Supplementary Materials

Hyperthermophilic methanogenic archaea act as high-pressure CH₄ cell factories

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Media compositions

141 medium KCl 0.34 g L⁻¹, MgCl₂·6H₂O 4 g L⁻¹, MgSO₄·7H₂O 3.45 g L⁻¹, NH₄Cl 0.25 g L⁻¹, CaCl₂·2H₂O 0.14 g L⁻¹, K₂HPO₄ 0.14 g L⁻¹, NaCl 18 g L⁻¹, TE solution (141 medium) 10 mL L⁻¹, FeII(NH₄)₂(SO₄)₂·6H₂O solution (w:v = 0.1%) 2 mL L⁻¹, Na-acetate 1 mL L⁻¹, Yeast extract 2 g L⁻¹, NaHCO₃ 5 g L⁻¹, vitamin solution 10 mL L⁻¹, L-Cysteine-HCl·H₂O 0.5 g L⁻¹, Na₂S·9H₂O 0.5 g L⁻¹. Trace element (TE) solution for 141-medium contained the following (TES1): nitrilotriacetic acid 1.5 g L⁻¹, MgSO4·7H₂O 3 g L⁻¹, MnCl₂·4H₂O 0.585 g L⁻¹, NaCl 1 g L⁻¹, FeSO₄·7H₂O 0.1 g L⁻¹, CoSO₄·7H₂O 0.18 g L⁻¹, CaCl₂·2H₂O 0.1 g L⁻¹, ZnSO₄·7H₂O 0.18 g L⁻¹, CuSO₄ 0.006 g L⁻¹, KAI(SO₄)₂·12H₂O 0.02 g L⁻¹, H₃BO₃ 0.01 g L⁻¹, Na2MoO4·2H2O 0.01g L⁻¹, NiCl2·6H2O 0.03 g L⁻¹, Na2SeO3·5H2O 0.3 mg L⁻¹, Na2WO4·2H2O 0.4 mg L⁻¹. Wolf's vitamin solution (vitamin solution of 141 medium) contained the following: biotine 20 mg L⁻¹ (81.9 µM), folic acid 20 mg L⁻¹ (45.3 µM), pyridoxamine dihydrochloride 100 mg L⁻¹ (386.0 μ M), thiamine hydrochloride 50 mg L⁻¹ (148.0 μ M), riboflavin 50 mg L⁻¹ (133.0 µM), nicotinic acid 50 mg L⁻¹ (406.0 µM), DL-calcium pantothenate 50 mg L⁻¹ (105.0 μ M), cyanocobaimine 5 mg L⁻¹ (3.7 μ M), p-aminobenzoic 50 mg L⁻¹ (365.0 μ M). $FeII(NH_4)_2(SO_4)_2 \cdot 6H_2O$ solution (w:v = 0.1%) comprised the following: (NH_4)_2SO_4 0.00337 g L⁻¹ and FeSO₄·7H₂O 0.00709 g L⁻¹. The FeII(NH₄)₂(SO₄)₂·6H₂O solution has to be prepared in dd.H₂O. 141b medium contained the same ingredients as 141-medium using NaCl 6 g L⁻¹, instead of NaCl 16 g L⁻¹. 141c medium contained the same ingredients as 141-medium including methanol 5 mL L^{-1} .

203 medium Mineral solution 1 (K₂HPO₄ 6 g L⁻¹; ultrapure H₂O Milli-Q® system) 37.5 mL L⁻¹, mineral solution 2 (KH₂PO₄ 6 g L⁻¹, (NH₄)₂SO₄ 6 g L⁻¹, NaCl 12 g L⁻¹, MgSO₄·7H₂O 2.4 g L⁻¹, CaCl₂·2H₂O 1.6 g L⁻¹; ultrapure H₂O Milli-Q® system) 37.5 mL L⁻¹, NiCl₂·6H₂O solution (0.1% w/v) 1 mL L⁻¹, FeSO₄·7H₂O solution (0.1% w/v in 0.1 M H₂SO₄) 2 mL L⁻¹. TE solution (TES1) (see medium 141) 10.0 mL, Na₂SO₄ 3.4 g, NaHCO₃ 2.0 g, Yeast extract (OXOID) 2 g L⁻¹, Trypticase peptone (BD BBL) 2 g L⁻¹, vitamin solution (see medium 141) 10 mL L⁻¹, Na₂S·9H₂O 0.5 g L⁻¹, L-Cysteine-HCl·H₂O 0.5 g L⁻¹. In case of *Methanothermus sociabilis* yeast extract and trypticase peptone is not needed and was therefore not added to the medium. 203c medium was prepared without the addition of vitamins. 203-c medium was prepared without the vitamins and L-Cysteine-HCl·H₂O.

511 medium NH4Cl 0.25 g L⁻¹, K₂HPO₄·3H₂O 0.07 g L⁻¹, KH₂PO₄ 0.09 g L⁻¹, NaCl 11.8 g L⁻¹, MgSO₄·7H₂O 1.75 g L⁻¹, MgCl₂·6H₂O 4.5 g L⁻¹, Na₂SO₄ 0.81 g L⁻¹, CaCl₂·2H₂O 0.78 g L⁻¹, KCl 0.3 g L⁻¹. TE solution 511 medium (TES5): 10 mL L⁻¹ 141-medium-TES, and marine TE (see below) 10 mL L⁻¹, (NH₄)₂Fe(SO₄)₂·6H₂O solution (0.1% w/v) 2 mL L⁻¹, (NH₄)₂Ni(SO₄)₂ solution (0.1% w/v) 2 mL L⁻¹, Na₂WO₄·2H₂O solution (0.1% w/v) 2 mL L⁻¹, NaHCO₃ 1 g L⁻¹, vitamins solution (see medium 141) 10 mL L⁻¹, Na₂S·9H₂O 0.5 g L⁻¹. Marine TE solution: NaBr 4 g L⁻¹, SrCl₂·6H₂O 1.8 g L⁻¹, H₃BO₃ 1.3 g L⁻¹, KI 1.25 mg L⁻¹, Na-silicate 100 mg L⁻¹, NaF 60 mg L⁻¹, KNO₃ 40 mg L⁻¹, Na₂HPO₄·3H₂O 0.25 mg L⁻¹. 511-v medium was prepared without vitamins.

SAB medium (modified): MgSO4·7H₂O 0.8 g L⁻¹, KH₂PO₄ 0.5 g L⁻¹, K₂HPO₄ 0.5 g L⁻¹, CaCl₂·6H₂O 0.05 g L⁻¹, NaCl 1.5 g L⁻¹, NH₄Cl 1 g L⁻¹, Na₂S·9H₂O 0.3 g L⁻¹, sodium acetate 1 g L⁻¹, yeast extract 2 g L⁻¹, 5mM valeric acid, 5 mM isovaleric acid, 5 mM 2-methylbutyric acid, 6 mM isobutyric acid, 5 mM 2-methyl valeric acid, 1000x TE solution 1 mL L⁻¹. The

SAB-TE solution (TES2) contained the following: nitrilotriacetic acid 1.5 g L⁻¹, NiCl₂·6H₂O 15 g L⁻¹, KCl 0.5 g L⁻¹, MnSO₄·7H₂O 6 g L⁻¹, ZnSO₄·7H₂O 1 g L⁻¹, CuSO₄ 1.278 g L⁻¹, KAl(SO₄)₂·12H₂O 2 mg L⁻¹, H₃BO₃ 70 mg L⁻¹, CoSO₄·7H₂O 40 mg L⁻¹, Na₂MoO₃·H₂O 5 g L⁻¹, Na₂SeO₃·5H₂O 30 mg L⁻¹, Na₂WO₄·2H₂O 40 mg L⁻¹, FeSO₄·7H₂O 9 g L⁻¹. After anaerobization and autoclaving the medium, L-Cysteine-HCl·H₂O 0.5 g L⁻¹, 4 M methanol 20 mL L⁻¹, 8 M sodium format 20 mL L⁻¹, 10% NaHCO₃ 20 mL L⁻¹, 2% Na₂S·9H₂O 20 mL L⁻¹ and vitamin solution 15 mL L⁻¹ (Wolf's vitamin solution) must be added to the serum bottles. The pH in the serum bottles was adjusted to 7.5 with 10 M KOH.

