 36]
$e^- + C_2H \rightarrow e^- + e^- + C^+ + CH$	f(σ)	[35, 36]
$e^- + C_2H \rightarrow e^- + e^- + CH^+ + C$	f(σ)	[35, 36]
$e^- + C_2H \rightarrow e^- + e^- + C_2^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_6 \rightarrow e^- + C_2H_5 + H$	f(σ)	[35, 36]
$e^- + C_2H_6 \rightarrow e^- + C_2H_4 + H_2$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + C_2H_3 + H_2 + H$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + C_2H_2 + 2\,H_2$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + CH_4 + CH_2$	f(σ)	[35]
$e^- + C_2H_6 \rightarrow e^- + CH_3 + CH_3$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + C_2H_4 + H$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + C_2H_3 + H_2$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + C_2H_3 + 2\,H$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + C_2H_2 + H_2 + H$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + C_2H + 2\,H_2$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + CH_4 + CH$	f(σ)	[35]
$e^- + C_2H_5 \rightarrow e^- + CH_3 + CH_2$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + C_2H_3 + H$	f(σ)	[35]

$e^- + C_2H_4 \rightarrow e^- + C_2H_2 + H_2$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + C_2H_2 + 2\,H$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + C_2H + H_2 + H$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + CH_3 + CH$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + CH_2 + CH_2$	f(σ)	[35]
$e^- + C_2H_4 \rightarrow e^- + C + CH_4$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + C_2H_2 + H$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + C_2H + H + H$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + C_2 + H_2 + H$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + CH_2 + CH$	f(σ)	[35]
$e^- + C_2H_3 \rightarrow e^- + C + CH_3$	f(σ)	[35]
$e^- + C_2H_2 \rightarrow e^- + C_2H + H$	f(σ)	[35]
$e^- + C_2H_2 \rightarrow e^- + C_2 + H_2$	f(σ)	[35]
$e^- + C_2H_2 \rightarrow e^- + C_2 + 2\,H$	f(σ)	[35]
$e^- + C_2H_2 \rightarrow e^- + CH + CH$	f(σ)	[35]
$e^- + C_2H_2 \rightarrow e^- + C + CH_2$	f(σ)	[35]
$e^- + C_2H \rightarrow e^- + C_2 + H$	f(σ)	[35]
$e^- + C_2H \rightarrow e^- + C + CH$	f(σ)	[35]
$e^- + H_2 \rightarrow H_2^*(b^3\Sigma_u^+) \rightarrow e^- + H + H$	f(σ)	[37]
$e^- + H_2(v1 - 14) \rightarrow H_2^*(b^3\Sigma_u^+) \rightarrow e^- + H + H$	f(σ)	[37]
$e^- + H_2(X, v1 - 14) \rightarrow H_2^*(a^3\Sigma_g^+, c^3\Pi_u^+, e^3\Sigma_u^+) \rightarrow e^- + H + H$	f(σ)	[38]
$e^- + H_2 \rightarrow e^- + H + H^*$	f(σ)	[39, 40]
$e^- + H_2 \rightarrow e^- + e^- + H_2^+$	f(σ)	[37]
$e^- + H_2(v1 - 14) \rightarrow e^- + e^- + H_2^+$	f(σ)	[37]
$e^- + H \rightarrow e^- + e^- + H^+$	f(σ)	IST Lisbon database – Lxcat net
$e^- + CH_4 \rightarrow CH_3 + H^-$	f(σ)	Itikawa database – Lxcat net
$e^- + H_2 \rightarrow H_2^* \rightarrow H + H^-$	f(σ)	IST Lisbon database – Lxcat net
$e^- + H_2(X, v1 - 14) \rightarrow H_2^*(B^1\Sigma_u^+, C^1\Pi_u) \rightarrow H^* + H^-$	f(σ)	[38]
$e^- + H_2(v1 - 14) \rightarrow H + H^-$	f(σ)	IST Lisbon database – Lxcat net
$e^- + C \rightarrow e^- + e^- + C^+$	f(σ)	[35]
$e^- + C_2 \rightarrow e^- + e^- + C_2^+$	f(σ)	[35]
$e^- + C_2 \rightarrow e^- + C + C$	f(σ)	[35]
$e^- + C_3 \rightarrow e^- + C_2 + C$	f(σ)	[35]
$e^- + C_3 \rightarrow e^- + C + C + C$	f(σ)	[35]

Table S6. Electron impact reactions of electrons with positive and negative ions and their corresponding rate coefficients. The rate coefficients [in $cm^3.s^{-1}$] are evaluated using cross section data *f(σ)* or as a function of T_{gas} [in K], with *R* being the gas constant [in $J.K^{-1}.mol^{-1}$]. References are shown in the last column. The table can be found in Appendix.

Reaction	Rate constant	Ref.
$e^- + CH_5^+ \rightarrow CH_4 + H$	$1.40 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.52}$	[41]
$e^- + CH_5^+ \rightarrow CH_3 + H + H$	$1.96 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.52}$	[41]
$e^- + CH_5^+ \rightarrow CH_3 + H_2$	$1.40 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.52}$	[41]
$e^- + CH_5^+ \rightarrow CH_2 + H_2 + H$	$4.76 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.52}$	[41]
$e^- + CH_5^+ \rightarrow CH + H_2 + H_2$	$8.40 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.52}$	[41]
$e^- + CH_4^+ \rightarrow CH_3 + H$	$1.75 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_4^+ \rightarrow CH_2 + H_2$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow CH_2 + H + H$	$1.75 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_4^+ \rightarrow CH + H_2 + H$	$1.41 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_4^+ \rightarrow C + 2H_2$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow CH_2 + H$	$7.75 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_3^+ \rightarrow CH + H_2$	$1.95 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_3^+ \rightarrow CH + H + H$	$2.00 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.40}$	[42]
$e^- + CH_3^+ \rightarrow C + H_2 + H$	$1.69 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_2^+ \rightarrow CH + H$	$1.60 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.60}$	[43]
$e^- + CH_2^+ \rightarrow C + H_2$	$7.68 \times 10^{-8}\ T_{gas}^{-0.60}$	[43]
$e^- + CH_2^+ \rightarrow C + H + H$	$4.03 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.60}$	[43]
$e^- + CH^+ \rightarrow C + H$	$1.50 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.42}$	[42]
$e^- + C^+ \rightarrow C$	$2.36 \times 10^{-12} \left(\frac{T_{gas}}{300}\right)^{-0.29} \exp\left(\frac{17.60}{T_{gas}}\right)$	[44]
$e^- + C_2H_6^+ \rightarrow C_2H_5 + H$	$1.50 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[45]

$e^- + C_2H_6^+ \rightarrow C_2H_4 + H_2$	$1.50 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[45]
$e^- + C_2H_6^+ \rightarrow C_2H_4 + H + H$	$3.36 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.71}$	[45]
$e^- + C_2H_6^+ \rightarrow C_2H_3 + H_2 + H$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow CH_2 + CH_2 + H_2$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow CH_3 + CH_2 + H$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow CH_3 + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow CH_4 + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow C_2H_4 + H$	$3.36 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.79}$	[46]
$e^- + C_2H_5^+ \rightarrow C_2H_3 + H + H$	$7.56 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.79}$	[46]
$e^- + C_2H_5^+ \rightarrow C_2H_2 + H_2 + H$	$8.12 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.79}$	[46]
$e^- + C_2H_5^+ \rightarrow C_2H_2 + H + H + H$	$3.64 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.79}$	[46]
$e^- + C_2H_5^+ \rightarrow CH_3 + CH_2$	$4.76 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.79}$	[46]
$e^- + C_2H_5^+ \rightarrow C_2H_3 + H_2$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow CH_4 + CH$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow C_2H_3 + H$	$6.16 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_4^+ \rightarrow C_2H_2 + H_2$	$3.36 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_4^+ \rightarrow C_2H_2 + H + H$	$3.70 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_4^+ \rightarrow C_2H + H_2 + H$	$5.60 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_4^+ \rightarrow CH_3 + CH$	$1.12 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_4^+ \rightarrow CH_2 + CH_2$	$2.24 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_4^+ \rightarrow CH_4 + C$	$5.60 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H_3^+ \rightarrow C_2H_2 + H$	$1.45 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.84}$	[48]
$e^- + C_2H_3^+ \rightarrow C_2H + H + H$	$2.95 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.84}$	[48]
$e^- + C_2H_3^+ \rightarrow C_2 + H + H_2$	$1.50 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.84}$	[48]
$e^- + C_2H_3^+ \rightarrow C_2H + H_2$	$3.00 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.84}$	[48]

$e^- + C_2H_3^+ \rightarrow CH_2 + CH$	$1.50 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.84}$	[48]
$e^- + C_2H_3^+ \rightarrow CH_3 + C$	$3.00 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.84}$	[48]
$e^- + C_2H_2^+ \rightarrow C_2H + H$	$9.00 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + C_2H_2^+ \rightarrow CH + CH$	$9.00 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + C_2H_2^+ \rightarrow C_2 + H + H$	$9.00 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + C_2H_2^+ \rightarrow CH_2 + C$	f(σ)	[35, 36]
$e^- + C_2H^+ \rightarrow C_2 + H$	$1.16 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H^+ \rightarrow CH + C$	$1.53 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.76}$	[47]
$e^- + C_2H^+ \rightarrow C + C + H$	f(σ)	[35, 36]
$e^- + C_2^+ \rightarrow C + C$	$3.00 \times 10^{-7} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[42]
$e^- + CH_4^+ \rightarrow e^- + C^+ + 2H_2$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + C^+ + H_2 + 2H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + C^+ + 4H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + CH_2^+ + H_2$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + CH_2^+ + H + H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + CH_3^+ + H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + CH^+ + H_2 + H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + CH^+ + 3H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + e^- + CH_3^+ + H^+$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H_2^+ + C + H_2$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H_2^+ + C + H + H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H_2^+ + CH_2$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H_2^+ + CH + H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H_3^+ + CH$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H^+ + CH_2 + H$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H^+ + CH_3$	f(σ)	[35, 36]
$e^- + CH_4^+ \rightarrow e^- + H^+ + CH + H_2$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + C^+ + H_2 + H$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + C^+ + 3H$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + CH_2^+ + H$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + CH^+ + H_2$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + CH^+ + 2H$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + H_2^+ + C + H$	f(σ)	[35, 36]

$e^- + CH_3^+ \rightarrow e^- + H_2^+ + CH$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + H^+ + C + H_2$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + H^+ + CH_2$	f(σ)	[35, 36]
$e^- + CH_3^+ \rightarrow e^- + H^+ + CH + H$	f(σ)	[35, 36]
$e^- + CH_2^+ \rightarrow e^- + C^+ + H_2$	f(σ)	[35, 36]
$e^- + CH_2^+ \rightarrow e^- + C^+ + 2H$	f(σ)	[35, 36]
$e^- + CH_2^+ \rightarrow e^- + CH^+ + H$	f(σ)	[35, 36]
$e^- + CH_2^+ \rightarrow e^- + H_2^+ + C$	f(σ)	[35, 36]
$e^- + CH_2^+ \rightarrow e^- + H^+ + C + H$	f(σ)	[35, 36]
$e^- + CH_2^+ \rightarrow e^- + H^+ + CH$	f(σ)	[35, 36]
$e^- + CH^+ \rightarrow e^- + C^+ + H$	f(σ)	[35, 36]
$e^- + CH^+ \rightarrow e^- + H^+ + C$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow e^- + C_2H_4^+ + H_2$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow e^- + C_2H_5^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_6^+ \rightarrow e^- + CH_3^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow e^- + C_2H_3^+ + H_2$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow e^- + C_2H_3^+ + H + H$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow e^- + C_2H_4^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow e^- + CH_2^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_5^+ \rightarrow e^- + CH_3^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + H_2^+ + C_2H_2$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + C_2H_2^+ + H_2$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + C_2H_3^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + CH_2^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + CH^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + CH_3^+ + CH$	f(σ)	[35, 36]
$e^- + C_2H_4^+ \rightarrow e^- + C^+ + CH_4$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + H^+ + C_2H_2$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + C_2H_2^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + C_2H + H_2^+$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + C_2H^+ + H_2$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + CH^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + CH_2^+ + CH$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + C^+ + CH_3$	f(σ)	[35, 36]
$e^- + C_2H_3^+ \rightarrow e^- + CH_3^+ + C$	f(σ)	[35, 36]
$e^- + C_2H_2^+ \rightarrow e^- + H^+ + C_2H$	f(σ)	[35, 36]
$e^- + C_2H_2^+ \rightarrow e^- + C_2H^+ + H$	f(σ)	[35, 36]
$e^- + C_2H_2^+ \rightarrow e^- + C^+ + CH_2$	f(σ)	[35, 36]
$e^- + C_2H_2^+ \rightarrow e^- + CH_2^+ + C$	f(σ)	[35, 36]
$e^- + C_2H_2^+ \rightarrow e^- + CH^+ + CH$	f(σ)	[35, 36]

$e^- + C_2H^+ \rightarrow e^- + CH^+ + C$	f(σ)	[35, 36]
$e^- + C_2H^+ \rightarrow e^- + C^+ + CH$	f(σ)	[35, 36]
$e^- + H^+ \rightarrow H$	See reference	[49]
$e^- + H_3^+ \rightarrow H_2 + H$	f(σ)	[50, 51]
$e^- + H_3^+ \rightarrow e^- + H_2 + H^+$	f(σ)	[50, 51]
$e^- + H_3^+ \rightarrow H + H + H$	f(σ)	[50, 51]
$e^- + H_2^+ \rightarrow e^- + H + H^+$	f(σ)	[42]
$e^- + H_3^+ \rightarrow e^- + H + H + H^+$	f(σ)	[50, 51]
$e^- + H^- \rightarrow e^- + e^- + H$	f(σ)	Itikawa database – Lxcat net
$e^- + H_2^+ \rightarrow H + H$	See reference	[42]

Table S7. Neutral-neutral pressure-dependent recombination reactions with low pressure (k_0) and high pressure (k_∞) limit rate coefficients, with T_{gas} being the gas temperature [in K]. The respective rate coefficients [in $cm^3.s^{-1}$] k_0 and k_∞ of each reaction are also given alongside the falloff curve expression (F_C) which incorporates the Troe parameters. k_0, k_∞ and F_C were used to calculate the rate coefficients of pressure dependent reactions (see details in Ref. [13]). References are shown in the last column. The table can be found in Appendix.