Medium 6 NH4Cl 1 g L⁻¹, MgCl₂·6H₂O 1 g L⁻¹, CaCl₂·2H₂O 0.4 g L⁻¹, KH₂PO₄·2H₂O 0.6325 g L⁻¹, NaHCO₃ 12 g L⁻¹, Na₂S·9H₂O 0.9092 g L⁻¹. TE solution 10 mL L⁻¹, vitamin solution¹ 10 mL L⁻¹. TE solution (TES6)²: nitrilotriacetic acid 1.5 g L⁻¹, dissolve nitrilotriacetic acid with KOH to pH 6.5; then proceed with mineral addition: MgSO₄·7H₂O 3 g L⁻¹, MnCl₂·4H₂O 0.529 g L⁻¹, NaCl 1 g L⁻¹, FeSO₄·7H₂O 0.1 g L⁻¹, CoCl₂·6H₂O 0.1833 g L⁻¹, CaCl₂·2H₂O 0.1 g L⁻¹, ZnSO₄·7H₂O 0.1781 g L⁻¹, CuSO₄ 0.0063 g L⁻¹, AlK(SO₄)₂ 0.01 g L⁻¹, H₃BO₃ 0.01 g L⁻¹, Na₂MoO₄·2H₂O 0.01 g L⁻¹(pH to 7.0 with KOH).

McN medium for Methanococci contained: KCl 0.335 g L⁻¹, MgCl₂·6H₂O 2.75 g L⁻¹, MgSO₄·7H₂O 3.45 g L⁻¹, NH₄Cl 0.5 g L⁻¹, CaCl₂·2H₂O 0.14 g L⁻¹, K₂HPO₄ 1.4 g L⁻¹ and NaCl 21.975 g L⁻¹. TE solution (TES3) 10 mL L⁻¹ (MM medium TE solution), iron stock solution 5 mL L⁻¹, After anaerobization and autoclaving the medium, Na₂S·9H₂O 0.5 g L⁻¹ must be added. Fe(NH₄)₂(SO₄)₂ solution for MCN medium: 2 g, Fe(NH₄)₂(SO₄)₂·6H₂O and 100 μ L conc. HCl must be mixed and filled up to 1 L with ultrapure H₂O Milli-Q[®].

282c 0, 282c 18, or 282c 30 medium (282 medium with cysteine and 0 g, 18 g, or 30 g NaCl): K₂HPO₄ 0.14 g L⁻¹, CaCl₂·2H₂O 0.14 g L⁻¹, NH₄Cl 0.25 g L⁻¹, MgSO₄·7H₂O 3.4 g L⁻¹, MgCl₂·6H₂O 4.1 g L⁻¹, KCl 0.33 g L⁻¹, NiCl₂·6H₂O solution (0.1% w/v) 0.5 mL, NaCl 0 g L⁻¹ (*M. palustre*), 18 g L⁻¹ (*M. villosus*) or 30 g L⁻¹ (*M. vulcanius, M. jannaschii*), Fe(NH₄)₂(SO₄)₂·6H₂O 0.01 g L⁻¹, TE solution (TES1) (DSMZ medium 141) 10 mL L⁻¹. After anaerobization and autoclaving the medium, NaHCO₃ 1 g L⁻¹, L-Cysteine-HCl·H₂O 0.5 g L⁻¹ have to be added. 282-c 30 was prepared without the addition of L-Cysteine-HCl·H₂O.

282c 18 _E medium K₂HPO₄ 0.14 g L⁻¹, CaCl₂·2H₂O 0.14 g L⁻¹, NH₄Cl 0.25 g L⁻¹, MgSO₄·7H₂O 3.4 g L⁻¹, MgCl₂·6H₂O 4.1 g L⁻¹, KCl 0.33 g L⁻¹, NiCl₂·6H₂O 0.5 mg L⁻¹, Na₂SeO₃·5H₂O 0.5 mg L⁻¹, NaCl 18 g L⁻¹ (*M. villosus*) or 30 g L⁻¹ (*M. vulcanius*, *M. jannaschii*), FeSO₄·7H₂O 7 mg L⁻¹, TE solution (TES1) (DSMZ medium 141) 10 mL L⁻¹. After anaerobization and autoclaving the medium, NaHCO₃ 1 g L⁻¹, L-Cysteine-HCl·H₂O 0.5 g L⁻¹, Na₂S·9H₂O 0.5 g L⁻¹ must be added. TE solution for 282 medium contained the following: nitrilotriacetic acid 1.5 g L⁻¹, MgSO₄·7H₂O 3 g L⁻¹, MnCl₂·4H₂O 0.585 g L⁻¹, NaCl 1 g L⁻¹, FeSO₄·7H₂O 0.1 g L⁻¹, CoSO₄·7H₂O 0.18 g L⁻¹, CaCl₂·2H₂O 0.1 g L⁻¹, ZnSO₄·7H₂O 0.18 g L⁻¹, CuSO₄ 0.006 g L⁻¹, KAI(SO₄)₂·12H₂O 0.02 g L⁻¹, H₃BO₃ 0.01 g L⁻¹, Na₂MoO₄·2H₂O 0.01 g L⁻¹, NiCl₂·6H₂O 0.03 g L⁻¹, Na₂SeO₃·5H₂O 0.3 mg L⁻¹, Na₂WO₄·2H₂O 0.4 mg L⁻¹.

Methanothermobacter marburgensis medium (MM) contained the following compounds: NH₄Cl 2.1 g L⁻¹, KH₂PO₄ 6.8 g L⁻¹, Na₂CO₃ 3.6 g L⁻¹, 100x TE 10 mL L⁻¹. After anaerobization and autoclaving the medium, 0.5 M Na₂S·9H₂O 2 mL L⁻¹ must be added. 100x TE solution (TES3) contained: Titriplex I 9 g L⁻¹, add 800 mL ultrapure H₂O Milli-Q® system and adjust the pH to 6.5 with 5M NaOH solution, then add: MgCl₂·6H₂O 4 g L⁻¹, FeCl₂·4H₂O 1 g L⁻¹, CoCl₂·6H₂O 20 mg L⁻¹, NiCl₂·6H₂O 120 mg L⁻¹, NaMoO₄·2H₂O 20 mg L⁻¹, put to pH= 7.0 with 1 M NaOH. MM15 and MM30 contained additionally 15 or 30 g L⁻¹ NaCl. MM15c and MM30c contained additionally L-Cysteine-HCl·H₂O 0.5 g L⁻¹. MM15v contained additionally 10 mL L⁻¹ of vitamins (medium 141).



Fig. S1 Results of the multivariate pre-screen of 80 methanogens in defined and complex media respectively to the biomass increase rate. Experiments were performed in closed batch cultivation systems at 2 bar (120mL flasks, 50 mL medium). On the y-axis, methanogens were arranged as groups according to their temperature optimum in psychrophiles, mesophiles, thermophiles or hyperthermophiles. Methanogens are listed with ascending strain specific temperature optimum from top to bottom. Coloured points next to the strain designation on the y-axis indicate the isolation site of the tested methanogen (terrestrial habitats: golden brown - soil sediment, dark green - swamp/permafrost/sludge, pink - post-volcanic region, grey - oil-field associated, light green - anaerobic digester/ bioreactor, brown - faeces, orange - eukaryote-associated; marine and freshwater environments: bright blue - marine sediment, turquoise - marine eukaryote-associated, red - marine hydrothermal vent and volcanic region, grey blue - freshwater sediment, sky blue - freshwater, green blue - waste/formation water). In total, 22 defined and complex media are shown on the x-axis in black and grey fonts, respectively. For each closed batch cultivation, three biological replicates (in some cases, two biological replicates) plus one negative control were used.



Fig. S2 Results of the maximum gas conversion (turnover_{max} / %) of 80 methanogens in defined and complex media during the multivariate pre-screening. Experiments were performed in closed batch cultivation systems at 2 bar (120mL flasks, 50 mL medium). On the y-axis, methanogens were arranged as groups according to their temperature optimum in psychrophiles, mesophiles, thermophiles, or hyperthermophiles. Methanogens are listed with ascending strain specific temperature optimum from top to bottom. Coloured points next to the strain designation on the y-axis indicate the isolation site of the tested methanogen (terrestrial habitats: golden brown - soil sediment, dark green - swamp/permafrost/sludge, pink - post-volcanic region, grey - oil-field associated, light green - anaerobic digester/ bioreactor, brown - faeces, orange - eukaryote-associated; marine and freshwater environments: bright blue - marine sediment, turquoise - marine eukaryote-associated, red - marine hydrothermal vent and volcanic region, grey blue - freshwater sediment, sky blue - freshwater, green blue - waste/formation water). In total, 22 defined and complex media were tested, but not every strain could be or was cultivated on every medium. Defined and complex media are shown on the x-axis in black and grey fonts, respectively. For each closed batch cultivation, three biological replicates (in some cases, two biological replicates) plus one negative control were used.



Fig. S3 k-means cluster analysis of the nutrimental demand and associated growth (OD_{max}) of tested methanogens. Fig. S3a shows a biplot including the variance of the variables and the corresponding clusters. Fig. S3b illustrates the k-means clusters after the PCA. For the k-means clustering two principle components were used. Fig. S3c shows a silhouette plot (quality of clustering) of the cluster.



Fig. S4 k-means cluster analysis of the nutrimental demand and associated turnover of the substrates (turnover_{max}) of tested methanogens. Fig. S4a shows a biplot including the variance of the variables and the corresponding clusters. Fig. S4b illustrates the k-means clusters after the PCA. For the k-means clustering two principle components were used. Fig. S4c shows a silhouette plot (quality of clustering) of the cluster.



Fig. S5 k-means cluster analysis of the nutrimental demand and associated volumetic CH_4 production rate (MER_{max}) of tested methanogens. Fig. S5a shows a biplot including the variance of the variables and the corresponding clusters. Fig. S5b illustrates the k-means clusters after the PCA. For the k-means clustering two principle components were used. Fig. S5c shows a silhouette plot (quality of clustering) of the cluster.



Fig. S6 k-means cluster analysis of the nutrimental demand and associated gowth (OD_{max}) , turnover of substrates (turnover_{max}), and volumetic CH₄ production rate (MER_{max}) of tested methanogens. Fig. S6a shows a biplot including the variance of the varibles and the corresponding clusters. Fig. S6b illustrates the k-means clusters after the PCA. For the k-means clustering two principle components were used. Fig. S6c shows a silhouette plot (quality of clustering) of the cluster.



Fig. S7 Repetitive closed-batch cultivation using high frequency gassing (HFG) for prioritized methanogens at 2 bar in defined medium. All experiments were performed in quadruplicates including a negative control. The turnover rate / h⁻¹ is shown. Three temperature blocks are distinguished and highlighted from left to right: mesophilic methanogens grown at 37°C (*Methanococcus maripaludis* S2, *Methanobacterium palustre* F, *Methanobacterium subterraneum* A8p); middle block: five thermophilic strains grown at 65°C (*Methanothermobacter marburgensis* Marburg, *Methanothermobacter thermophilus* M, *Methanobacterium thermaggregans*, *Methanothermobacter thermautotrophicus* DeltaH, *Methanothermococcus okinawensis* IH1); right block: six hyperthermophilic methanogens (*Methanocaldococcus jannaschii* JAL-1 (80°C), *Methanocaldococcus vulcanius* M7 (80°C), *Methanocaldococcus villosus* KIN24-T80 (80°C), *Methanothermus fervidus* H9 (80°C), *Methanopyrus kandleri* AV19 (98°C)).