Reaction	Rate coefficient	Ref.
$CH_3 + H \rightarrow CH_4$	$k_0 = 1.5625 \times 10^{-26} * \exp\left(\left(-\frac{T_{gas}}{21220}\right)^2\right)$ $k\infty = (3.34 \times 10^{-10}) * \left(\frac{T_{gas}}{298.15}\right)^{-0.186} * \exp\left(-\frac{T_{gas}}{25200}\right)$ $F_C = (0.710) * \exp\left(-\frac{T_{gas}}{3079}\right) + 0.290 * \exp\left(-\frac{T_{gas}}{54}\right)$	[52]
$CH_3 + CH_3 \rightarrow C_2H_6$	$k_0 = (3.50 \times 10^{-7}) * (T_{gas})^{-7.0} * \exp\left(-\frac{1390}{T_{gas}}\right)$ $k\infty = (6.00 \times 10^{-11})$ $F_C = 0.381 * \exp\left(-\frac{T_{gas}}{73}\right) + 0.619 * \exp\left(-\frac{T_{gas}}{1180}\right)$	[53]
$CH_2 + H \rightarrow CH_3$	$k_0 = 1.5625 * (9.00 \times 10^{-32}) * \exp\left(-\frac{550}{T_{gas}}\right)$ $k\infty = (8.55 \times 10^{-12}) * (T_{gas})^{0.15}$ $F_C = (1 - 0.562) * \exp\left(-\frac{T_{gas}}{91}\right) + 0.562 * \exp\left(-\frac{T_{gas}}{5836}\right) + \exp\left(-\frac{8552}{T_{gas}}\right)$	[53]
$CH + H_2 \rightarrow CH_3$	$k = 1.5625 * (4.70 \times 10^{-26}) * T_{gas}^{-1.60}$ $k\infty = (8.50 \times 10^{-11}) * (T_{gas})^{0.15}$ $F_C = (1 - 0.578) + \left(0.25 * \exp\left(-\frac{T_{gas}}{300}\right)\right)$	[53]
$H + C_2H_4 \rightarrow C_2H_5$	$k_0 = (1.30 \times 10^{-29}) * \exp\left(-\frac{380}{T_{gas}}\right)$	[13]

	$k\infty = (6.60 \times 10^{-15}) * (T_{gas})^{1.28} * \exp\left(-\frac{650}{T_{gas}}\right)$ $F_C = (0.240) * \exp\left(-\frac{T_{gas}}{40}\right) + 0.760 * \exp\left(-\frac{T_{gas}}{1025}\right)$	
$C_2H_4 \rightarrow C_2H_2 + H_2$	$k_0 = (1.70 \times 10^{-6}) * T_{gas} * \exp\left(-\frac{39390}{T_{gas}}\right)$ $k\infty = (8.00 \times 10^{12}) * (T_{gas})^{0.44} * \exp\left(-\frac{88770}{T_{gas}}\right)$ $F_C = (1 - 0.735) * \exp\left(-\frac{T_{gas}}{180}\right) + 0.735 * \exp\left(-\frac{T_{gas}}{1035}\right) + \exp\left(-\frac{5417}{T_{gas}}\right)$	[13]
$H + C_2H_5 \rightarrow C_2H_6$	$k_0 = 0.56 * (4.00 \times 10^{-19}) * (T_{gas})^{-3.00} * \exp\left(-\frac{600}{T_{gas}}\right)$ $k\infty = (2.00 \times 10^{-10})$ $F_C = (1 - 0.842) * \exp\left(-\frac{T_{gas}}{125}\right) + 0.842 * \exp\left(-\frac{T_{gas}}{2219}\right) + \exp\left(-\frac{6682}{T_{gas}}\right)$	[13]
$H + C_2H_3 \rightarrow C_2H_4$	$k_0 = 3.50 \times 10^{-27}$ $k\infty = 1.60 \times 10^{-10}$ $F_C = 0.5$	[13]
$H + C_2H_2 \rightarrow C_2H_3$	$k_0 = (1.60 \times 10^{-20}) * (T_{gas})^{-3.47} * \exp\left(-\frac{475}{T_{gas}}\right)$ $k\infty = (9.20 \times 10^{-16}) * (T_{gas})^{1.64} * \exp\left(-\frac{1055}{T_{gas}}\right)$ $F_C = 7.94 \times 10^{-4} * (T_{gas})^{0.78}$	[13]
$H + C_2H \rightarrow C_2H_2$	$k_0 = (1.26 \times 10^{-18}) * (T_{gas})^{-3.10} * \exp\left(-\frac{721}{T_{gas}}\right)$ $k\infty = (3.00 \times 10^{-10})$ $F_C = (1 - 0.646) * \exp\left(-\frac{T_{gas}}{132}\right) + 0.65 * \exp\left(-\frac{T_{gas}}{1315}\right) + \exp\left(-\frac{5566}{T_{gas}}\right)$	[13]
$C_2H_6 \rightarrow CH_3 + CH_3$	$k_0 = (2.60 \times 10^{25}) * (T_{gas})^{-8.37} * \exp\left(-\frac{47290}{T_{gas}}\right)$ $k\infty = (4.50 \times 10^{21}) * (T_{gas})^{-1.37} * \exp\left(-\frac{45900}{T_{gas}}\right)$ $F_C = (0.38) * \exp\left(-\frac{T_{gas}}{73}\right) + 0.62 * \exp\left(-\frac{T_{gas}}{1180}\right)$	[13]
$CH_4 \rightarrow H + CH_3$	$k_0 = (1.40 \times 10^{-6}) * \exp\left(-\frac{45700}{T_{gas}}\right)$ $k\infty = (2.40 \times 10^{16}) * \exp\left(-\frac{52800}{T_{gas}}\right)$ $F_C = (0.31) * \exp\left(-\frac{T_{gas}}{91}\right) + 0.69 * \exp\left(-\frac{T_{gas}}{2207}\right)$	[52]
$C_2H_3 \rightarrow C_2H_2 + H$	$k = (4.30 \times 10^{3}) * (T_{gas})^{-3.40} * \exp\left(-\frac{18020}{T_{gas}}\right)$	[13]

	$k\infty = (3.90 \times 10^{8}) * (T_{gas})^{1.62} * \exp\left(-\frac{18650}{T_{gas}}\right)$ $F_C = (7.37 \times 10^{-4}) * (T_{gas})^{0.80}$	
$C_2H_5 \rightarrow C_2H_4 + H$	$K_0 = (1.70 \times 10^{-6}) * \exp\left(-\frac{16800}{T_{gas}}\right)$ $K\infty = (8.20 \times 10^{13}) * \exp\left(-\frac{20070}{T_{gas}}\right)$ $F_C = (0.25) * \exp\left(-\frac{T_{gas}}{97}\right) + 0.75 * \exp\left(-\frac{T_{gas}}{1379}\right)$	[13]
$H + H \rightarrow H_2$	$k_0 = 1.5625 * (2.70 \times 10^{-31}) * (T_{gas})^{-0.60}$ $k\infty = (1.00 \times 10^{-11})$ $F_C = (0.0506) * (T_{gas})^{0.40}$	[54]
$C + H_2 \rightarrow CH_2$	$k_0 = 1.5625 * (7.00 \times 10^{-32})$ $k\infty = (2.06 \times 10^{-11}) * \exp\left(-\frac{57}{T_{gas}}\right)$ $F_C = (0.0506) * (T_{gas})^{0.40}$	[55]

Table S8. Neutral-neutral molecular recombination reactions and their corresponding rate coefficients [in cm^3.s^{-1} or cm^6.s^{-1}], with T_{gas} being the gas temperature [in K] and R being the gas constant [in J.mol^{-1}.K^{-1}]. References are shown in the last column. The table can be found in Appendix.

Reaction	Rate coefficient	Ref.
$CH_4 + CH_3 \rightarrow H + C_2H_6$	$4.95 \times 10^{-13}\left(\frac{T_{gas}}{298.15}\right)\exp\left(-\frac{188000}{RT_{gas}}\right)$	[56]
$CH_4 + CH_3 \rightarrow H_2 + C_2H_5$	$1.66 \times 10^{-11}\exp\left(\frac{-96450}{RT_{gas}}\right)$	[56]
$CH_4 + CH_2 \rightarrow CH_3 + CH_3$	$7.14 \times 10^{-12}\exp\left(-\frac{41990}{RT_{gas}}\right)$	[57]
$CH_4 + CH \rightarrow C_2H_4 + H$	1.70×10^{-11}	[58]
$CH_4 + C \rightarrow CH + CH_3$	$8.30 \times 10^{-11}\, exp\left(-\frac{24.015}{1.987 \times T_{gas}}\right)$	[59]
$CH_4 + C \rightarrow C_2H_4$	5.00×10^{-15}	[59]
$CH_4 + C_2H_5 \rightarrow C_2H_6 + CH_3$	$2.51 \times 10^{-15}\left(\frac{T_{gas}}{298.15}\right)^{2.84}\exp\left(-\frac{52550}{RT_{gas}}\right)$	[60]
$CH_4 + C_2H_3 \rightarrow C_2H_4 + CH_3$	$2.13 \times 10^{-14}\left(\frac{T_{gas}}{298.15}\right)^{4.02}\exp\left(-\frac{22860}{RT_{gas}}\right)$	[60]
$CH_4 + C_2H \rightarrow C_2H_2 + CH_3$	$3.01 \times 10^{-12}\exp\left(-\frac{2080}{RT_{gas}}\right)$	[60]
$CH_4 + H \rightarrow CH_3 + H_2$	$4.63 \times 10^{-13}\left(\frac{T_{gas}}{298.15}\right)^{3.16}\exp\left(-\frac{36630}{RT_{gas}}\right)$	[61]

$CH_3 + CH_3 \rightarrow C_2H_5 + H$	$1.46 \times 10^{-11} \left(\frac{T_{gas}}{298.15}\right)^{0.10} \exp\left(-\frac{44400}{RT_{gas}}\right)$	[62]
$CH_3 + CH_3 \rightarrow CH_2 + CH_4$	$1.16 \times 10^{-13} \left(\frac{T_{gas}}{298.15}\right)^{1.34} \exp\left(-\frac{67910}{RT_{gas}}\right)$	[63]
$CH_3 + CH_3 \rightarrow C_2H_4 + H_2$	$1.66 \times 10^{-8} \exp\left(-\frac{138000}{RT_{gas}}\right)$	[64]
$CH_3 + CH_2 \rightarrow C_2H_4 + H$	5.01×10^{-11}	[65]
$CH_3 + C_2H_6 \rightarrow C_2H_5 + CH_4$	$1.74 \times 10^{-16} \left(\frac{T_{gas}}{298}\right)^{6.00} \exp\left(-\frac{25280}{RT_{gas}}\right)$	[60]
$CH_3 + C_2H_5 \rightarrow C_2H_4 + CH_4$	$1.88 \times 10^{-12} \left(\frac{T_{gas}}{298.0}\right)^{-0.5}$	[60]
$CH_3 + C_2H_5 \rightarrow C_2H_6 + CH_2$	$3.0 \times 10^{-44} (T_{gas})^{9.0956}$	[60]
$CH_3 + C_2H_4 \rightarrow C_2H_3 + CH_4$	$6.91 \times 10^{-12} \exp\left(-\frac{46560}{RT_{gas}}\right)$	[60]
$CH_3 + C_2H_3 \rightarrow C_2H_2 + CH_4$	$1.5 \times 10^{-11} \exp\left(\frac{3200}{RT_{gas}}\right)$	[66]
$CH_3 + C_2H_2 \rightarrow CH_4 + C_2H$	$3.01 \times 10^{-13} \exp\left(-\frac{72340}{RT_{gas}}\right)$	[60]
$CH_3 + H_2 \rightarrow CH_4 + H$	$2.52 \times 10^{-14} \left(\frac{T_{gas}}{298}\right)^{3.12} \exp\left(\frac{36420}{RT_{gas}}\right)$	[61]
$CH_3 + H \rightarrow CH_2 + H_2$	$1.00 \times 10^{-10} \exp\left(-\frac{63190}{RT_{gas}}\right)$	[61]
$CH_3 \rightarrow H_2 + CH$	$8.30 \times 10^{-9} \exp\left(-\frac{356000}{RT_{gas}}\right)$	[13]
$CH_3 \rightarrow CH_2 + H$	$1.69 \times 10^{-8} \exp\left(-\frac{379000}{RT_{gas}}\right)$	[13]
$CH_2 + CH_2 \rightarrow C_2H_2 + H + H$	$3.32 \times 10^{-10} \exp\left(-\frac{45980}{RT_{gas}}\right)$	[57]
$CH_2 + CH_2 \rightarrow C_2H_2 + H_2$	$2.62 \times 10^{-9} \exp\left(-\frac{49970}{RT_{gas}}\right)$	[57]
$CH_2 + CH_3 \rightarrow C_2H_5$	$7.00 \times 10^{-23} (T_{gas})^{3.6337}$	[57]
$CH_2 + C_2H_6 \rightarrow C_2H_5 + CH_3$	$9.0 \times 10^{-33} (T_{gas})^{6.4162}$	[57]
$CH_2 + C_2H_5 \rightarrow C_2H_4 + CH_3$	8.01×10^{-11}	[57]
$CH_2 + C_2H_3 \rightarrow C_2H_2 + CH_3$	8.01×10^{-11}	[57]
$CH_2 + C_2H \rightarrow C_2H_2 + CH$	3.01×10^{-11}	[57]
$CH_2 + H_2 \rightarrow CH_3 + H$	$3.59 \times 10^{-13} \left(\frac{T_{gas}}{298}\right)^{2.30} \exp\left(-\frac{30760}{RT_{gas}}\right)$	[57]
$CH_2 + H \rightarrow CH + H_2$	$1.00 \times 10^{-11} \exp\left(\frac{7480}{RT_{gas}}\right)$	[63]