CM	HISE	PROPER	Phene type	Gitten	PHER AVER AVER	ASPER CYSE	ASTAR	٥- ٥-
VV <mark>QEH</mark> MA <mark>E</mark>	KHS	RR	GFTQDG	FGGSQR		QDQCG	ALNTE	WP_086637809 Methanonatronarchaeum thermophilum
VV <mark>QEH</mark> MA <mark>E</mark>	<mark>кн</mark> ѕ	RR	<mark>G</mark> FTQYA	F GG <mark>SQ</mark> R	L <mark>GFYGYD</mark> L	<mark>Q DQ</mark> CG	am <mark>n</mark> ∨ <mark>g</mark>	WP_019176774 Methanomassiliicoccus luminyensis *
VV <mark>QEH</mark> MV <mark>E</mark>	KHA	RR	GFTQYA	F G G S Q R	LGFYGYDL		AM <mark>N</mark> VG	WP_013180513 Methanococcus voltae
VVQEHMVE	KHA	RR	GETOYA	FGGSQR		Q DQ CG		CAA30633 Methanococcus voltae PS*
VVQEHMVE	КНА	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	ABR54777 Methanococcus vannielii SB*
VVQEHMVE	KHA	RR	<mark>g</mark> f <mark>t q y</mark> a	F GG <mark>SQ</mark> R	LGFYGYDL	Q DQ CG	AM <mark>N</mark> ∨G	WP_011171503 Methanococcus maripaludis *
∨∨ <mark>QЕН</mark> М∨ <mark>Е</mark>	<mark>к</mark> на	RR	<mark>G</mark> FTQYA	F GG <mark>SQ</mark> R	L <mark>GFYGYD</mark> L	<mark>Q DQ</mark> CG	am <mark>n</mark> ∨ <mark>g</mark>	CAF31115 Methanococcus maripaludis S2* 🎽
VV <mark>QEH</mark> MV <mark>E</mark>	KHA	RR	GFTQYA	FGG <mark>SQ</mark> R	LGFYGYDL		AM <mark>N</mark> VG	WP_146778459 Methanococcus maripaludis *
VVQEHMVE	KHA	RR	GETQYA	FGGSQR	LGFYGYDL		AMNVG	WP_011977191 Methanococcus maripaludis *
	КНА	RR	GETQYA	FGGSOR				WP_012195868 Methanococcus marinaludis *
				FGGSQR	LGFYGYDL	QDQCG		AAL29288 Methanotorris igneus Kol 5* ¥ 单
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>к</mark> на	RR	<mark>G</mark> F <mark>TQY</mark> A	F G G <mark>S Q</mark> R	LGFYGYDL	<mark>q dq</mark> cg	AM <mark>N</mark> ∨ <mark>G</mark>	ENN96460 Methanocaldococcus villosus KIN24-T80* 🔻
∨∨ <mark>QEH</mark> M∨ <mark>E</mark>	КНА	RR	<mark>G F T Q Y</mark> A	F G G <mark>S Q</mark> R	L <mark>GFYGYD</mark> L	<mark>Q DQ</mark> CG	AM <mark>N</mark> ∨G	WP_013099697 Methanocaldococcus infernus
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL	Q DQ CG	AMNVG	WP_012819563 Methanocaldococcus vulcanius *
VVQEHMVE	KHA	RR	GETQYA	FGGSQR			AMNVG	WP_010870360 Methanocaldococcus jannaschii * 🐥 🚽
	КНА	RR	GETQYA	FGGSOR				WP_011975976 Methanofervidicoccus sp. A16
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	AEH06926 Methanothermococcus okinawensis IH1* ¥
VV <mark>QEH</mark> MVE	<mark>к</mark> на	RR	<mark>G</mark> F <mark>TQY</mark> A	FGG <mark>SQ</mark> R	LGFYGYDL	<mark>q dq</mark> cg	AM <mark>N</mark> ∨ <mark>G</mark>	WP_067147089 Methanobrevibacter olleyae *
∨∨ <mark>QEH</mark> M∨ <mark>E</mark>	<mark>к</mark> на	RR	<mark>G F T Q Y</mark> A	F G G <mark>S Q</mark> R	L <mark>GFYGYD</mark> L	Q DQ A G	AM <mark>N</mark> ∨ <mark>G</mark>	WP_069575111 Methanobrevibacter
VV <mark>QEH</mark> MVE	<mark>к</mark> на	RR	GFTQYA	FGGSQR	L <mark>G F Y G Y D</mark> L		am <mark>n</mark> v <mark>g</mark>	RPF51676 Methanobrevibacter gottschalkii HO*
VVQEHMVE	KHA	RR	GETOYA	FGGSQR	LGFYGYDL	UDQ CG	AMNVG	WP_011954158 Methanobrevibacter
VVOEHMVE	KHA	RR	GETOYA	FGGSOR				CAF48306 Methanosphaera stadtmanae MCR-3*
VVQEHMVE	KHA	RR	GFTQYA	FGGSOR	LGFYGYDI		AMNVG	WP_048080940 Methanobacterium
VV <mark>QEH</mark> MVE	<mark>к</mark> на	RR	GFTQYA	FGGSQR	LGFYGYDL		AM <mark>N</mark> VG	PAV05908 Methanobacterium bryantii *
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>кн</mark> а	RR	<mark>G F T Q Y</mark> A	F G G <mark>S Q</mark> R	L <mark>GFYGYD</mark> L	Q DQ CG	AM <mark>N</mark> ∨ <mark>G</mark>	WP_100905456 Methanobacterium
VV <mark>QEH</mark> MVE	K H A	RR	GFTQYA	F G G <mark>S Q</mark> R	LGFYGYDL	Q DQ CG	AM <mark>N</mark> VG	AUB55475 Methanobacterium subterraneum * 🔻
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR		Q DQ CG	AM <mark>N</mark> VG	WP_023992931 Methanobacterium sp. MB1
	KHA	RR	GETOYA	FGGSQR			AMNVG	WP_004029250 Methanobacterium formicicum *
VVQEHMVE	КНА	RR	GFTQYA	FGGSOR	LGFYGYDL		AMNVG	WP 048085732 Methanobacterium formicicum *
VVQEHMVE	КНА	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	WP_048072649 Methanobacterium formicicum *
VV <mark>QEH</mark> MVE	KHA	RR	<mark>g f tq y</mark> a	F G G <mark>S Q</mark> R	LGFYGYDL		AM <mark>N</mark> ∨G	WP_074359401 Methanothermobacter wolfeii*
∨∨ <mark>QEH</mark> M∨ <mark>E</mark>	<mark>к</mark> на	RR	<mark>G F T Q Y</mark> A	F GG <mark>SQ</mark> R	L <mark>G</mark> F <mark>YGYD</mark> L	<mark>Q DQ</mark> CG	AM <mark>N</mark> ∨ <mark>G</mark>	WP_010876753 Methanothermobacter thermautotrophicus * ¥
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>к</mark> на	RR	GFTQYA	F G G S Q R	L <mark>G F Y G Y D</mark> L	Q D Q C G	AM <mark>N</mark> VG	WP_048175703 Methanothermobacter spp.
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	WP_013296302 Methanothermobacter spp.
VVQEHMVE	K H A	RR	GETOYA	FGGSQR				WP_018154763 Methanothermococcus thermolithotrophicus ~ WP_048115624 Methanotorris formicicus
	КНА	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	WP_015733272 Methanocaldococcus vulcanius * *
VVQEHMVE	KHA	RR	GFTQYA	FGG <mark>SQ</mark> R	LGFYGYDL	QDQCG	AMNVG	WP_012980029 Methanocaldococcus sp. FS406-22
∨∨ <mark>QEH</mark> M∨ <mark>E</mark>	<mark>к</mark> на	RR	<mark>G</mark> F <mark>TQY</mark> A	F GG <mark>SQ</mark> R	L <mark>GFYGY</mark> AL	<mark>Q DQ</mark> CG	am <mark>n</mark> ∨ <mark>g</mark>	WP_011019025 Methanopyrus kandleri * 🔻
∨∨ <mark>QEH</mark> M∨ <mark>E</mark>	<mark>к</mark> на	RR	<mark>G F T Q Y</mark> A	F G G <mark>S Q</mark> R	L <mark>GFYGYD</mark> L	<mark>Q DQ</mark> CG	AM <mark>N</mark> ∨ <mark>G</mark>	WP_088335801 Methanopyrus sp. KOL6
VIQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	WP_067147710 Methanobrevibacter olleyae *
	KHA	RR	GETOYA	FGGSQR				ADC47774 Methanobrevibacter ruminantium
	КНА	RR	GETQYA	FGGSOR				WP 116669466 Methanobrevibacter woesei *
VVQEHMVE	KHA	RR	GFTQYA	FGG <mark>SQ</mark> R	LGFYGYDL	QDQCG	AMNVG	WP_011954235 Methanobrevibacter spp.
∨∨ <mark>QEH</mark> M∨ <mark>E</mark>	<mark>к</mark> на	RR	<mark>G</mark> F <mark>TQY</mark> A	F <mark>GG <mark>SQ</mark> R</mark>	L <mark>GFYGYD</mark> L	<mark>Q DQ</mark> CG	AM <mark>N</mark> ∨ <mark>G</mark>	WP_049780206 Methanobrevibacter smithii *
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>к</mark> на	RR	GFTQYA	F G G <mark>S Q</mark> R	L <mark>GFYGFD</mark> L	<mark>Q DQ</mark> CG	AM <mark>N</mark> ∨G	WP_063720576 Methanobrevibacter oralis
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGFDL		AMNVG	WP_149732200 Methanobrevibacter millerae *
	КНА	RR	GETOYA	FGGSQR				WP_116592380 Wethanobrevibacter thaueri *
	КНА	RR	GFTQYA	FGGSQR	LGFYGFDL		AMNVG	WP_069575737 Methanobrevibacter spp.
VV <mark>QEH</mark> MVE	<mark>к</mark> на	RR	<mark>G F T Q Y</mark> A	FGG <mark>SQ</mark> R	LGFYGYDL	<mark>q dq</mark> cg	am <mark>n</mark> ∨ <mark>g</mark>	WP_040682084 Methanobrevibacter boviskoreani *
VV <mark>QEH</mark> MV <mark>E</mark>	K H A	RR	G F T Q Y A	FGG <mark>SQ</mark> R	L <mark>GFYGYD</mark> L	Q DQ CG	AM <mark>N</mark> ∨G	WP_016359092 Methanobrevibacter sp. AbM4
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>к</mark> на	RR	GFTQYA	F G G S Q R	L <mark>GFYGYD</mark> L	Q DQ CG	am <mark>n</mark> v <mark>g</mark>	WP_067089747 Methanobrevibacter curvatus
VVQEHMVE	KHA	RR	GETOYA	FGGSQR	LGFYGYDL	Q DQ CG	AMNVG	WP_U66972991 Methanobrevibacter filiformis
VVQEHMVE	КНА	RR	GETOYA	FGGSOR				WP 054834881 Methanobrevibacter arboriphilus *
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL	QDQCG	AMNVG	WP_013413861 Methanothermus fervidus * *
			<mark>G F T Q Y</mark> A	FGG <mark>SQ</mark> R	LGFYGYDL			AAQ18233 Methanothermus sociabilis *
			G F T Q Y A	F G G <mark>S Q</mark> R	L <mark>GFYGYD</mark> L	Q DQ CG	AM <mark>N</mark> V -	AEI26141 Methanothermobacter crinale *
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR		Q DQ CG	AMNVG	RAO79542 Methanothermobacter tenebrarum*
VVOEHMVE	KHA	RR	GETOYA	FGGSQR		Q DQ CG		BAID/101 Methanobacterium oryzae *
VVQEHMVE	КНА	RR	GETOYA	FGGSOR	LGEYGYDL			BAI67100 Methanobacterium iyanovii *
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL	QDQCG		BAI67104 Methanobacterium uliginosum *
VV <mark>QEH</mark> MVE	K H A	RR	GFTQYA	FGGSQR	LGFYGYDL			ADM52196 Methanobacterium flexile *
VV <mark>QEH</mark> MVE	KHA	RR	G F T Q Y A	F G G <mark>S Q R</mark>	L <mark>GFYGYD</mark> L	<mark>Q DQ</mark> CG		AAR27839 Methanobacterium aarhusense *
			GFTQYA	F G G S Q R	LGFYGYDL	Q DQ CG	A	ABO93182 Methanobacterium beijingense *
VVQEHMVE	KHA	RR	GETQYA	FGGSQR		Q DQ CG	AM <mark>N</mark> VG	WP_147671448 Methanothermobacter sp. KEPCO-1
			GETOYA	FGGSQR				AAQ16256 IVIETIANOBACTERIUM thermoggregans * 🗢
	KHA	RR	GFTQYA	FGGSQR	LGFYGYDI	QDQCG	AMNVG	WP 160322962 Methanothermobacter sp. THM-2
VVQEHMVE	KHA	RR	GFTQYA	FGGSQR	LGFYGYDL		AMNVG	WP_074359432 Methanothermobacter wolfeii *
VV <mark>QEH</mark> MVE	<mark>к</mark> на	RR	<mark>G F T Q Y</mark> A	FGG <mark>SQ</mark> R			AM <mark>N</mark> ∨G	WP_013296337 Methanothermobacter marburgensis * 🔻
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>К</mark> НА	RR	G F T Q Y A	FGG <mark>SQ</mark> R	L <mark>GFYGYD</mark> L	Q DQ CG	AM <mark>N</mark> ∨G	WP_115891951 Methanothermobacter defluvii
VVQEHMVE	KHA	RR	GFTQYA	F G G S Q R	LGFYGYDL	Q DQ CG	AM <mark>N</mark> ∨G	WP_048175731 Methanothermobacter sp. CaT2
		P.P	GETOYA	FGGSQR	LGFYGYDL	Q DQ CG		AAU21198 Methanothermobacter thermoflexus *
VVOEHMVE	KHA	RP	GETOYA	FGGSQR			AMNVC	WP 048191628 Methanobacterium so SMA-27
VVQEHMVE	KHA	RR	GFTQYA	FGGSOR	LGFYGYDL		AMNVG	WP 013643956 Methanobacterium lacus *
VVQEHMVE	K H A	RR	GFTQYG	FGGSQR	LGFYGYDL		AMNVG	SCG86533 Methanobacterium congolense *
VV <mark>QEH</mark> MV <mark>E</mark>	<mark>к</mark> на	RR	<mark>G F T Q Y</mark> A	FGG <mark>SQ</mark> R	L <mark>GFYGYD</mark> L	Q DQ CG	AM <mark>N</mark> ∨G	WP_023992801 Methanobacterium sp. MB1
VVQEHMVE	KHA	RR	GFTQYA	F G G S Q R	LGFYGYDL	QDQXG		BAI67102 Methanobacterium palustre * ¥
		P P	GETOXA	FGGSQR		Q DQ CG		BAI94570 Methanobacterium kanagiense *

	E KHA	RR C	G F T Q Y A	FGGSQR	LGFYGYDLQDQCG		AB542744 Methanobacterium petrolearium Mic5c12*
	E KHA	RR C	G F T Q Y A	FGGSQR	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_013718622 Methanothrix soehngenii *
VVOE HMV	КНА	RR C	BETOYA	EGGSOR	MGEEGYDLODOCG	AMNVG	WP_014586065 Methanosaeta harundinacea *
			ETOYA	FCCSOR			WB_012104266 Methanobalohium quastigatum
			F T O Y O				WP_015154500 Wethanohaloblain evestigatain
		RR C	JFTQT5	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_105460658 Wethanonalophilus eunalopius
VVQEHMV	E KHA	RR (SFTQYS	FGGSQR	LGFFGFDLQDQCG	AM <mark>N</mark> VG	WP_129596984 Methanohalophilus sp. SLHTYRO
	E KHA	RR (F TQYS	FGG <mark>SQ</mark> R	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_123136699 Methanohalophilus sp. RSK
	E KHA	RR (F TQYS	FGGSQR	LGFFGFDLQDQCG	AM <mark>N</mark> VG	WP_072560206 Methanohalophilus halophilus
	E KHA	RR C	SFTQYS	FGGSQR	LGFFGFDLQDQCG	AMNVG	WP 013037080 Methanohalophilus mahii
	- KHA	RR C	SFTQYS	FGGSOR			WP 072359425 Methanohalophilus portucalensis
V/VOE XMV		RR (FTOYA	FCCSOR	LOFECYDLODOCC	AMNVG	WP_013898158 Methanosalsum zhilinge
			ETOYA	FCCCC			WB_015335038 Methanomethylovorgas hollandica
VVQEHMV				FOODOR		AMINVG	WP_013525028 Methanomethylovoruns holianaica
V V Q E HM V	E KHA	RR C	SFIQYA	FGGSQR		AMNVG	WP_011500403 Methanococcoides burtonii
V V <mark>Q E H</mark> M V	E KHA	RR C	3 F T Q Y A	F G G S Q R	LGFFGFDLQDQCG	AM <mark>N</mark> VG	WP_135613124 Methanococcoides sp. AM1
	E KHA	RR (FTQY A	FGG <mark>SQ</mark> R	LGFFGFDLQDQCG	AM <mark>N</mark> VG	WP_048193230 Methanococcoides methylutens
	E KHA	RR (FTQYA	FGGSQR	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_048204805 Methanococcoides methylutens
	E KHA	RR C	G F T Q Y A	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_091936029 Methanolobus profundi *
	E KHA	RR C	BFTQYA	FGGSQR	LGFFGFDLODOCG	AMNVG	WP 154810046 Methanolobus vulcani *
VVOE HMV	КНА	RR (FTOYA	EGGSOR	LGEEGYDLODOCG	AMNVG	WP 135388105 Methanolobus sp. SY-01
			ETOYA	FCCSOR			ACD92409 Mathanolohus zinderi*
				FOODO			ND 12251705C Mathemission and blatticele
			JFTQTA	FOOSUR		AMINVG	WP_155517056 Wethanimicrococcus blatticola
	E KHA	RR	SFIQYA	FGGSQR		AMNVG	WP_048177090 Methanosarcina sp. MTP4
VV <mark>QE</mark> MMV	E KHA	RR C	3 F T Q Y A	FGG <mark>SQR</mark>	LGFFGFDLQDQCG	AM <mark>N</mark> VG	WP_148704465 Methanosarcina thermophila
	E KHA	RR (G F T Q Y A	FGG <mark>SQ</mark> R	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_054299716 Methanosarcina flavescens
	E KHA	RR (FTQY A	FGGSQR	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_048131296 Methanosarcina sp. 1.H.T.1A.1
	E KHA	RR C	G F T Q Y A	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_048172209 Methanosarcina sp. 2.H.A.1B.4
	- кна	RR C	SFTQYA	FGGSOR		AMNVG	WP 048136663 Methanosarcina horonobensis *
	K H A	RR (BETOYA	FGGSOR	LGEEGYDLODOCG	AMNVG	WP_048048304 Methanosarcina mazei *
		RP	ETOYA	FGGSOF		AMNVC	WP_048050667 Methanosarcina soliaelidi*
			FTOVA	FCCCCC			WD_049027202 Methanesarsin=**
V V Q E MM V	KHA	KK (FTQTA	FOOSQR	LGFFGFDLQDQCG	AMNVG	WP_046037303 Wethanosarcina mazel*
V V <mark>Q E</mark> MM V		RR C	JE TOYA	FGGSQR	LGFFGFDLQDQCG	AM <mark>N</mark> VG	WP_04803/134 Methanosarcina mazei *
VV <mark>QE</mark> MMV	E KHA	RR C	3 F TQYA	FGG <mark>SQ</mark> R	L G F F G F D L Q D Q C G	AM <mark>N</mark> VG	WP_011033189 Methanosarcina mazei *
	E KHA	RR C	G F T Q Y A	FGGSQR	LGFFGFDLQDQCG	AMNVG	WP_048174272 Methanosarcina siciliae *
	E KHA	RR C	FTQYA	FGGSQR		AMNVG	WP 011024419 Methanosarcina acetivorans *
	КНА	RR (FTOYA	EGGSOR	LGEEGYDLODOCG	AMNVG	WP 048157992 Methanosarcina sp. Kolksee
		RR	FTOYA	FGGSOR		AMNVG	WP_011305916 Methanosarcing barkeri
			ETOYA	FCCCOR			WP_011303310 Methanosarcing_cpp
	KHA		JFTQTA	FGGSQR	LGFFGFDLQDQCG	AMNVG	WP_048120720 Methanosarcina spp.
	E KHA	RR C	SFIQYA	FGGSQR		AMNVG	WP_048108547 Methanosarcina barkeri
VVQEHMV	E KHA	RR (3 F T Q Y A	FGGSQR	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_014405506 Methanocella conradii
	E KHA	RR (G F T Q Y A	FGG <mark>SQ</mark> R	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_012899268 Methanocella paludicola
	E KHA	RR (FTQY A	FGGSQR	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_012106121 Methanoregula boonei *
	E KHA	RR C	G F T Q Y A	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_048111146 Methanoregula formicica
	KHA	RR C	FTOYA	FGGSOR			WP_007314361 Methanolinea tarda
VVOE HMV		RR (BETOYA	FGGSOR	LGEEGYDLODOCG	AMNVG	WP_095642342 Methanocorpusculum parvum
			ETOYA	FGGSOR			ABN07725 Methanocorpusculum Jahragnum 7*
				FCCCC			MD 042705004 Methanomicschium mehile
VVQEHMV	K HA		JFTQTA	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_042705994 Methanomicrobium mobile
	= KHA	RR	SFIQYA	FGGSQR		AMNVG	WP_004079635 Methanoplanus limicola *
VVQEHMV	E KHA	RR (3 F T Q Y A	FGG <mark>SQR</mark>	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_013330338 Methanolacinia petrolearia *
VVQEHMV	E KHA	RR (FTQYA	FGG <mark>SQ</mark> R	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_048152823 Methanolacinia paynteri
	E KHA	RR (FTQY A	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_062396498 Methanogenium cariaci *
	- <mark>кн</mark> а	RR C	G F T Q Y A	FGGSQR	LGFFGYDLQDQCG		BAF74593 Methanogenium organophilum *
	КНА	RR C	FTOYA	FGGSOR	I GEEGYDI ODOCG	AMNVG	WP 012618913 Methanosphaerula palustris
		PP C	FTOYA	FCCSOR			WP_109941049 Methanospirillum stamsii *
			ETOYA	FGGSOR			APD41954 Methanospirillum hungatai IE-1*
VVQEHMV			JFTQTA	FGGSQR		AMINVG	ABD41854 Methanospiniari nangater JF-1
	E KHA	RR C	JFTQTA	FGGSQR	LGFFGYDLQDQCG		WP_013329918 Methanolacinia petrolearia
	= KHA	RR	SFIQYA	FGGSQR		AMNVG	WP_048153025 Methanolacinia paynteri
VVQEHMV	E KHA	RR (3 F T Q Y A	FGG <mark>SQR</mark>	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_074370629 Methanoculleus chikugoensis *
VV <mark>QEH</mark> MV	E KHA	RR (3 F T Q Y A	F G G S Q R	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_067074736 Methanoculleus horonobensis *
	E KHA	RR (G F T Q Y A	FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_048180309 Methanoculleus sediminis
	E KHA	RR (FTQY A	FGGSQR	LGFFGYDLQDQCG	AM <mark>N</mark> VG	WP_066957227 Methanoculleus thermophilus *
				FGGSQR	LGFFGYDLQDQCG	AMNVG	WP_150468770 Methanoculleus thermophilus *
	E KHA	RR (SFTQYA	FGGSOR	LGFFGYDLODOCG	AMNVG	WP 014867635 Methanoculleus bouraensis
	KHA	RR	BETOYA	FGGSOP			
					I GEEGYDI ODOCC	AMNVC	CCI36661 Methanoculleus houraensis MS2*
VVQEHMV		_	SETOYA	FGGSOF			CCJ36661 Methanoculleus bourgensis MS2*
VVQEHMV			GFTQYA	FGG <mark>SQ</mark> R		AMNVG AMNVG	CCJ36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1
	к <mark>н</mark> а		G F T Q Y A G F T Q Y A	F GG <mark>SQ R</mark> F GG <mark>SQ R</mark>	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG	CCJ36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofolis iminatans