$CH_2 \rightarrow C + H_2$	$5.00 \times 10^{-10} \exp\left(-\frac{32600}{T_{gas}}\right)$	[57]
$CH_2 \rightarrow CH + H$	$1.56 \times 10^{-8} \exp\left(-\frac{44880}{T_{gas}}\right)$	[57]
$CH + H_2 \rightarrow CH_2 + H$	$1.48 \times 10^{-11} \left(\frac{T_{gas}}{298.0}\right)^{1.79} \exp\left(-\frac{6980}{RT_{gas}}\right)$	[58]
$CH + H \rightarrow C + H_2$	$6.50 \times 10^{-10} (T_{gas})^{0.01} \exp\left(-\frac{22330}{RT_{gas}}\right)$	[64]
$CH + CH_3 \rightarrow C_2H_3 + H$	$\left(\frac{3.0 \times 10^{13}}{6.0223 \times 10^{23}}\right)$	[58]
$CH + CH_2 \rightarrow C_2H_2 + H$	$\left(\frac{4.0 \times 10^{13}}{6.0223 \times 10^{23}}\right)$	[58]
$CH + CH \rightarrow C_2H_2$	1.99×10^{-10}	[58]
$CH + C_2H_2 \rightarrow C_2H + CH_2$	$3.80 \times 10^{-8} (T_{gas})^{-0.859} \exp\left(-\frac{33.5}{T_{gas}}\right)$	[67]
$CH + C_2H_3 \rightarrow CH_2 + C_2H_2$	8.3×10^{-11}	[67]
$CH + C_2H_4 \rightarrow C_2H_2 + CH_3$	$0.50 \times 1.59 \times 10^{-9} (T_{gas})^{-0.546} \exp\left(-\frac{29.6}{T_{gas}}\right)$	[67]
$CH + C_2H_4 \rightarrow CH_4 + C_2H$	$0.50 \times 1.59 \times 10^{-9} (T_{gas})^{-0.546} \exp\left(-\frac{29.6}{T_{gas}}\right)$	[67]
$CH + C_2H_6 \rightarrow C_2H_4 + CH_3$	$3.80 \times 10^{-8} (T_{gas})^{-0.859} \exp\left(-\frac{53.2}{T_{gas}}\right)$	[67]
$CH \rightarrow C + H$	$3.16 \times 10^{-10} \exp\left(-\frac{280000}{RT_{gas}}\right)$	[58]
$C_2H_6 + C_2H_3 \rightarrow C_2H_5 + C_2H_4$	$1.46 \times 10^{-13} \left(\frac{T_{gas}}{298}\right)^{3.30} \exp\left(-\frac{43900}{RT_{gas}}\right)$	[68]
$C_2H_6 + C_2H \rightarrow C_2H_2 + C_2H_5$	$3.50 \times 10^{-11} \exp\left(\frac{20}{RT_{gas}}\right)$	[13]
$C_2H_6 + H \rightarrow C_2H_5 + H_2$	$1.23 \times 10^{-11} \left(\frac{T_{gas}}{298}\right)^{1.50} \exp\left(-\frac{31010}{RT_{gas}}\right)$	[63]
$H + C_2H_6 \rightarrow CH_4 + CH_3$	$8.97 \times 10^{-20} \exp\left(-\frac{48640}{RT_{gas}}\right)$	[64]
$C_2H_6 \rightarrow C_2H_5 + H$	$8.11 \times 10^{17} \left(\frac{T_{gas}}{298}\right)^{-1.23} \exp\left(-\frac{427000}{RT_{gas}}\right)$	[69]
$C_2H_6 \rightarrow C_2H_4 + H_2$	$1.32 \times 10^{15} \exp\left(-\frac{306000}{RT_{gas}}\right)$	[69]
$C_2H_5 + C_2H_3 \rightarrow C_2H_6 + C_2H_2$	2.3985×10^{-11}	[66]
$C_2H_5 + C_2H_3 \rightarrow C_2H_4 + C_2H_4$	9.60×10^{-11}	[66]
$C_2H_5 + C_2H_5 \rightarrow C_2H_6 + C_2H_4$	2.41×10^{-12}	[13]
$C_2H_5 + C_2H_4 \rightarrow C_2H_6 + C_2H_3$	$5.83 \times 10^{-14} \left(\frac{T_{gas}}{298}\right)^{3.13} \exp\left(-\frac{75330}{RT_{gas}}\right)$	[13]

$C_2H_5 + C_2H_2 \rightarrow C_2H_6 + C_2H$	$4.50 \times 10^{-13} \exp\left(-\frac{98110}{RT_{gas}}\right)$	[68]
$C_2H_5 + C_2H \rightarrow C_2H_4 + C_2H_2$	3.01×10^{-12}	[68]
$C_2H_5 + H_2 \rightarrow C_2H_6 + H$	$5.10 \times 10^{-24} \left(\frac{T_{gas}}{298}\right)^{3.60} \exp\left(-\frac{35340}{RT_{gas}}\right)$	[13]
$H + C_2H_5 \rightarrow CH_3 + CH_3$	$1.79 \times 10^{-10} \exp\left(-\frac{3640}{RT_{gas}}\right)$	[13]
$H + C_2H_5 \rightarrow C_2H_4 + H_2$	3.321×10^{-12}	[68]
$C_2H_5 \rightarrow CH_2 + CH_3$	$1.0 \times 10^{-118} (T_{gas})^{37.47}$	[69]
$C_2H_4 + C_2H \rightarrow C_2H_2 + C_2H_3$	1.40×10^{-10}	[68]
$C_2H_4 + C_2H_2 \rightarrow C_2H_3 + C_2H_3$	$4.0 \times 10^{-11} \exp\left(-\frac{286000}{RT_{gas}}\right)$	[68]
$C_2H_4 + C_2H_4 \rightarrow C_2H_5 + C_2H_3$	$8.0 \times 10^{-10} \exp\left(-\frac{299000}{RT_{gas}}\right)$	[68]
$C_2H_4 + H \rightarrow C_2H_3 + H_2$	$8.41 \times 10^{-17} (T_{gas})^{1.93} \exp\left(-\frac{6518}{T_{gas}}\right)$	[63]
$C_2H_4 + H_2 \rightarrow C_2H_5 + H$	$1.69 \times 10^{-11} \exp\left(-\frac{285000}{RT_{gas}}\right)$	[68]
$C_2H_4 + H_2 \rightarrow C_2H_6$	$1.03 \times 10^{-15} \exp\left(-\frac{175000}{RT_{gas}}\right)$	[70]
$C_2H_4 + C \rightarrow C_2H_2 + CH_2$	1.24×10^{-11}	[71]
$C_2H_4 \rightarrow C_2H_3 + H$	$2.00 \times 10^{16} \exp\left(-\frac{461000}{RT_{gas}}\right)$	[69]
$C_2H_3 + C_2H_3 \rightarrow C_2H_4 + C_2H_2$	3.50×10^{-11}	[68]
$C_2H_3 + C_2H \rightarrow C_2H_2 + C_2H_2$	3.15×10^{-11}	[68]
$C_2H_3 + H_2 \rightarrow C_2H_4 + H$	$1.61 \times 10^{-13} \left(\frac{T_{gas}}{298}\right)^{2.63} \exp\left(-\frac{35750}{RT_{gas}}\right)$	[72]
$C_2H_3 + H \rightarrow C_2H_2 + H_2$	$1.50 \times 10^{-12} (T_{gas})^{0.50}$	[13]
$C_2H_2 + C_2H_2 \rightarrow C_2H + C_2H_3$	$1.6 \times 10^{-11} \exp\left(-\frac{353000}{RT_{gas}}\right)$	[68]
$C_2H_2 + H_2 \rightarrow C_2H_4$	$5.0 \times 10^{-13} \exp\left(-\frac{163000}{RT_{gas}}\right)$	[68]
$C_2H_2 + H_2 \rightarrow C_2H_3 + H$	$1.33 \times 10^{-12} \exp\left(-\frac{236000}{RT_{gas}}\right)$	[68]
$C_2H_2 + H \rightarrow C_2H + H_2$	$2.77 \times 10^{-10} \left(\frac{T_{gas}}{298.0}\right)^{1.32} \exp\left(-\frac{128000}{RT_{gas}}\right)$	[64]
$C_2H_2 \rightarrow C_2H + H$	$2.63 \times 10^{15} \exp\left(-\frac{519000}{RT_{gas}}\right)$	[69]
$C_2H + C_2H \rightarrow C_2H_2 + C_2$	3.01×10^{-12}	[68]

$C_2H + H_2 \rightarrow C_2H_2 + H$	$1.59 \times 10^{-11} \left(\frac{T_{gas}}{298}\right)^{0.90} \exp\left(-\frac{8310}{RT_{gas}}\right)$	[68]
$H + C_2H \rightarrow H_2 + C_2$	$5.99 \times 10^{-11} \exp\left(-\frac{118000}{RT_{gas}}\right)$	[63]
$C + C \rightarrow C_2$	2.20×10^{-11}	[73]
$C_2 \rightarrow C + C_s$	$1.5 \times 10^{16} \exp\left(-\frac{594630}{RT_{gas}}\right)$	[74]
$C_2 + M \rightarrow C + C_s + M$	$2.49 \times 10^{-8} \exp\left(-\frac{595000}{RT_{gas}}\right)$	[74]
$C_3 \rightarrow C_2 + C_s$	$3.474 \times 10^{11} (T_{gas})^{1.1256} \exp\left(-\frac{131430}{RT_{gas}}\right)$	[74]
$C_2 + C_2 \rightarrow C + C_3$	5.31×10^{-10}	[74]
$C + H_2 \rightarrow CH + H$	$6.64 \times 10^{-10} \exp\left(-\frac{97280}{RT_{gas}}\right)$	[59]
$C + CH_2 \rightarrow CH + CH$	$2.69 \times 10^{-12} \exp\left(-\frac{196000}{RT_{gas}}\right)$	[75]
$C + CH_2 \rightarrow H + C_2H$	8.30×10^{-11}	[76]
$C + CH_3 \rightarrow H + C_2H_2$	8.30×10^{-11}	[76]
$C_2 + H_2 \rightarrow C_2H_2$	$1.77 \times 10^{-10} \exp\left(-\frac{1470}{T_{gas}}\right)$	[64]
$C_2 + H_2 \rightarrow C_2H + H$	$1.10 \times 10^{-10} \exp\left(-\frac{33260}{RT_{gas}}\right)$	[64]
$C_2 + CH_4 \rightarrow C_2H + CH_3$	$5.05 \times 10^{-11} \exp\left(-\frac{297}{T_{gas}}\right)$	[64]
$H_2 + M \rightarrow H + H + M$	$3.64 \times 10^{-8} \left(\frac{T_{gas}}{298.15}\right)^{-1.00} \exp\left(-\frac{431000}{RT_{gas}}\right)$	[54]
$H_2 + H \rightarrow H + H + H$	See reference	[77]
$H + H \rightarrow e^- + H + H^+$	See reference	[49]
$H^* + M \rightarrow H + M$	See reference	[78]
$CH_3CH_2CH_2 + H \rightarrow CH_3CH_2CH_3$	1.6605×10^{-10}	[79-81]
$CH_3CH_2CH_3 + H \rightarrow CH_3CH_2CH_2 + H_2$	$2.9059 \times 10^{-19} (T_{gas})^{2.69} \exp\left(-\frac{26987}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + C_2H_3 \rightarrow CH_3CH_2CH_2 + C_2H_4$	$1.6605 \times 10^{-13} \exp\left(-\frac{43514}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + C_2H_5 \rightarrow CH_3CH_2CH_2 + C_2H_6$	$1.6605 \times 10^{-13} \exp\left(-\frac{43514}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CH_3 \rightarrow CH_3CH_2CH_2$	$1.2736 \times 10^{24} (T_{gas})^{-11.17} \exp\left(-\frac{93579}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_3CH_2CH_2 \rightarrow C_2H + CH_3CH_2CH_3$	$4.4835 \times 10^{-20} (T_{gas})^{2.0} \exp\left(-\frac{55501}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + H \rightarrow CH_3CH_2CH_3$	1.6605×10^{-10}	[79-81]

$CH_3CHCH_3 + CH_3CH_2CH_3 \rightarrow CH_3CH_2CH_2 + CH_3CH_2CH_3$	$4.9816 \times 10^{-14} \exp\left(-\frac{53974}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + H \rightarrow CH_3CHCH_3 + H_2$	$1.0794 \times 10^{-18}(T_{gas})^{2.4} \exp\left(-\frac{18707}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + CH_3 \rightarrow CH_3CHCH_3 + CH_4$	$1.0627 \times 10^{-19}(T_{gas})^{2.17} \exp\left(-\frac{31464}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + C_2H_3 \rightarrow CH_3CHCH_3 + C_2H_4$	$1.6605 \times 10^{-13} \exp\left(-\frac{43514}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + C_2H_5 \rightarrow CH_3CHCH_3 + C_2H_6$	$1.6605 \times 10^{-13} \exp\left(-\frac{43514}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + H \rightarrow C_2H_5 + CH_3$	3.3211×10^{-11}	[79-81]
$CH_3CHCH_3 + C_2H_5 \rightarrow CH_3CH_2CH_3 + C_2H_4$	8.3027×10^{-13}	[79-81]
$CH_3CHCH_3 \rightarrow CH_3CH_2CH_2$	$3.3211 \times 10^{-12} \exp\left(-\frac{175728}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + C_2H_2 \rightarrow CH_3CH_2CH_3 + C_2H$	$4.4835 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{71396}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 \rightarrow C_2H_3 + CH_3$	$9.6311 \times 10^{51}(T_{gas})^{-17.2} \exp\left(-\frac{560656}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 \rightarrow C_2H_4 + CH_3$	$4.4336 \times 10^{-12}(T_{gas})^{0.47} \exp\left(-\frac{22723}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + H \rightarrow CH_3CH_2CH_2$	$1.7270 \times 10^{25}(T_{gas})^{-11.5} \exp\left(-\frac{64262}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + H \rightarrow CH_3CHCH_3$	$5.4134 \times 10^{37}(T_{gas})^{-14.94} \exp\left(-\frac{84354}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + CH_3 \rightarrow CH_2CHCH_3 + CH_4$	9.632×10^{-14}	[79-81]
$CH_2CHCH_3 + C_2H_5 \rightarrow CH_3CH_2CH_2 + C_2H_4$	$1.6605 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + C_2H_4 \rightarrow CH_2CHCH_3 + C_2H_5$	$1.6605 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3CHCH_3 \rightarrow CH_2CHCH_3 + CH_3CH_2CH_2$	$8.3027 \times 10^{-14} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 \rightarrow CH_2CHCH_3 + H_2$	$8.3027 \times 10^{-11} \exp\left(-\frac{292880}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3CHCH_3$	$1.3175 \times 10^{-12} \exp\left(-\frac{67781}{RT_{gas}}\right)$	[79-81]