VV <mark>QЕ</mark> НМV	<mark>КН</mark> А КНА		GFTQYA GFTQYA GFTQYA	F GG <mark>SQ</mark> R F GG <mark>SQ R</mark> F GG <mark>SQ R</mark>	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_06226443 Methanoculleus sp. MAB1 WP_00407242 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus
VV <mark>QEH</mark> MV VV <mark>QE</mark> HMV	KHA KHA	RR (RR (RR (G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A	F GG <mark>SQ R</mark> F GG <mark>SQ R</mark> F GG <mark>SQ R</mark> F GG <mark>SQ R</mark>	L G F F G Y D L Q D Q C G L G F F G Y D L Q D Q C G L G F F G Y D L Q D Q C G L G F F G Y D L Q D Q C G L G F F G Y D L Q D Q C G	AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_067049872 Methanofollis ethanolicus
VV <mark>QE</mark> HMV VVQEHMV	КНА КНА КНА - КНА	RR C RR C RR C RR C	G F T Q Y A G F T Q Y A	F GG <mark>SQ</mark> R F GG <mark>SQ R</mark> F GG <mark>SQ R</mark> F GG <mark>SQ R</mark> F <mark>GG <mark>SQ</mark> R</mark>	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_057049872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei *
VVQ E HMV VVQ E HMV VVQ E HMV	КНА КНА КНА КНА КНА	RR C RR C RR C RR C	GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA	FGG <mark>SQ</mark> R FGG <mark>SQ</mark> R FGG <mark>SQ</mark> R FGG <mark>SQ</mark> R FGG <mark>SQ</mark> R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei* WP_062263961 Methanoculleus sp. MAB1
VVQEHMV VVQEHMV VVQEHMV VVQEHMV	КНА КНА КНА КНА КНА	RR C RR C RR C RR C RR C	GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA	F GG SQ R F GG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_067049872 Methanofollis ethanolicus BAF56653 Methanoculleus palmolei * WP_062263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus sbourgensis
VVQEHMV VVQEHMV VVQEHMV VVQEHMV	KHA KHA KHA KHA KHA	RR C RR C RR C RR C RR C RR C	GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA	F GG SQ R F GG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis iminatans WP_067023907 Methanofollis ethanolicus WP_067049872 Methanoculleus palmolei * WP_062263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_014867419 Methanoculleus bourgensis
	KHAAA KHAAA KHAAAA	RR C RR C RR C RR C RR C RR C RR C	G F T Q Y A G F T Q Y A	F GG SQ R F GG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei* WP_052263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_014867149 Methanoculleus thermanhilus *
V VQ E HMV V VQ E HMV	КНА КНА КНА КНА КНА КНА	RR C RR C RR C RR C RR C RR C RR C	GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA GFTQYA	F GG SOR F GG SOR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_067049872 Methanofollis ethanolicus BAF56653 Methanoculleus palmolei * WP_0426263961 Methanoculleus sp. MAB1 WP_07474927 Methanoculleus bourgensis WP_014867419 Methanoculleus bourgensis WP_150468708 Methanoculleus sharmophilus * WP_04811400 Methanoculleus sp.
V V Q E HMV V V Q E HMV	К НА К НА К НА К НА К НА К НА К НА	RRRR CO	G F T Q Y A G F T Q Y A	F GG SO R F GG SO R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037424 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus pinnolei * WP_062263961 Methanoculleus sp. MAB1 WP_014867419 Methanoculleus bourgensis WP_150468708 Methanoculleus berrapohilus * WP_088114200 Methanoculleus sp. MH98A MP_0811676 Methanoculleus sp. MH98A
V V Q E HMV V V Q E HMV	КНА КНА КНА КНА КНА КНА КНА	RRRR CO	S F T Q Y A G F T Q Y A S F T Q Y A	FGG SQ R FGG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei* WP_062263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_1504867419 Methanoculleus thermophilus * WP_048114200 Methanoculleus sp. MI98A WP_048179676 Methanoculleus sp. MI98A WP_0827656 Methanoculleus sp. MI98A
V V Q E HMV V V Q E HMV	К НА К НА К НА К НА К НА К НА К НА К НА	<pre></pre>	G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A G F T Q Y A	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037742 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus WP_067049872 Methanofollis ethanolicus BAF56653 Methanoculleus palmolei * WP_0426263961 Methanoculleus sp. MAB1 WP_04174927 Methanoculleus bourgensis WP_014867419 Methanoculleus bourgensis WP_014867419 Methanoculleus shurmophilus * WP_048170670 Methanoculleus sp. MH98A WP_048179676 Methanoculleus sediminis WP_048179676 Methanoculleus sediminis WP_04817967078350 Methanoculleus sediminis
V V Q E HMV V V Q E HMV	К НА К НА К НА К НА К НА К НА К НА К НА	R R	S F T Q Y A S F T Q Y A	FGG SQ R FGG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG AMNVG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004077424 Methanofollis liminatans WP_067052907 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_062263961 Methanoculleus polymensis WP_014867419 Methanoculleus bourgensis WP_150468708 Methanoculleus beranohilus * WP_048114200 Methanoculleus stermophilus * WP_048119676 Methanoculleus sediminis WP_073350 Methanoculleus sediminis WP_073350 Methanoculleus horonobensis * ABN56311 Methanoculleus marisnigri JR1*
V V Q E HMV V V Q E HMV		RR RR RR COC	G F T Q Y A G F T Q Y A	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_001037742 Methanofollis liminatans WP_06702907 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_052263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_014867419 Methanoculleus bourgensis WP_0486749 Methanoculleus thermophilus * WP_048179676 Methanoculleus sp. MH98A WP_067078350 Methanoculleus sp. MH98A WP_067078350 Methanoculleus sp. ontobensis * ABN56311 Methanoculleus horonobensis * ABN56311 Methanoculleus thermophilus *
V V Q E HMV V V Q E HMV		RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR	G F T Q Y A G F T Q Y A	FGG SQ R FGG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_00407424 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF5663 Methanoculleus palmolei * WP_062263961 Methanoculleus sp. MAB1 WP_014867419 Methanoculleus bourgensis WP_150468708 Methanoculleus bourgensis WP_048114200 Methanoculleus sp. MH98A WP_048114200 Methanoculleus sp. MH98A WP_048114206 Methanoculleus sp. MH98A WP_04813676 Methanoculleus sp. MH98A WP_04813676 Methanoculleus sp. MH98A WP_04813676 Methanoculleus sp. MH98A WP_04813676 Methanoculleus sp. MH98A WP_0637078350 Methanoculleus thermophilus * WP_06597677 Methanoculleus thermophilus * WP_073369714 Methanoculleus thermophilus *
V V Q E HM V V V Q E HM V	КНА КНА КНА КНА КНА КНА КНА КНА КНА КНА	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR	S F T Q Y A S F T Q Y A S F T Q Y A S F T Q Y A 3 F T Q Y A	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004037424 Methanofollis Iminatans WP_067052907 Methanofollis Iminatans WP_062703872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_062263961 Methanoculleus polymone WP_014867419 Methanoculleus bourgensis WP_150468708 Methanoculleus thermophilus * WP_048114200 Methanoculleus sp. MH98A WP_048179676 Methanoculleus sp. MH98A WP_048179676 Methanoculleus sp. MH98A WP_0683508 Methanoculleus horonobensis * ABN56311 Methanoculleus horonobensis * ABN56311 Methanoculleus thermophilus * WP_074369714 Methanoculleus chikugoensis *
V V Q E HMV V V Q E HMV	КНА КНА КНА КНА КНА КНА КНА КНА КНА	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR	S F T Q Y A S F T Q Y A	FGG SQ R FGG SQ R		AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_001037742 Methanofollis liminatans WP_06702907 Methanofollis ethanolicus WP_0627039872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_062263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_014867419 Methanoculleus thermophilus * WP_048179676 Methanoculleus sp. MH98A WP_048179676 Methanoculleus sp. MH98A WP_0620708350 Methanoculleus sediminis WP_0627078350 Methanoculleus hermophilus * WP_066957677 Methanoculleus thermophilus * WP_074369714 Methanoculleus chikugoensis *
V V Q E HM V V V Q E HM V	КНА КНА КНА КНА КНА КНА КНА КНА КНА	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR	SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA	FGG SQ R FGG SQ R	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_00403724 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus pelmolei * WP_062263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_11867419 Methanoculleus bourgensis WP_150468708 Methanoculleus sp. MH98A WP_048114200 Methanoculleus sediminis WP_0743500 Methanoculleus sediminis WP_074350 Methanoculleus sediminis WP_066957677 Methanoculleus thermophilus * WP_074369714 Methanoculleus chikugoensis *
V V Q E HMV V V Q E HMV S V Q E HMV V V Q E HMV V V Q E HMV	KHA	RRR CCCCRRR CCCCRRR CCCCCRRR CCCCCCRRR CCCCCC	SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA SFTOYA	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR		AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_0602764453 Methanoculleus sp. MAB1 WP_004077424 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_062263961 Methanoculleus sp. MAB1 WP_074174927 Methanoculleus bourgensis WP_150468708 Methanoculleus thermophilus * WP_048114200 Methanoculleus sp. MH98A WP_048179676 Methanoculleus sp. MH98A WP_0683508 Methanoculleus sp. MH98A WP_0683505 Methanoculleus sp. MH98A WP_066957677 Methanoculleus marisnigri JR1* WP_074369714 Methanoculleus mermophilus * WP_074369714 Methanoculleus chermophilus *
V V Q E HMV V Q E HMV S V Q E HMV V Q E HMV V V Q E HMV V Q E HMV V V V E HMV V V Q E HMV V V Q E HMV V V V E HMV V V V Q E HMV V V V Q E HMV V V V E HMV V V V E HMV V V V Q E HMV V V V E HMV V V E HMV V V E HMV V V V E HMV V V E	KHA	NRR CCCRRRR CCCCRRRR CCCCRRRR CCCCCRRRR CCCCCC	SFT0YA SFT0YA SFT0YA SFT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA 3FT0YA	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_004073742 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF5663 Methanoculleus palmolei * WP_04263263961 Methanoculleus sp. MAB1 WP_042632419 Methanoculleus bourgensis WP_014867419 Methanoculleus bourgensis WP_048114200 Methanoculleus sp. MH98A WP_048114200 Methanoculleus sp. MH98A WP_048114206 Methanoculleus sp. MH98A WP_048114206 Methanoculleus sp. MH98A WP_048114206 Methanoculleus sp. MH98A WP_048114206 Methanoculleus sp. MH98A WP_0697078350 Methanoculleus sp. MH98A WP_06970778 Methanoculleus sp. MH98A WP_0696777 Methanoculleus thermophilus * WP_074369714 Methanoculleus thermophilus * * Little methanogenic strains * High Frequency Gasting [HEG]/ mignitrad ettains
V V Q E HM V V Q E HM V V Q E HM V V Q E HM V	KHA KHA </td <td>RRR CC RRR RR CC RRR RR CC RRR RR CC RRR RR RRR CC RRR RR CC RC RRR RR CC RC RRR RR CC RC RRR RR CC RC RR RR CC RC RC RC RC RR RR CC RC RC RR RR CC RC RC RR RR CC RC RC RC RC RR RR CC RC RC RC RC RC RC RC RC RC RC RC RC R</td> <td>SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA</td> <td>FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR</td> <td>LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG</td> <td>AMN VG AMN VG</td> <td>CCI36661 Methanoculleus bourgensis MS2* WP_0602264453 Methanoculleus sp. MAB1 WP_00407742 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_062263961 Methanoculleus pourgensis WP_014867141 Methanoculleus bourgensis WP_150468708 Methanoculleus bourgensis WP_10486708 Methanoculleus bermophilus * WP_048114200 Methanoculleus sediminis WP_0673350 Methanoculleus sediminis WP_0687678 Methanoculleus sediminis WP_0673350 Methanoculleus hornobensis * ABN56311 Methanoculleus hornobensis * ABN56311 Methanoculleus hornobensis * ABN56311 Methanoculleus hornobensis * MP_074369714 Methanoculleus chikugoensis * * Cultured methanogenic strains * High Frequency Gassing (HFG)/ prioritzed strains * Of the effectories</td>	RRR CC RRR RR CC RRR RR CC RRR RR CC RRR RR RRR CC RRR RR CC RC RRR RR CC RC RRR RR CC RC RRR RR CC RC RR RR CC RC RC RC RC RR RR CC RC RC RR RR CC RC RC RR RR CC RC RC RC RC RR RR CC RC RC RC RC RC RC RC RC RC RC RC RC R	SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA SFTQYA	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_0602264453 Methanoculleus sp. MAB1 WP_00407742 Methanofollis liminatans WP_067049872 Methanofollis ethanolicus BAF56663 Methanoculleus palmolei * WP_062263961 Methanoculleus pourgensis WP_014867141 Methanoculleus bourgensis WP_150468708 Methanoculleus bourgensis WP_10486708 Methanoculleus bermophilus * WP_048114200 Methanoculleus sediminis WP_0673350 Methanoculleus sediminis WP_0687678 Methanoculleus sediminis WP_0673350 Methanoculleus hornobensis * ABN56311 Methanoculleus hornobensis * ABN56311 Methanoculleus hornobensis * ABN56311 Methanoculleus hornobensis * MP_074369714 Methanoculleus chikugoensis * * Cultured methanogenic strains * High Frequency Gassing (HFG)/ prioritzed strains * Of the effectories
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VVQEHMV VVQEHMV VVQEHMV VQEHMV VQE	КНА КНА КНА КНА КНА КНА КНА КНА КНА КНА	RRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRRR	SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA SFT0YA	FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR FGGSQR	LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG LGFFGYDLQDQCG	AMN VG AMN VG	CCI36661 Methanoculleus bourgensis MS2* WP_062264453 Methanoculleus sp. MAB1 WP_060704872 Methanofollis liminatans WP_06704872 Methanofollis ethanolicus BAF5663 Methanoculleus gelmolei * WP_062263961 Methanoculleus sp. MAB1 WP_014867149 Methanoculleus bourgensis WP_1150468708 Methanoculleus bourgensis WP_048114200 Methanoculleus sp. MH98A WP_048114200 Methanoculleus sp. MH98A WP_04811676 Methanoculleus sediminis WP_04813676 Methanoculleus sediminis WP_04813676 Methanoculleus sediminis WP_04813676 Methanoculleus sediminis WP_06376350 Methanoculleus stermophilus * WP_064511 Methanoculleus stermophilus * WP_074369714 Methanoculleus chikugoensis *