$CH_2CHCH_2 + CH_3CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3CH_2CH_2$	$1.3175 \times 10^{-12} \exp\left(-\frac{85772}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_3 \rightarrow CH_2CHCH_2 + H$	$8.8009 \times 10^{4}(T_{gas})^{-4.57} \exp\left(-\frac{60250}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 \rightarrow CH_2CHCH_2 + H$	$1.7934 \times 10^{47}(T_{gas})^{-1.59} \exp\left(-\frac{522414}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + H \rightarrow CH_2CHCH_2 + H_2$	$6.0510 \times 10^{-19}(T_{gas})^{2.455} \exp\left(-\frac{18246}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3 \rightarrow CH_2CHCH_2 + CH_4$	$3.3211 \times 10^{-24}(T_{gas})^{3.5} \exp\left(-\frac{23744}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + C_2H_5 \rightarrow CH_2CHCH_2 + C_2H_6$	$1.6605 \times 10^{-13} \exp\left(-\frac{41003}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + C_2H_5 \rightarrow CH_2CHCH_3 + C_2H_4$	6.6422×10^{-13}	[79-81]
$C_2H_2 + CH_3 \rightarrow CH_2CHCH_2$	$4.4502 \times 10^{29}(T_{gas})^{-12.82} \exp\left(-\frac{149494}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_2CHCH_3 \rightarrow C_2H_3 + CH_2CHCH_2$	$6.6422 \times 10^{-11} \exp\left(-\frac{195811}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_2CHCH_3 \rightarrow CH_2CHCH_2 + CH_3CH_2CH_2$	$1.6605 \times 10^{-9} \exp\left(-\frac{284512}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_2CHCH_3 \rightarrow CH_2CHCH_2 + CH_3CHCH_3$	$1.6605 \times 10^{-9} \exp\left(-\frac{284512}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_2CHCH_2 \rightarrow C_2H + CH_2CHCH_3$	$1.7901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{85487}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CH_2CHCH_2 \rightarrow C_2H_3 + CH_2CHCH_3$	$7.1602 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{85487}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_2CHCH_3 \rightarrow C_2H_4 + CH_2CHCH_2$	$3.775 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18543}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 \rightarrow CHCHCH_3 + H$	$1.2803 \times 10^{46}(T_{gas})^{-16.09} \exp\left(-\frac{585760}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + H \rightarrow CHCHCH_3 + H_2$	$8.4687 \times 10^{-22}(T_{gas})^{3.234} \exp\left(-\frac{51702}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3 \rightarrow CHCHCH_3 + CH_4$	$1.6605 \times 10^{-24}(T_{gas})^{3.5} \exp\left(-\frac{53764}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 \rightarrow CHCHCH_3$	$8.3027 \times 10^{27}(T_{gas})^{-13.02} \exp\left(-\frac{306687}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_3 \rightarrow CHCHCH_3$	$1.976 \times 10^{20}(T_{gas})^{-10.19} \exp\left(-\frac{78358}{RT_{gas}}\right)$	[79-81]

$C_2H_2 + CHCHCH_3 \rightarrow C_2H + CH_2CHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_2H_6 + CHCHCH_3 \rightarrow C_2H_5 + CH_2CHCH_3$	$4.0351 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CHCHCH_3 \rightarrow C_2H_3 + CH_2CHCH_3$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + CHCHCH_3 \rightarrow CH_2CHCH_3 + CH_3CH_2CH_2$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + CHCHCH_3 \rightarrow CH_2CHCH_3 + CH_3CHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CHCHCH_3 \rightarrow CH_2CHCH_2 + CH_2CHCH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_2CHCH_3 \rightarrow C_2H_4 + CHCHCH_3$	$4.5034 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{36865}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_2CHCH_3 \rightarrow C_2H_6 + CHCHCH_3$	$1.3284 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53815}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3CH_2CH_2 \rightarrow CH_3CH_2CH_3 + CHCHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{53815}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3CHCH_3 \rightarrow CH_3CH_2CH_3 + CHCHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{69714}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_2CHCH_3 \rightarrow CH_2CHCH_3 + CHCHCH_3$	$3.5801 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{85487}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + H \rightarrow CH_2CHCH_3$	$3.8358 \times 10^{36}(T_{gas})^{-14} \exp\left(-\frac{916296}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + H \rightarrow CH_2CHCH_2 + H$	$4.9484 \times 10^{6}(T_{gas})^{-4.79} \exp\left(-\frac{50208}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + H \rightarrow C_2H_3 + CH_3$	$3.3377(T_{gas})^{-2.86} \exp\left(-\frac{45.6056}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + H \rightarrow CH_2CCH_3 + H_2$	$2.4742 \times 10^{-22}(T_{gas})^{3.3810} \exp\left(-\frac{37275}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 \rightarrow CH_2CCH_3$	$1.1723 \times 10^{33}(T_{gas})^{-14.08} \exp\left(-\frac{317432}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_3 \rightarrow CH_2CCH_3$	$8.2861 \times 10^{-2}(T_{gas})^{-4.39} \exp\left(-\frac{78868}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 \rightarrow CHCHCH_3$	$2.4908 \times 10^{24}(T_{gas})^{-12.71} \exp\left(-\frac{225518}{RT_{gas}}\right)$	[79-81]

$C_2H_2 + CH_2CCH_3 \rightarrow C_2H + CH_2CHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CH_2CCH_3 \rightarrow C_2H_3 + CH_2CHCH_3$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_2H_6 + CH_2CCH_3 \rightarrow C_2H_5 + CH_2CHCH_3$	$4.0351 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_3CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3CH_2CH_2$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_3CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3CHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_2CHCH_3 \rightarrow CH_2CHCH_2 + CH_2CHCH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_2CHCH_3 \rightarrow CH_2CHCH_3 + CHCHCH_3$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_2CHCH_3 \rightarrow C_2H_4 + CH_2CCH_3$	$1.5762 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{36865}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_2CHCH_3 \rightarrow C_2H_6 + CH_2CCH_3$	$4.6495 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{53815}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3CH_2CH_2 \rightarrow CH_2CCH_3 + CH_3CH_2CH_3$	$3.1384 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{53815}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_3CHCH_3 \rightarrow CH_2CCH_3 + CH_3CH_2CH_3$	$3.1384 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{69714}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CHCHCH_3 \rightarrow CH_2CCH_3 + CH_2CHCH_3$	$6.2768 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_2CHCH_2 \rightarrow CH_2CCH_3 + CH_2CHCH_3$	$1.253 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{85487}{RT_{gas}}\right)$	[79-81]
$CHCHCH_3 + H \rightarrow CH_3CCH + H_2$	5.5462×10^{-12}	[79-81]
$CH_3 + CHCHCH_3 \rightarrow CH_3CCH + CH_4$	1.6605×10^{-13}	[79-81]
$CH_2CCH_3 + H \rightarrow CH_3CCH + H_2$	5.5462×10^{-12}	[79-81]
$CH_2CCH_3 + CH_3 \rightarrow CH_3CCH + CH_4$	1.6605×10^{-13}	[79-81]
$CH_3CCH + H \rightarrow CH_2CCH_3$	$1.1508 \times 10^{16}(T_{gas})^{-9.11} \exp\left(-\frac{31204}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + H \rightarrow CHCHCH_3$	$2.2749 \times 10^{27}(T_{gas})^{-12.55} \exp\left(-\frac{64551}{RT_{gas}}\right)$	[79-81]

$CH_3CCH + H \rightarrow C_2H_2 + CH_3$	$5.7455 \times 10^{-12}(T_{gas})^{0.442} \exp\left(-\frac{22857}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + H \rightarrow CH_2CHCH_2$	$8.1532 \times 10^{36}(T_{gas})^{-14.37} \exp\left(-\frac{132398}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 \rightarrow CH_3CCH + H_2$	$2.989 \times 10^{-11} \exp\left(-\frac{326352}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + H \rightarrow H_2CCCH_2 + H_2$	$2.0458 \times 10^{-21}(T_{gas})^{3.035} \exp\left(-\frac{10803}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3 \rightarrow H_2CCCH_2 + CH_4$	$4.9816 \times 10^{-12}(T_{gas})^{-0.32} \exp\left(-\frac{548}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + C_2H_5 \rightarrow H_2CCCH_2 + C_2H_6$	6.6422×10^{-13}	[79-81]
$CH_2CHCH_2 + C_2H_3 \rightarrow H_2CCCH_2 + C_2H_4$	1.6605×10^{-12}	[79-81]
$CHCHCH_3 + H \rightarrow H_2CCCH_2 + H_2$	5.5346×10^{-12}	[79-81]
$CHCHCH_3 + CH_3 \rightarrow H_2CCCH_2 + CH_4$	1.6605×10^{-13}	[79-81]
$CH_2CHCH_2 + CH_2CHCH_2 \rightarrow CH_2CHCH_3 + H_2CCCH_2$	$7.9208 \times 10^{16}(T_{gas})^{-9.3} \exp\left(-\frac{52174}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H \rightarrow CH_3CCH + H$	$4.1181 \times 10^{-9}(T_{gas})^{-0.33} \exp\left(-\frac{26928}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H \rightarrow CH_2CHCH_2$	$2.2749 \times 10^{27}(T_{gas})^{-12.55} \exp\left(-\frac{64551}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H \rightarrow CHCHCH_3$	$9.5491 \times 10^{15}(T_{gas})^{-9.51} \exp\left(-\frac{31204}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H \rightarrow CH_2CCH_3$	$3.115 \times 10^{29}(T_{gas})^{-12.59} \exp\left(-\frac{69982}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H \rightarrow C_2H_2 + CH_3$	$4.7657 \times 10^{29}(T_{gas})^{-12.51} \exp\left(-\frac{70513}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + H_2CCCH_2 \rightarrow C_2H + CH_2CHCH_2$	$8.3027 \times 10^{-10} \exp\left(-\frac{305432}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 \rightarrow H_2 + H_2CCCH_2$	$2.989 \times 10^{-11} \exp\left(-\frac{326352}{RT_{gas}}\right)$	[79-81]
$CH_3CCH \rightarrow H_2CCCH_2$	$8.6348 \times 10^{36}(T_{gas})^{-13.93} \exp\left(-\frac{381162}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_2 \rightarrow HCCCH_2 + H$	$1.9926 \times 10^{-11} \exp\left(-\frac{27698}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H_2CCCH_2 \rightarrow CH_2CHCH_2 + HCCCH_2$	$8.3027 \times 10^{-10} \exp\left(-\frac{270897}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + HCCCH_2 \rightarrow H_2CCCH_2 + HCCCH_2$	$1.0196 \times 10^{-17}(T_{gas})^{1.74} \exp\left(-\frac{43723}{RT_{gas}}\right)$	[79-81]

$CH_3CCH + H \rightarrow HCCCH_2 + H_2$	$5.9314 \times 10^{-20}(T_{gas})^{2.825} \exp\left(-\frac{20171}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + CH_3 \rightarrow HCCCH_2 + CH_4$	$2.9890 \times 10^{-12} \exp\left(-\frac{32217}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + C_2H \rightarrow HCCCH_2 + C_2H_2$	1.6605×10^{-11}	[79-81]
$C_2H_3 + CH_3CCH \rightarrow C_2H_4 + HCCCH_2$	$1.6605 \times 10^{-12} \exp\left(-\frac{32217}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3CCH \rightarrow CH_2CHCH_3 + HCCCH_2$	$4.9816 \times 10^{-12} \exp\left(-\frac{32217}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + H \rightarrow HCCCH_2 + H_2$	$1.1001 \times 10^{-20}(T_{gas})^{3.095} \exp\left(-\frac{23104}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + CH_3 \rightarrow HCCCH_2 + CH_4$	$2.1587 \times 10^{-12} \exp\left(-\frac{32217}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + H_2CCCH_2 \rightarrow CH_2CHCH_3 + HCCCH_2$	$3.3211 \times 10^{-13} \exp\left(-\frac{32217}{RT_{gas}}\right)$	[79-81]
$H_2CCCH_2 + C_2H \rightarrow HCCCH_2 + C_2H_2$	1.6605×10^{-11}	[79-81]
$C_2H + C_2H_5 \rightarrow CH_3 + HCCCH_2$	3.0056×10^{11}	[79-81]
$HCCCH_2 + H \rightarrow H_2CCCH_2$	$5.2473 \times 10^{5}(T_{gas})^{-5.0} \exp\left(-\frac{19711}{RT_{gas}}\right)$	[79-81]
$HCCCH_2 + H \rightarrow CH_3CCH$	$1.3185 \times 10^{6}(T_{gas})^{-5.06} \exp\left(-\frac{20338}{RT_{gas}}\right)$	[79-81]
$C_2H_6 + HCCCH_2 \rightarrow C_2H_5 + H_2CCCH_2$	$4.0351 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{69224}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + HCCCH_2 \rightarrow C_2H_3 + H_2CCCH_2$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{86366}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + HCCCH_2 \rightarrow CH_3CH_2CH_2 + H_2CCCH_2$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{69224}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_3 + HCCCH_2 \rightarrow CH_3CHCH_3 + H_2CCCH_2$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{58844}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + HCCCH_2 \rightarrow CHCHCH_3 + H_2CCCH_2$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{86981}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + HCCCH_2 \rightarrow CH_2CCH_3 + H_2CCCH_2$	$6.2768 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{86981}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + H_2CCCH_2 \rightarrow C_2H_4 + HCCCH_2$	$6.7551 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44108}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + H_2CCCH_2 \rightarrow C_2H_6 + HCCCH_2$	$1.9926 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{56672}{RT_{gas}}\right)$	[79-81]

$CH_3CH_2CH_2 + H_2CCCH_2 \rightarrow CH_3CH_2CH_3 + HCCCH_2$	$1.345 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{56672}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + H_2CCCH_2 \rightarrow CH_3CH_2CH_3 + HCCCH_2$	$1.345 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{72571}{RT_{gas}}\right)$	[79-81]
$CHCHCH_3 + H_2CCCH_2 \rightarrow CH_2CHCH_3 + HCCCH_2$	$2.6901 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + H_2CCCH_2 \rightarrow CH_2CHCH_3 + HCCCH_2$	$2.6901 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_3CCH \rightarrow C_2H_6 + HCCCH_2$	$1.9926 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{56672}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + CH_3CH_2CH_2 \rightarrow CH_3CH_2CH_3 + HCCCH_2$	$1.345 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{56672}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + CH_3CHCH_3 \rightarrow CH_3CH_2CH_3 + HCCCH_2$	$1.345 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{72571}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + CHCHCH_3 \rightarrow CH_2CHCH_3 + HCCCH_2$	$2.6901 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_3CCH \rightarrow CH_2CHCH_3 + HCCCH_2$	$2.6901 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$HCCCH_2 + H \rightarrow HCCCH + H_2$	$3.5536 \times 10^{-19}(T_{gas})^{2.52} \exp\left(-\frac{31183}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH \rightarrow HCCCH + H$	1.3948×10^{-10}	[79-81]
$HCCCH_2 \rightarrow HCCCH + H$	$1.6605 \times 10^{-11}(T_{gas})^{2.0} \exp\left(-\frac{405848}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 \rightarrow CH_2CH_2CH_2CH_3 + H$	$8.2031 \times 10^{34}(T_{gas})^{-12.32} \exp\left(-\frac{524820}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + H \rightarrow CH_2CH_2CH_2CH_3$	$2.9059 \times 10^{-19}(T_{gas})^{2.69} \exp\left(-\frac{26987}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + CH_3 \rightarrow CH_2CH_2CH_2CH_3 + CH_4$	$2.989 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{31142}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + C_2H_3 \rightarrow CH_2CH_2CH_2CH_3 + C_2H_4$	$6.7551 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{26104}{RT_{gas}}\right)$	[79-81]

$CH_3CH_2CH_2CH_3 + C_2H_5 \rightarrow CH_2CH_2CH_2CH_3 + C_2H_6$	$1.9926 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{38865}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2 + CH_3CH_2CH_2CH_3 \rightarrow CH_3CH_2CH_3 + CH_2CH_2CH_2CH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{38865}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_3CH_2CH_3 + CH_2CH_2CH_2CH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53241}{RT_{gas}}\right)$	[79-81]
$CHCHCH_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_2CH_2CH_2CH_3$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_2CH_2CH_2CH_3$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_2CH_2CH_2CH_3$	$5.3702 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{66149}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + HCCCH_2 \rightarrow CH_2CH_2CH_2CH_3 + H_2CCCH_2$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{71463}{RT_{gas}}\right)$	[79-81]
$CH_2CH_2CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3$	$3.4041 \times 10^{18}(T_{gas})^{-9.61} \exp\left(-\frac{194200}{RT_{gas}}\right)$	[79-81]
$CH_2CH_2CH_2CH_3 \rightarrow C_2H_4 + C_2H_5$	$1.2404 \times 10^{20}(T_{gas})^{-9.67} \exp\left(-\frac{162013}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CH_2CH_2CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3CH_2CH_2$	$2.4908 \times 10^{-13} \exp\left(-\frac{31794}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 \rightarrow CH_3CHCH_2CH_3 + H$	$1.2271 \times 10^{32}(T_{gas})^{-11.52} \exp\left(-\frac{502913}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + H \rightarrow CH_3CHCH_2CH_3 + H_2$	$2.1587 \times 10^{-18}(T_{gas})^{2.4} \exp\left(-\frac{18707}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_2CH_3 \rightarrow CH_2CH_2CH_2CH_3$	$1.0843 \times 10^{32}(T_{gas})^{-14.27} \exp\left(-\frac{210669}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_2CH_3 \rightarrow C_2H_4 + C_2H_5$	$7.5388 \times 10^{18}(T_{gas})^{-9.54} \exp\left(-\frac{212710}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3$	$7.871 \times 10^{20}(T_{gas})^{-9.85} \exp\left(-\frac{175063}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + CH_3 \rightarrow CH_3CHCH_2CH_3 + CH_4$	$1.9926 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{20920}{RT_{gas}}\right)$	[79-81]

$C_2H_3 + CH_3CH_2CH_2CH_3 \rightarrow C_2H_4 + CH_3CHCH_2CH_3$	$4.5034 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{16318}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_3CH_2CH_2CH_3 \rightarrow C_2H_6 + CH_3CHCH_2CH_3$	$1.3284 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28033}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2 + CH_3CH_2CH_2CH_3 \rightarrow CH_3CH_2CH_3 + CH_3CHCH_2CH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{28033}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_3CH_2CH_3 + CH_3CHCH_2CH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{41422}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + CHCHCH_3 \rightarrow CH_2CHCH_3 + CH_3CHCH_2CH_3$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + CH_2CCH_3 \rightarrow CH_2CHCH_3 + CH_3CHCH_2CH_3$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_3 + CH_3CHCH_2CH_3$	$3.5801 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53555}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 + HCCCH_2 \rightarrow CH_3CHCH_2CH_3 + H_2CCCH_2$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{58576}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 \rightarrow CH_2CHCH_2 + CH_3$	$1.2454 \times 10^{42}(T_{gas})^{-15.6} \exp\left(-\frac{407103}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + H \rightarrow C_2H_4 + C_2H_5$	$4.9982 \times 10^{-7}(T_{gas})^{-1.09} \exp\left(-\frac{58672}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + H \rightarrow CH_2CHCH_3 + CH_3$	$4.8322 \times 10^{-5}(T_{gas})^{-1.39} \exp\left(-\frac{39183}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + H \rightarrow CH_2CH_2CH_2CH_3$	$6.692 \times 10^{6}(T_{gas})^{-6.17} \exp\left(-\frac{50292}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + H \rightarrow CH_3CHCH_2CH_3$	$9.0499 \times 10^{9}(T_{gas})^{-6.61} \exp\left(-\frac{31627}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_2CHCH_3 \rightarrow C_2H_4 + CH_3CHCHCH_3$	$8.3027 \times 10^{-13} \exp\left(-\frac{192464}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 \rightarrow CH_3CHCHCH_3 + H_2$	$4.1513 \times 10^{-11} \exp\left(-\frac{297064}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + H \rightarrow CH_3 + CH_3CCH + H_2$	$8.9669 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{16736}{RT_{gas}}\right)$	[79-81]

$CH_3CHCHCH_3 + CH_3 \rightarrow CH_3 + CH_3CCH + CH_4$	$8.9669 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{20920}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + C_2H_3 \rightarrow CH_3 + CH_3CCH + C_2H_4$	$2.0265 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{16318}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + C_2H_5 \rightarrow CH_3 + CH_3CCH + C_2H_6$	$5.9779 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{28033}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + CH_3CH_2CH_3$	$4.035 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{28033}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + CH_3CH_2CH_3$	$4.035 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{41422}{RT_{gas}}\right)$	[79-81]
$CHCHCH_3 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + CH_2CHCH_3$	$8.0703 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + CH_2CHCH_3$	$8.0703 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + CH_2CHCH_3$	$1.6111 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{53555}{RT_{gas}}\right)$	[79-81]
$HCCCH_2 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + H_2CCCH_2$	$8.0703 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{58576}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + C_2H_5 \rightarrow CH_3CHCH_2CH_3 + C_2H_4$	$2.4908 \times 10^{-14} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow C_2H_4 + C_2H_5$	$1.5725 \times 10^{-7}(T_{gas})^{-1.03} \exp\left(-\frac{56120}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow CH_2CHCH_3 + CH_3$	$7.5887 \times 10^{-5}(T_{gas})^{-1.54} \exp\left(-\frac{37911}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow CH_2CH_2CH_2CH_3$	$3.155 \times 10^{7}(T_{gas})^{-6.46} \exp\left(-\frac{50074}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow CH_3CHCH_2CH_3$	$5.8617 \times 10^{10}(T_{gas})^{-6.95} \exp\left(-\frac{31485}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow CH_3CHCHCH_3 + H$	$1.6937 \times 10^{-9}(T_{gas})^{-0.25} \exp\left(-\frac{38631}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 \rightarrow CH_2CHCHCH_3$	$1.6605 \times 10^{-12} \exp\left(-\frac{255224}{RT_{gas}}\right)$	[79-81]

$C_2H_5 + CH_2CHCH_3 \rightarrow CH_2CHCH_2CH_3 + CH_3$	$1.4945 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + C_2H_4 \rightarrow CH_2CHCH_2CH_3$	$1.6605 \times 10^{-14} \exp\left(-\frac{167360}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_2CHCH_3 \rightarrow C_2H_3 + CH_2CHCH_2CH_3$	$3.9853 \times 10^{-14} \exp\left(-\frac{62760}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_2CH_3 + H_2$	$4.1513 \times 10^{-11} \exp\left(-\frac{297064}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CHCHCH_3 \rightarrow CH_2CHCH_2CH_3 + C_2H_3$	$1.1624 \times 10^{-13} \exp\left(-\frac{25104}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 \rightarrow C_2H_3 + C_2H_4$	$4.7159 \times 10^{-14}(T_{gas})^{0.99} \exp\left(-\frac{163168}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + C_2H_5 \rightarrow CH_2CHCH_2CH_2$	$4.9816 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_2CHCH_3 \rightarrow CH_2CHCH_2CH_2 + C_2H_4$	$6.9743 \times 10^{-14} \exp\left(-\frac{62760}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + H_2 \rightarrow CH_2CHCH_2CH_3 + H$	$3.1384 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{43618}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_4 \rightarrow CH_2CHCH_2CH_3 + CH_3$	$1.5692 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53840}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + C_2H_2 \rightarrow CH_2CHCH_2CH_3 + C_2H$	$4.4835 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + C_2H_4 \rightarrow CH_2CHCH_2CH_3 + C_2H_3$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + C_2H_6 \rightarrow CH_2CHCH_2CH_3 + C_2H_5$	$2.0175 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{38413}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_3CH_2CH_3 \rightarrow CH_2CHCH_2CH_3 + CH_3CH_2CH_2$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{38413}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_3CH_2CH_3 \rightarrow CH_2CHCH_2CH_3 + CH_3CHCH_3$	$4.4835 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{27614}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_2CHCH_3 \rightarrow CH_2CHCH_2CH_3 + CH_2CHCH_2$	$6.7252 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{27614}{RT_{gas}}\right)$	[79-81]

$CH_2CHCH_2CH_2 + CH_2CHCH_3 \rightarrow CH_2CHCH_2CH_3 + CHCHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_2CHCH_3 \rightarrow CH_2CHCH_2CH_3 + CH_2CCH_3$	$3.1384 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + H_2CCCH_2 \rightarrow CH_2CHCH_2CH_3 + HCCCH_2$	$1.345 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_3CCH \rightarrow CH_2CHCH_2CH_3 + HCCCH_2$	$1.345 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow CH_2CHCH_2CH_2 + H_2$	$1.4945 \times 10^{-17}(T_{gas})^{2.0} \exp\left(-\frac{25204}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_3 \rightarrow CH_2CHCH_2CH_2 + CH_4$	$1.4945 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28916}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + C_2H_3 \rightarrow CH_2CHCH_2CH_2 + C_2H_4$	$3.3775 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{23782}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + C_2H_5 \rightarrow CH_2CHCH_2CH_2 + C_2H_6$	$9.9632 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{37949}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_3CH_2CH_2 \rightarrow CH_2CHCH_2CH_2 + CH_3CH_2CH_3$	$6.7252 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{37949}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_3CHCH_3 \rightarrow CH_2CHCH_2CH_2 + CH_3CH_2CH_3$	$6.7252 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{52325}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CHCHCH_3 \rightarrow CH_2CHCH_2CH_2 + CH_2CHCH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_2CCH_3 \rightarrow CH_2CHCH_2CH_2 + CH_2CHCH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_2CHCH_2CH_3 \rightarrow CH_2CHCH_2CH_2 + CH_2CHCH_3$	$2.6851 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{66149}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + HCCCH_2 \rightarrow CH_2CHCH_2CH_2 + H_2CCCH_2$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{69141}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_3CHCHCH_3 \rightarrow CH_2CHCH_2CH_3 + CH_3 + CH_3CCH$	$4.035 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{27614}{RT_{gas}}\right)$	[79-81]

$CH_2CHCH_2CH_2 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_2CH_3 + CH_2CH_2CH_2CH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{38413}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CHCH_2CH_3 + CH_3CHCH_2CH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{27614}{RT_{gas}}\right)$	[79-81]
$CH_3 + H_2CCCH_2 \rightarrow C_4H_7$	$6.677 \times 10^{-20}(T_{gas})^{2.5} \exp\left(-\frac{37016}{RT_{gas}}\right)$	[79-81]
$C_4H_7 + C_2H_4 \rightarrow CH_3CH_2CH_2 + H_2CCCH_2$	$2.4658 \times 10^{-14} \exp\left(-\frac{75312}{RT_{gas}}\right)$	[79-81]
$C_4H_7 + C_2H_4 \rightarrow CH_2CHCH_2 + CH_2CHCH_3$	$4.9315 \times 10^{-14} \exp\left(-\frac{75312}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + H \rightarrow CH_2CHCH_2CH_3$	$8.3027 \times 10^{-11} \exp\left(-\frac{20920}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 \rightarrow CH_2CHCHCH_3 + H$	$7.6385 \times 10^{60}(T_{gas})^{-20.03} \exp\left(-\frac{555.581}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + H \rightarrow CH_2CHCHCH_3 + H_2$	$9.3322 \times 10^{-22}(T_{gas})^{3.5} \exp\left(-\frac{6807}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + CH_3 \rightarrow CH_2CHCHCH_3 + CH_4$	$1.1624 \times 10^{-23}(T_{gas})^{3.57} \exp\left(-\frac{31974}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + CH_2CHCHCH_3 \rightarrow C_2H + CH_3CHCHCH_3$	$1.1292 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{89818}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_3CHCHCH_3 \rightarrow C_2H_4 + CH_2CHCHCH_3$	$6.5524 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{16318}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_2CHCH_2CH_3 \rightarrow C_2H_4 + CH_2CHCHCH_3$	$6.7551 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{19108}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CH_2CHCHCH_3 \rightarrow C_2H_3 + CH_3CHCHCH_3$	$4.5167 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{89818}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_2CHCHCH_3 \rightarrow C_2H_4 + CH_2CHCH_2CH_3$	$4.3008 \times 10^{-12} \exp\left(-\frac{548}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_2CHCH_2CH_3 \rightarrow C_2H_6 + CH_2CHCHCH_3$	$1.9926 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{29133}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + CH_3CHCHCH_3 \rightarrow C_2H_6 + CH_2CHCHCH_3$	$1.9329 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28033}{RT_{gas}}\right)$	[79-81]

$C_2H_6 + CH_2CHCHCH_3 \rightarrow C_2H_5 + CH_3CHCHCH_3$	$5.0812 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{70136}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_3CH_2CH_3 \rightarrow CH_3CHCHCH_3 + CH_3CH_2CH_2$	$4.5167 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{70136}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_3CH_2CH_3 \rightarrow CH_3CHCHCH_3 + CH_3CHCH_3$	$1.1292 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_2CHCHCH_3 \rightarrow CH_2CHCH_2 + CH_3CHCHCH_3$	$1.6937 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_2CHCHCH_3 \rightarrow CHCHCH_3 + CH_3CHCHCH_3$	$2.2583 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{89818}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_3 + CH_2CHCHCH_3 \rightarrow CH_2CCH_3 + CH_3CHCHCH_3$	$7.9042 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{89818}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + H_2CCCH_2 \rightarrow CH_3CHCHCH_3 + HCCCH_2$	$3.3875 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_3CCH \rightarrow CH_3CHCHCH_3 + HCCCH_2$	$3.3875 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + H \rightarrow CH_2CHCHCH_3 + H_2$	$2.989 \times 10^{-17}(T_{gas})^{2.0} \exp\left(-\frac{18364}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_3 \rightarrow CH_2CHCHCH_3 + CH_4$	$2.989 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{23589}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_3CH_2CH_2 \rightarrow CH_2CHCHCH_3 + CH_3CH_2CH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{29133}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_3CHCH_3 \rightarrow CH_2CHCHCH_3 + CH_3CH_2CH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{42522}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CHCHCH_3 \rightarrow CH_2CHCHCH_3 + CH_2CHCH_3$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_2CCH_3 \rightarrow CH_2CHCHCH_3 + CH_2CHCH_3$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_2CHCH_2 \rightarrow CH_2CHCHCH_3 + CH_2CHCH_3$	$5.3702 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53555}{RT_{gas}}\right)$	[79-81]

$CH_2CHCH_2CH_2 + CH_2CHCH_2CH_3 \rightarrow CH_2CHCH_2CH_3 + CH_2CHCHCH_3$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{27614}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_2CHCHCH_3 \rightarrow CH_2CHCHCH_3 + CH_3CHCHCH_3$	$3.3875 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + HCCCH_2 \rightarrow CH_2CHCHCH_3 + H_2CCCH_2$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{61367}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 + CH_2CHCHCH_3 \rightarrow CH_2CHCH_2CH_2 + CH_3CHCHCH_3$	$1.6937 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{70136}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2 + CH_3CHCHCH_3 \rightarrow CH_3CH_2CH_3 + CH_2CHCHCH_3$	$1.3407 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28033}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + CH_3CHCHCH_3 \rightarrow CH_3CH_2CH_3 + CH_2CHCHCH_3$	$1.3407 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{41422}{RT_{gas}}\right)$	[79-81]
$CHCHCH_3 + CH_3CHCHCH_3 \rightarrow CH_2CHCH_3 + CH_2CHCHCH_3$	$2.6094 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + CH_3CHCHCH_3 \rightarrow CH_2CHCH_3 + CH_2CHCHCH_3$	$2.6094 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + CH_3CHCHCH_3 \rightarrow CH_2CHCH_3 + CH_2CHCHCH_3$	$5.2091 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53555}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_3CHCHCH_3 \rightarrow CH_2CHCH_2CH_3 + CH_2CHCHCH_3$	$1.3407 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{27614}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_3CHCHCH_3 \rightarrow CH_2CHCHCH_3 + CH_3CHCHCH_3$	$3.2859 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + CH_3CHCHCH_3$	$1.0162 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_3 + HCCCH_2 \rightarrow CH_2CHCHCH_3 + H_2CCCH_2$	$2.6094 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{58576}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 \rightarrow C_2H_3 + C_2H_4$	$2.4908 \times 10^{-11} \exp\left(-\frac{209200}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CH_2CH_2CH_3 + CH_3CHCHCH_3$	$3.3875 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{70136}{RT_{gas}}\right)$	[79-81]

$CH_2CHCHCH_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_3CHCH_2CH_3 + CH_3CHCHCH_3$	$2.2583 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{57321}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 \rightarrow C_4H_6 + H$	$1.4164 \times 10^{-16}(T_{gas})^{1.95} \exp\left(-\frac{198698}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 \rightarrow C_4H_6 + H$	$2.1919 \times 10^{-19}(T_{gas})^{2.28} \exp\left(-\frac{139097}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_3 \rightarrow C_4H_6 + H_2$	$4.9816 \times 10^{-11} \exp\left(-\frac{292880}{RT_{gas}}\right)$	[79-81]
$CH_3CHCHCH_2 \rightarrow C_4H_6 + H_2$	$3.3211 \times 10^{-12} \exp\left(-\frac{297064}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + H \rightarrow C_2H_3 + C_2H_4$	$1.076 \times 10^{9}(T_{gas})^{-4.91} \exp\left(-\frac{110784}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + H \rightarrow CH_3 + CH_3CCH$	$3.3211 \times 10^{-12} \exp\left(-\frac{29288}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + H \rightarrow CH_3 + H_2CCCCH_2$	$3.3211 \times 10^{-12} \exp\left(-\frac{29288}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + C_2H_3 \rightarrow C_4H_6$	$2.4908 \times 10^{18}(T_{gas})^{-8.84} \exp\left(-\frac{52229}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_2CHCH_3 \rightarrow C_4H_6 + CH_3$	$2.989 \times 10^{-13} \exp\left(-\frac{25104}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + CH_2CHCHCH_3 \rightarrow C_2H_4 + C_4H_6$	3.3211×10^{-12}	[79-81]
$C_2H_5 + CH_2CHCHCH_3 \rightarrow C_2H_6 + C_4H_6$	1.6605×10^{-12}	[79-81]
$CH_3 + HCCCH_2 \rightarrow C_4H_6$	6.6422×10^{-12}	[79-81]
$C_4H_6 + CH_3 \rightarrow C_2H_4 + CH_2CHCH_2$	$1.6605 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + C_2H_5 \rightarrow C_2H_4 + CH_2CHCHCH_3$	$1.6605 \times 10^{-14} \exp\left(-\frac{20920}{RT_{gas}}\right)$	[79-81]
$C_2H_4 + CHCHCH_3 \rightarrow C_4H_6 + CH_3$	$3.3211 \times 10^{-13} \exp\left(-\frac{25104}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_2CHCH_3 \rightarrow C_4H_6 + CH_3CH_2CH_2$	$4.9816 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + C_2H_4 \rightarrow C_4H_6$	$8.3027 \times 10^{-14} \exp\left(-\frac{112968}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + HCCCH_2 \rightarrow C_2H_2 + C_4H_6$	4.1513×10^{-13}	[79-81]
$CH_2CHCH_2 + CH_2CHCHCH_3 \rightarrow C_4H_6 + CH_2CHCH_3$	$8.3027 \times 10^{-13} \exp\left(-\frac{12552}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2CH_2 + CH_2CHCH_2CH_3 \rightarrow C_4H_6 + CH_2CH_2CH_2CH_3$	$4.9816 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]

$CH_2CHCH_2CH_2 + CH_3CHCHCH_3 \rightarrow C_4H_6 + CH_2CHCH_2CH_3$	$4.9816 \times 10^{-13} \exp\left(-\frac{31798}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + CH_2CHCHCH_3 \rightarrow C_4H_6 + CH_2CHCH_2CH_3$	9.9632×10^{-13}	[79-81]
$CH_2CHCH_3 + CHCHCH_3 \rightarrow C_4H_6 + C_2H_5$	$1.6605 \times 10^{-13} \exp\left(-\frac{25104}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_4 \rightarrow C_4H_6 + CH_3$	$3.1384 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{39405}{RT_{gas}}\right)$	[79-81]
$C_4H_6 \rightarrow C_4H_5 + H$	$9.4651 \times 10^{12}(T_{gas})^{-6.27} \exp\left(-\frac{470085}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + C_4H_6 \rightarrow C_2H_4 + C_4H_5$	$8.3027 \times 10^{-11} \exp\left(-\frac{95395}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + HCCCH_2 \rightarrow C_4H_5 + H_2CCCH_2$	$1.6605 \times 10^{-11} \exp\left(-\frac{94140}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_2CHCH_2 \rightarrow C_4H_5 + CH_2CHCH_3$	$1.6605 \times 10^{-11} \exp\left(-\frac{94140}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + C_2H_3 \rightarrow C_4H_5$	$1.5443 \times 10^{15}(T_{gas})^{-8.76} \exp\left(-\frac{50208}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + C_2H_3 \rightarrow C_4H_5 + H$	$3.9853 \times 10^{-4}(T_{gas})^{-2.04} \exp\left(-\frac{64270}{RT_{gas}}\right)$	[79-81]
$C_2H + C_4H_5 \rightarrow HCCCH_2 + HCCCH_2$	6.6422×10^{-12}	[79-81]
$C_4H_5 \rightarrow C_2H + C_2H_4$	$3.3211 \times 10^{-12} \exp\left(-\frac{251040}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + C_4H_6 \rightarrow C_4H_5 + CH_2CHCHCH_3$	$8.3027 \times 10^{-10} \exp\left(-\frac{267776}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + H \rightarrow C_2H_2 + C_2H_4$	1.6605×10^{-11}	[79-81]
$C_2H_2 + C_4H_5 \rightarrow C_2H + C_4H_6$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_2H_6 + C_4H_5 \rightarrow C_2H_5 + C_4H_6$	$4.0351 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{26619}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CH_2CH_3 \rightarrow C_4H_6 + CH_3CH_2CH_2$	$3.5868 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{26619}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CH_2CH_3 \rightarrow C_4H_6 + CH_3CHCH_3$	$8.9669 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{19096}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_2CHCH_3 \rightarrow C_4H_6 + CHCHCH_3$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{39991}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_2CHCH_3 \rightarrow C_4H_6 + CH_2CCH_3$	$6.2768 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{39991}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CCH \rightarrow C_4H_6 + HCCCH_2$	$2.6901 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{47233}{RT_{gas}}\right)$	[79-81]

$C_4H_6 + H \rightarrow C_4H_5 + H_2$	$1.1956 \times 10^{-16}(T_{gas})^{2.0} \exp\left(-\frac{39162}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_3 \rightarrow C_4H_5 + CH_4$	$1.1956 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{42752}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + C_4H_6 \rightarrow C_2H_6 + C_4H_5$	$7.9706 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53815}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_3CH_2CH_2 \rightarrow C_4H_5 + CH_3CH_2CH_3$	$5.3801 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53815}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_3CHCH_3 \rightarrow C_4H_5 + CH_3CH_2CH_3$	$5.3801 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{69714}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CHCHCH_3 \rightarrow C_4H_5 + CH_2CHCH_3$	$1.076 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_2CCH_3 \rightarrow C_4H_5 + CH_2CHCH_3$	$1.076 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{44263}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_2CHCH_2CH_2 \rightarrow C_4H_5 + CH_2CHCH_2CH_3$	$5.3801 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{54994}{RT_{gas}}\right)$	[79-81]
$C_4H_6 + CH_2CHCHCH_3 \rightarrow C_4H_5 + CH_3CHCHCH_3$	$1.355 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{89818}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_2CHCH_2CH_3 \rightarrow C_4H_6 + CH_2CHCHCH_3$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{21619}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_2CHCH_2CH_3 \rightarrow C_4H_6 + CH_2CHCH_2CH_2$	$1.345 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{26535}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CHCHCH_3 \rightarrow C_4H_6 + CH_2CHCHCH_3$	$2.6094 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CHCHCH_3 \rightarrow C_4H_6 + CH_3 + CH_3CCH$	$8.0703 \times 10^{-21}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CH_2CH_2CH_3 \rightarrow C_4H_6 + CH_2CH_2CH_2CH_3$	$2.6901 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28857}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + CH_3CH_2CH_2CH_3 \rightarrow C_4H_6 + CH_3CHCH_2CH_3$	$1.7934 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{18828}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + H_2 \rightarrow C_4H_6 + H$	$6.2768 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{28911}{RT_{gas}}\right)$	[79-81]
$C_4H_6 \rightarrow H_2 + HCCCHCH_2$	$4.1513 \times 10^{-9} \exp\left(-\frac{396225}{RT_{gas}}\right)$	[79-81]

$C_2H_2 + C_2H_3 \rightarrow HCCCHCH_2 + H$	$3.3211 \times 10^{-6}(T_{gas})^{-1.68} \exp\left(-\frac{44350}{RT_{gas}}\right)$	[79-81]
$CH_2 + HCCCH_2 \rightarrow HCCCHCH_2 + H$	8.3027×10^{-11}	[79-81]
$HCCCHCH_2 + H \rightarrow C_4H_5$	$2.1587 \times 10^{27}(T_{gas})^{-11.92} \exp\left(-\frac{69.036}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + H \rightarrow HCCCHCH_2 + H_2$	2.4908×10^{-11}	[79-81]
$HCCCH_2 + HCCCH_2 \rightarrow HCCCHCH_2 + C_2H_2$	1.6605×10^{-13}	[79-81]
$C_2H_2 + C_2H_2 \rightarrow HCCCHCH_2$	$8.3027 \times 10^{-13} \exp\left(-\frac{154808}{RT_{gas}}\right)$	[79-81]
$C_2H + C_2H_3 \rightarrow HCCCHCH_2$	1.6605×10^{-10}	[79-81]
$C_2H_2 + HCCCHCH_2 \rightarrow C_2H + C_4H_5$	$1.6605 \times 10^{-10} \exp\left(-\frac{397480}{RT_{gas}}\right)$	[79-81]
$HCCCH + CH_3 \rightarrow HCCCHCH_2 + H$	4.1513×10^{-12}	[79-81]
$HCCCH_2 + CH_2CHCHCH_3 \rightarrow HCCCHCH_2 + CH_2CHCH_3$	6.6422×10^{-12}	[79-81]
$C_4H_7 + HCCCH_2 \rightarrow CH_2CHCH_3 + HCCCHCH_2$	6.6422×10^{-12}	[79-81]
$H_2CCCH_2 + H_2CCCH_2 \rightarrow C_2H_4 + HCCCHCH_2$	$8.3027 \times 10^{-13} \exp\left(-\frac{121336}{RT_{gas}}\right)$	[79-81]
$CH_3CCH + CH_3CCH \rightarrow C_2H_4 + HCCCHCH_2$	$8.3027 \times 10^{-13} \exp\left(-\frac{121336}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + H \rightarrow HCCCHCH_2$	$5.6458 \times 10^{19}(T_{gas})^{-9.01} \exp\left(-\frac{50710}{RT_{gas}}\right)$	[79-81]
$HCCCHCH_2 + H \rightarrow C_4H_3 + H_2$	$1.1043 \times 10^{-18}(T_{gas})^{2.53} \exp\left(-\frac{51212}{RT_{gas}}\right)$	[79-81]
$HCCCHCH_2 + CH_3 \rightarrow C_4H_3 + CH_4$	$8.3027 \times 10^{-11} \exp\left(-\frac{82843}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + C_2H_3 \rightarrow HCCCH_2 + HCCCH_2$	6.6422×10^{-12}	[79-81]
$HCCCH_2 + CH \rightarrow C_4H_3 + H$	8.3027×10^{-11}	[79-81]
$C_4H_3 + CH_2 \rightarrow H_2CCCH_2 + C_2H$	3.3211×10^{-11}	[79-81]
$C_2H_2 + HCCCHCH_2 \rightarrow C_2H_3 + C_4H_3$	$4.9816 \times 10^{-10} \exp\left(-\frac{305432}{RT_{gas}}\right)$	[79-81]
$HCCCHCH_2 + HCCCHCH_2 \rightarrow C_4H_5 + C_4H_3$	$8.3027 \times 10^{-8} \exp\left(-\frac{340996}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + C_2H_2 \rightarrow C_4H_3 + H$	$3.3211 \times 10^{-8} \exp\left(-\frac{340996}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_2 \rightarrow C_2H + CH_3CCH$	3.3211×10^{-11}	[79-81]
$C_2H_2 + C_4H_3 \rightarrow C_2H + HCCCHCH_2$	$1.3583 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{47873}{RT_{gas}}\right)$	[79-81]

$C_2H_4 + C_4H_3 \rightarrow C_2H_3 + HCCCHCH_2$	$5.4333 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{43191}{RT_{gas}}\right)$	[79-81]
$C_2H_6 + C_4H_3 \rightarrow C_2H_5 + HCCCHCH_2$	$6.1124 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{29911}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CH_2CH_3 \rightarrow HCCCHCH_2 + CH_3CH_2CH_2$	$5.4333 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{29911}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CH_2CH_3 \rightarrow HCCCHCH_2 + CH_3CHCH_3$	$1.3583 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{22016}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_2CHCH_3 \rightarrow HCCCHCH_2 + CH_2CHCH_2$	$2.0375 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{23891}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_2CHCH_3 \rightarrow HCCCHCH_2 + CHCHCH_3$	$2.7166 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{43781}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_2CHCH_3 \rightarrow HCCCHCH_2 + CH_2CCH_3$	$9.5082 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{43781}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + H_2CCCH_2 \rightarrow HCCCHCH_2 + HCCCH_2$	$4.075 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{50718}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CCH \rightarrow HCCCHCH_2 + HCCCH_2$	$4.075 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{50718}{RT_{gas}}\right)$	[79-81]
$C_2H_3 + HCCCHCH_2 \rightarrow C_2H_4 + C_4H_3$	$1.5762 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{36497}{RT_{gas}}\right)$	[79-81]
$C_2H_5 + HCCCHCH_2 \rightarrow C_2H_6 + C_4H_3$	$4.6495 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{52923}{RT_{gas}}\right)$	[79-81]
$CH_3CH_2CH_2 + HCCCHCH_2 \rightarrow C_4H_3 + CH_3CH_2CH_3$	$3.1384 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{52923}{RT_{gas}}\right)$	[79-81]
$CH_3CHCH_3 + HCCCHCH_2 \rightarrow C_4H_3 + CH_3CH_2CH_3$	$3.1384 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{68714}{RT_{gas}}\right)$	[79-81]
$CHCHCH_3 + HCCCHCH_2 \rightarrow C_4H_3 + CH_2CHCH_3$	$6.2768 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{43187}{RT_{gas}}\right)$	[79-81]
$CH_2CCH_3 + HCCCHCH_2 \rightarrow C_4H_3 + CH_2CHCH_3$	$6.2768 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{43187}{RT_{gas}}\right)$	[79-81]
$CH_2CHCH_2 + HCCCHCH_2 \rightarrow C_4H_3 + CH_2CHCH_3$	$1.253 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{84140}{RT_{gas}}\right)$	[79-81]
$C_4H_5 + HCCCHCH_2 \rightarrow C_4H_3 + C_4H_6$	$6.2768 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{39597}{RT_{gas}}\right)$	[79-81]

$CH_2CHCH_2CH_2 + HCCCHCH_2 \rightarrow C_4H_3 + CH_2CHCH_2CH_3$	$3.1384 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{53840}{RT_{gas}}\right)$	[79-81]
$CH_2CHCHCH_3 + HCCCHCH_2 \rightarrow C_4H_3 + CH_3CHCHCH_3$	$7.9042 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{88441}{RT_{gas}}\right)$	[79-81]
$HCCCH_2 + HCCCHCH_2 \rightarrow C_4H_3 + H_2CCCH_2$	$6.2768 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{86282}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + C_4H_6 \rightarrow C_4H_5 + HCCCHCH_2$	$1.63 \times 10^{-18}(T_{gas})^{2.0} \exp\left(-\frac{43781}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_2CHCH_2CH_3 \rightarrow CH_2CHCHCH_3 + HCCCHCH_2$	$4.075 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{24426}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_2CHCH_2CH_3 \rightarrow CH_2CHCH_2CH_2 + HCCCHCH_2$	$2.0375 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{29828}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CHCHCH_3 \rightarrow CH_2CHCHCH_3 + HCCCHCH_2$	$3.9527 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{21757}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CHCHCH_3 \rightarrow CH_3 + CH_3CCH + HCCCHCH_2$	$1.2225 \times 10^{-20}(T_{gas})^{2.0} \exp\left(-\frac{21757}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_2CH_2CH_2CH_3 + HCCCHCH_2$	$4.075 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{32054}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + CH_3CH_2CH_2CH_3 \rightarrow CH_3CHCH_2CH_3 + HCCCHCH_2$	$2.7166 \times 10^{-19}(T_{gas})^{2.0} \exp\left(-\frac{21757}{RT_{gas}}\right)$	[79-81]
$C_2H + C_2H_2 \rightarrow HCCCCH + H$	1.5941×10^{-10}	[79-81]
$HCCCCH + H \rightarrow C_4H_3$	$1.8266 \times 10^{18}(T_{gas})^{-8.72} \exp\left(-\frac{64015}{RT_{gas}}\right)$	[79-81]
$C_4H_3 + H \rightarrow HCCCCH + H_2$	4.9816×10^{-11}	[79-81]
$HCCCHCH_2 \rightarrow HCCCCH + H_2$	$8.3027 \times 10^{-13} \exp\left(-\frac{276144}{RT_{gas}}\right)$	[79-81]
$C_2H_2 + C_2H_2 \rightarrow HCCCCH + H_2$	$1.6605 \times 10^{-8} \exp\left(-\frac{285349}{RT_{gas}}\right)$	[79-81]
$HCCCH + HCCCH \rightarrow C_2H_2 + HCCCCH$	$3.3211 \times 10^{-11} \exp\left(-\frac{355640}{RT_{gas}}\right)$	[79-81]
$HCCCH + CH \rightarrow HCCCCH + H$	8.3027×10^{-11}	[79-81]
$HCCCH_2 + CH \rightarrow HCCCCH + H + H$	8.3027×10^{-11}	[79-81]
$HCCCCH + C_2H_2 \rightarrow C_4H_3 + C_2H$	$4.9816 \times 10^{-10} \exp\left(-\frac{405848}{RT_{gas}}\right)$	[79-81]

$C_2H + CH_3CCH \rightarrow CH_3 + HCCCCH$	$4.9816 \times 10^{-13} \exp\left(-\frac{33472}{RT_{gas}}\right)$	[79-81]

Table S9. Negative and positive ion-ion and ion-neutral molecular recombination reactions and respective rate coefficients [in cm^3.s^{-1} or cm^6.s^{-1}]. T_{gas} is given in [K]. References are shown in the last column. The table can be found in Appendix.

Reaction	Rate constant	Ref.
$CH_5^+ + CH_2 \rightarrow CH_3^+ + CH_4$	0.960×10^{-9}	[82]
$CH_5^+ + CH \rightarrow CH_2^+ + CH_4$	$0.690 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[82]
$CH_5^+ + C \rightarrow CH^+ + CH_4$	0.120×10^{-8}	[82]
$CH_5^+ + C_2H_6 \rightarrow C_2H_5^+ + H_2 + CH_4$	0.225×10^{-9}	[82]
$CH_5^+ + C_2H_4 \rightarrow C_2H_5^+ + CH_4$	0.150×10^{-8}	[83]
$CH_5^+ + C_2H_2 \rightarrow C_2H_3^+ + CH_4$	0.160×10^{-8}	[84]
$CH_5^+ + C_2H \rightarrow C_2H_2^+ + CH_4$	0.900×10^{-9}	[82]
$CH_5^+ + C_2 \rightarrow C_2H^+ + CH_4$	0.950×10^{-9}	[82]
$CH_5^+ + H \rightarrow CH_4^+ + H_2$	0.150×10^{-9}	[85]
$CH_4^+ + CH_4 \rightarrow CH_5^+ + CH_3$	0.15×10^{-8}	[86]
$CH_4^+ + C_2H_6 \rightarrow C_2H_4^+ + CH_4 + H_2$	0.191×10^{-8}	[87]
$CH_4^+ + C_2H_4 \rightarrow C_2H_5^+ + CH_3$	0.423×10^{-9}	[87]
$CH_4^+ + C_2H_4 \rightarrow C_2H_4^+ + CH_4$	1.38×10^{-9}	[87]
$CH_4^+ + C_2H_2 \rightarrow C_2H_3^+ + CH_3$	1.23×10^{-9}	[87]
$CH_4^+ + C_2H_2 \rightarrow C_2H_2^+ + CH_4$	1.13×10^{-9}	[87]
$CH_4^+ + H_2 \rightarrow CH_5^+ + H$	$4.89 \times 10^{-11} \left(\frac{300}{T_{gas}}\right)^{0.14} \exp\left(-\frac{36.10}{T_{gas}}\right)$	[88]
$CH_4^+ + H \rightarrow CH_3^+ + H_2$	0.10×10^{-10}	[85]
$CH_3^+ + CH_4 \rightarrow CH_4^+ + CH_3$	0.136×10^{-9}	[87]
$CH_3^+ + CH_4 \rightarrow C_2H_5^+ + H_2$	0.120×10^{-8}	[87]
$CH_3^+ + CH_2 \rightarrow C_2H_3^+ + H_2$	0.990×10^{-9}	[87]
$CH_3^+ + CH \rightarrow C_2H_2^+ + H_2$	0.710×10^{-9}	[87]
$CH_3^+ + C \rightarrow C_2H^+ + H_2$	1.200×10^{-9}	[87]
$CH_3^+ + C_2H_6 \rightarrow C_2H_5^+ + CH_4$	1.48×10^{-9}	[87]
$CH_3^+ + C_2H_4 \rightarrow C_2H_3^+ + CH_4$	0.35×10^{-9}	[87]
$CH_3^+ + C_2H_3 \rightarrow C_2H_3^+ + CH_3$	0.300×10^{-9}	[87]
$CH_3^+ + H_2 \rightarrow CH_4^+ + H$	1.58×10^{-9}	[88]
$CH_3^+ + H \rightarrow CH_2^+ + H_2$	$7.00 \times 10^{-10} \exp\left(-\frac{10560}{T_{gas}}\right)$	[87]
$CH_2^+ + CH_4 \rightarrow CH_3^+ + CH_3$	0.138×10^{-9}	[86]
$CH_2^+ + CH_4 \rightarrow C_2H_5^+ + H$	0.360×10^{-9}	[86]

$CH_2^+ + CH_4 \rightarrow C_2H_4^+ + H_2$	0.84×10^{-9}	[86]
$CH_2^+ + CH_4 \rightarrow C_2H_3^+ + H_2 + H$	0.231×10^{-9}	[86]
$CH_2^+ + CH_4 \rightarrow C_2H_2^+ + 2\,H_2$	0.397×10^{-9}	[86]
$CH_2^+ + C \rightarrow C_2H^+ + H$	0.12×10^{-8}	[86]
$CH_2^+ + H \rightarrow CH^+ + H_2$	$1.00 \times 10^{-9} \exp\left(-\frac{7080}{T_{gas}}\right)$	[86]
$CH_2^+ + H_2 \rightarrow CH_3^+ + H$	0.16×10^{-8}	[86]
$CH^+ + CH_2 \rightarrow C_2H^+ + H_2$	0.10×10^{-8}	[82]
$CH^+ + CH \rightarrow C_2^+ + H_2$	0.740×10^{-9}	[82]
$CH^+ + C \rightarrow C_2^+ + H$	1.2×10^{-9}	[82]
$CH^+ + H \rightarrow C^+ + H_2$	$9.06 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.37} \exp\left(-\frac{29.10}{T_{gas}}\right)$	[89]
$CH^+ + CH_4 \rightarrow C_2H_4^+ + H$	0.65×10^{-10}	[86]
$CH^+ + CH_4 \rightarrow C_2H_3^+ + H_2$	0.109×10^{-8}	[86]
$CH^+ + CH_4 \rightarrow C_2H_2^+ + H_2 + H$	0.143×10^{-9}	[86]
$CH^+ + H_2 \rightarrow CH_2^+ + H$	1.20×10^{-9}	[85]
$C_2H_6^+ + C_2H_4 \rightarrow C_2H_4^+ + C_2H_6$	1.15×10^{-9}	[87]
$C_2H_6^+ + C_2H_2 \rightarrow C_2H_5^+ + C_2H_3$	2.47×10^{-10}	[90]
$C_2H_6^+ + H \rightarrow C_2H_5^+ + H_2$	1.00×10^{-10}	[90]
$C_2H_5^+ + H \rightarrow C_2H_4^+ + H_2$	1.00×10^{-11}	[85]
$C_2H_4^+ + C_2H_3 \rightarrow C_2H_5^+ + C_2H_2$	$5.00 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[87]
$C_2H_4^+ + C_2H_3 \rightarrow C_2H_3^+ + C_2H_4$	$5.00 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[87]
$C_2H_4^+ + H \rightarrow C_2H_3^+ + H_2$	3.00×10^{-10}	[85]
$C_2H_3^+ + C_2H_6 \rightarrow C_2H_5^+ + C_2H_4$	2.91×10^{-10}	[87]
$C_2H_3^+ + C_2H_4 \rightarrow C_2H_5^+ + C_2H_2$	8.90×10^{-10}	[87]
$C_2H_3^+ + C_2H_3 \rightarrow C_2H_5^+ + C_2H$	$5.00 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[91]
$C_2H_3^+ + C_2H \rightarrow C_2H_2^+ + C_2H_2$	3.30×10^{-10}	[91]
$C_2H_3^+ + H \rightarrow C_2H_2^+ + H_2$	6.80×10^{-11}	[85]
$C_2H_2^+ + CH_4 \rightarrow C_2H_3^+ + CH_3$	4.10×10^{-9}	[87]
$C_2H_2^+ + C_2H_6 \rightarrow C_2H_5^+ + C_2H_3$	1.31×10^{-10}	[87]
$C_2H_2^+ + C_2H_6 \rightarrow C_2H_4^+ + C_2H_4$	2.48×10^{-10}	[87]
$C_2H_2^+ + C_2H_4 \rightarrow C_2H_4^+ + C_2H_2$	4.14×10^{-10}	[87]
$C_2H_2^+ + C_2H_3 \rightarrow C_2H_3^+ + C_2H_2$	$3.30 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[87]
$C_2H_2^+ + H_2 \rightarrow C_2H_3^+ + H$	1.00×10^{-11}	[86]
$C_2H^+ + CH_2 \rightarrow CH_3^+ + C_2$	4.40×10^{-10}	[91]
$C_2H^+ + CH \rightarrow CH_2^+ + C_2$	3.20×10^{-10}	[91]

$C_2H^+ + CH_4 \rightarrow C_2H_2^+ + CH_3$	3.74×10^{-10}	[91]
$C_2H^+ + H_2 \rightarrow C_2H_2^+ + H$	1.10×10^{-9}	[86]
$H_3^+ + CH_4 \rightarrow CH_5^+ + H_2$	2.40×10^{-9}	[82]
$H_3^+ + CH_3 \rightarrow CH_4^+ + H_2$	2.10×10^{-9}	[92]
$H_3^+ + CH_2 \rightarrow CH_3^+ + H_2$	1.70×10^{-9}	[82]
$H_3^+ + CH \rightarrow CH_2^+ + H_2$	1.20×10^{-9}	[82]
$H_3^+ + C \rightarrow CH^+ + H_2$	2.00×10^{-9}	[82]
$H_3^+ + C_2H \rightarrow C_2H_2^+ + H_2$	1.70×10^{-9}	[92]
$H_3^+ + C_2 \rightarrow C_2H^+ + H_2$	1.80×10^{-9}	[82]
$H_3^+ + C_2H_6 \rightarrow C_2H_5^+ + H_2 + H_2$	2.40×10^{-9}	[82]
$H_3^+ + C_2H_5 \rightarrow C_2H_6^+ + H_2$	1.40×10^{-9}	[92]
$H_3^+ + C_2H_4 \rightarrow C_2H_5^+ + H_2$	1.15×10^{-9}	[82]
$H_3^+ + C_2H_4 \rightarrow C_2H_3^+ + H_2 + H_2$	1.15×10^{-9}	[82]
$H_3^+ + C_2H_3 \rightarrow C_2H_4^+ + H_2$	$2.00 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[92]
$H_3^+ + C_2H_2 \rightarrow C_2H_3^+ + H_2$	3.50×10^{-9}	[82]
$H_2^+ + CH_4 \rightarrow CH_5^+ + H$	1.14×10^{-10}	[82]
$H_2^+ + CH_4 \rightarrow CH_4^+ + H_2$	1.40×10^{-9}	[82]
$H_2^+ + CH_4 \rightarrow CH_3^+ + H_2 + H$	2.30×10^{-9}	[82]
$H_2^+ + CH_2 \rightarrow CH_3^+ + H$	1.00×10^{-9}	[82]
$H_2^+ + CH_2 \rightarrow CH_2^+ + H_2$	1.00×10^{-9}	[82]
$H_2^+ + CH \rightarrow CH_2^+ + H$	7.10×10^{-10}	[82]
$H_2^+ + CH \rightarrow CH^+ + H_2$	7.10×10^{-10}	[82]
$H_2^+ + C \rightarrow CH^+ + H$	2.40×10^{-9}	[82]
$H_2^+ + C_2H \rightarrow C_2H_2^+ + H$	1.00×10^{-9}	[82]
$H_2^+ + C_2H \rightarrow C_2H^+ + H_2$	1.00×10^{-9}	[82]
$H_2^+ + C_2 \rightarrow C_2H^+ + H$	1.10×10^{-9}	[82]
$H_2^+ + C_2 \rightarrow C_2^+ + H_2$	1.10×10^{-9}	[82]
$H_2^+ + C_2H_6 \rightarrow C_2H_6^+ + H_2$	2.94×10^{-9}	[82]
$H_2^+ + C_2H_6 \rightarrow C_2H_5^+ + H_2 + H$	1.37×10^{-9}	[82]
$H_2^+ + C_2H_6 \rightarrow C_2H_4^+ + H_2 + H_2$	2.35×10^{-9}	[82]
$H_2^+ + C_2H_6 \rightarrow C_2H_3^+ + 2\,H_2 + H$	6.86×10^{-9}	[82]
$H_2^+ + C_2H_6 \rightarrow C_2H_2^+ + 3\,H_2$	1.96×10^{-9}	[82]
$H_2^+ + C_2H_4 \rightarrow C_2H_4^+ + H_2$	2.21×10^{-9}	[82]
$H_2^+ + C_2H_4 \rightarrow C_2H_3^+ + H_2 + H$	1.81×10^{-9}	[82]
$H_2^+ + C_2H_4 \rightarrow C_2H_2^+ + H_2 + H_2$	8.82×10^{-10}	[82]
$H_2^+ + C_2H_2 \rightarrow C_2H_3^+ + H$	4.80×10^{-10}	[82]
$H_2^+ + C_2H_2 \rightarrow C_2H_2^+ + H_2$	4.82×10^{-9}	[82]
$H^+ + CH_4 \rightarrow CH_4^+ + H$	1.50×10^{-9}	[93]

$H^+ + CH_4 \rightarrow CH_3^+ + H_2$	2.30×10^{-9}	[93]
$H^+ + CH_3 \rightarrow CH_3^+ + H$	3.40×10^{-9}	[82]
$H^+ + CH_2 \rightarrow CH_2^+ + H$	1.40×10^{-9}	[82]
$H^+ + CH_2 \rightarrow CH^+ + H_2$	1.40×10^{-9}	[82]
$H^+ + CH \rightarrow CH^+ + H$	$1.90 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[82]
$H^+ + C_2H_6 \rightarrow C_2H_5^+ + H_2$	1.30×10^{-9}	[93]
$H^+ + C_2H_6 \rightarrow C_2H_4^+ + H_2 + H$	1.40×10^{-9}	[93]
$H^+ + C_2H_6 \rightarrow C_2H_3^+ + H_2 + H_2$	2.80×10^{-9}	[93]
$H^+ + C_2H_5 \rightarrow C_2H_4^+ + H_2$	1.65×10^{-9}	[82]
$H^+ + C_2H_5 \rightarrow C_2H_3^+ + H_2 + H$	3.06×10^{-9}	[82]
$H^+ + C_2H_4 \rightarrow C_2H_4^+ + H$	1.00×10^{-9}	[93]
$H^+ + C_2H_4 \rightarrow C_2H_3^+ + H_2$	3.00×10^{-9}	[93]
$H^+ + C_2H_4 \rightarrow C_2H_2^+ + H_2 + H$	1.00×10^{-9}	[93]
$H^+ + C_2H_3 \rightarrow C_2H_3^+ + H$	$2.00 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[91]
$H^+ + C_2H_3 \rightarrow C_2H_2^+ + H_2$	$2.00 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[91]
$H^+ + C_2H_2 \rightarrow C_2H_2^+ + H$	5.40×10^{-10}	[93]
$H^+ + C_2H \rightarrow C_2H^+ + H$	1.50×10^{-9}	[82]
$H^+ + C_2H \rightarrow C_2^+ + H_2$	1.50×10^{-9}	[82]
$H^+ + C_2 \rightarrow C_2^+ + H$	3.10×10^{-9}	[82]
$C^+ + CH_4 \rightarrow C_2H_3^+ + H$	1.00×10^{-9}	[94]
$C^+ + CH_4 \rightarrow C_2H_2^+ + H_2$	3.89×10^{-10}	[94]
$C^+ + CH_3 \rightarrow C_2H_2^+ + H$	1.30×10^{-9}	[94]
$C^+ + CH_3 \rightarrow C_2H^+ + H_2$	1.00×10^{-9}	[94]
$C^+ + CH_2 \rightarrow CH_2^+ + C$	5.20×10^{-10}	[94]
$C^+ + CH_2 \rightarrow C_2H^+ + H$	5.20×10^{-10}	[94]
$C^+ + CH \rightarrow CH^+ + C$	$3.80 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[82]
$C^+ + CH \rightarrow C_2^+ + H$	$3.80 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[82]
$C^+ + C_2H_6 \rightarrow C_2H_5^+ + CH$	2.31×10^{-10}	[94]
$C^+ + C_2H_6 \rightarrow C_2H_4^+ + CH_2$	1.16×10^{-10}	[94]
$C^+ + C_2H_6 \rightarrow C_2H_3^+ + CH_3$	4.95×10^{-10}	[94]
$C^+ + C_2H_6 \rightarrow C_2H_2^+ + CH_4$	8.25×10^{-11}	[94]
$C^+ + C_2H_5 \rightarrow C_2H_5^+ + C$	5.00×10^{-10}	[94]
$C^+ + C_2H_4 \rightarrow C_2H_4^+ + C$	1.70×10^{-11}	[94]
$C^+ + C_2H_4 \rightarrow C_2H_3^+ + CH$	8.50×10^{-11}	[94]
$C^+ + H_2 \rightarrow CH^+ + H$	$1.00 \times 10^{-10} \exp\left(-\frac{4640}{T_{gas}}\right)$	[95]

$C_2^+ + C \rightarrow C_2 + C^+$	1.10×10^{-10}	[82]
$C_2^+ + CH_4 \rightarrow C_2H_2^+ + CH_2$	1.82×10^{-10}	[86]
$C_2^+ + CH_4 \rightarrow C_2H^+ + CH_3$	2.38×10^{-10}	[86]
$C_2^+ + H_2 \rightarrow C_2H^+ + H$	1.0×10^{-9}	[85]
$C_2^+ + CH_2 \rightarrow CH_2^+ + C_2$	4.50×10^{-10}	[96]
$C_2^+ + CH \rightarrow CH^+ + C_2$	3.20×10^{-10}	[96]
$H^+ + 2\,H_2 \rightarrow H_2 + H_3^+$	$3.10 \times 10^{-29} \left(\frac{300}{T_{gas}}\right)^{0.5}$	[42]
$H^+ + H + M \rightarrow H_2^+ + M$	1.00×10^{-34}	[42]
$H^+ + H_2 + M \rightarrow H_3^+ + M$	1.50×10^{-29}	[32]
$H_2^+ + H_2 \rightarrow H_2 + H^+ + H$	$1.00 \times 10^{-8} \exp\left(-\frac{84100.0}{T_{gas}}\right)$	[88]
$H_2^+ + H_2 \rightarrow H + H_3^+$	2.11×10^{-9}	[88]
$H_2^+ + H \rightarrow H_3^+$	2.08×10^{-9}	[97]
$H_2^+ + H \rightarrow H_2 + H^+$	6.40×10^{-10}	[97]
$C^+ + H^- \rightarrow C + H$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[98]
$H^- + M \rightarrow H + e^- + M$	$2.70 \times 10^{-10} \left(\frac{T_{gas}}{300}\right)^{-0.50} \exp\left(-\frac{5590.0}{T_{gas}}\right)$	[98]
$H^- + H_2^+ \rightarrow H + H + H$	$2.0 \times 10^{-7} \left(\frac{300}{T_{gas}}\right)^{0.50}$	[99]
$H^- + H_3^+ \rightarrow H_2 + H + H$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[99]
$H^- + H_3^+ \rightarrow H_2 + H_2$	$2.0 \times 10^{-7} \left(\frac{300}{T_{gas}}\right)^{0.50}$	[99]
$H^- + H^+ \rightarrow H + H$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[99]
$H^- + H_2^+ \rightarrow H_2 + H$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[100]
$H^- + H \rightarrow e^- + H_2$	$4.32 \times 10^{-9} \left(\frac{T_{gas}}{300}\right)^{-0.39} \exp\left(-\frac{39.40}{T_{gas}}\right)$	[101]
$H^- + CH_3 \rightarrow CH_4 + e^-$	1.00×10^{-9}	[82]
$H^- + CH_2 \rightarrow CH_3 + e^-$	1.00×10^{-9}	[82]
$H^- + CH \rightarrow CH_2 + e^-$	1.00×10^{-10}	[82]
$H^- + C \rightarrow CH + e^-$	1.00×10^{-9}	[82]
$H^- + C_2H \rightarrow C_2H_2 + e^-$	1.00×10^{-9}	[82]
$H^- + C_2 \rightarrow C_2H + e^-$	1.00×10^{-9}	[82]
$H^- + CH_4^+ \rightarrow H + CH_4$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[99]

$H^- + CH_3^+ \rightarrow H + CH_3$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[99]
$H^- + C_2H_2^+ \rightarrow H + C_2H_2$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[102]
$H^- + C_2H_3^+ \rightarrow H + C_2H_3$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[102]
$H^- + C_2H^+ \rightarrow H + C_2H$	$7.51 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[102]
$H^- + C_2H_4^+ \rightarrow H + C_2H_4$	$6.23 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[102]
$H^- + C_2H_5^+ \rightarrow H + C_2H_5$	$5.16 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[102]
$H^- + C_2H_6^+ \rightarrow H + C_2H_6$	$6.04 \times 10^{-8} \left(\frac{T_{gas}}{300}\right)^{-0.50}$	[102]

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