Fig. S8 Amino acid conservation within alpha subunit of the methyl-coenzyme M reductase (MCR, coenzyme-B sulfoethylthiotransferase). Blastp (Refseq, query: *M. marburgensis* Marburg, GenBank: ADL59127.1) and UniProtK data. Positions according to ^{3,4}.

As it was shown by Borrel *et al.* 2019, *Methanonatronarchaeum thermophilum* uses asparagine instead of tyrosine on position 333 (Tyr^{α 333}) and threonine instead of Val^{α 482}. *Methanobrevibacter gottschalkii* shows an amino acid exchange from Cys^{α 452} to alanine and *Methanobacterium palustre* shows a deletion on that position indicated with X, see **Fig. S8**. It seems like, the Arg³³⁴ is quite conserved, but some methanogens use glycine (*Methanonatronarchaeum thermophilum*, *Methanobacterium movens*, *Methanobacterium congolense*) and serine (*Methanohalophilus* spp.) instead. *Methanosaeta harundinacea* uses methionine instead of lysine on position 441. In *M. kandleri*, an alanine replaces asparagine on position 447.





Fig. S9 Substrate uptake kinetics of twelve methanogens in RCB cultivation mode in SBRS at 10 bar.



Fig. S10 Repetitive closed batch (RCB) high pressure cultivations of prioritized methanogens in the simultaneous bioreactor system (SBRS) at 10 bar H₂/CO₂ (4:1) atmosphere. All experiments were performed in quadruplicates in the SBRS system⁵. The principle of the cultivation was to repressurize each of the bioreactors to 10 bar after full headspace gas conversion. RCB1, RCB2, RCB3, and RCB4 indicate results from individual and successive closed batch headspace gas conversions. The turnover rate / h⁻¹ is shown. Legend: the left block indicates mesophilic methanogens grown at 37°C (*Methanococcus maripaludis* S2, *Methanobacterium palustre* F, *Methanobacterium subterraneum* A8p); the middle block shows the thermophilic methanogens grown at 65°C (*Methanothermobacter marburgensis* Marburg, *Methanobacterium thermaggregans, Methanothermobacter thermautotrophicus* DeltaH, *Methanothermococcus okinawensis* IH1); the right block shows hyperthermophilic methanogens (*Methanocaldococcus jannaschii* JAL-1(80°C), *Methanocaldococcus vulcanius* M7 (80°C), *Methanocaldococcus villosus* KIN24-T80 (80°C), *Methanothermus fervidus* H9 (80°C), *Methanopyrus kandleri* AV19 (98°C)).



Fig. S11 Maximum negative slope k_{min} / bar h⁻¹ of RCB cultivations in the SBRS at a) 10 bar and b) 50 bar.



Fig. S12 Substrate uptake kinetics showing repetetive closed batch (RCB) cultivations in the SBRS at 50 bar



Fig. S13 Repetitive closed batch cultivations of thermophilic and hyperthermophilic methanogens in the SBRS at 50 bar. The RCB cultivations were performed in quadruplicates with 4 runs RCB1, RCB2, RCB3, and RCB4. Turnover rate / h⁻¹ is shown. Legend: thermophile- *Methanothermobacter marburgensis* Marburg (65°C, MM medium); hyperthermophiles- *Methanocaldococcus jannaschii* JAL-1 (80°C, 282c 30 medium), *Methanocaldococcus villosus* KIN24-T80 (80°C, 282c18_E medium*) and *Methanotorris igneus* Kol 5 (85°C, 282c 30 medium).



Fig. S14 Correlation plot of maximum conversion rate k_{min} / bar h⁻¹ and MER_{max} / mmol L⁻¹ h⁻¹ of RCB cultivations in the SBRS at (a) 10 bar and (b) 50 bar.

Reactivation of methanogens after dormacy

It was examined how to store methanogens for fast reactivation from a state of dormancy. In case of failure due to e.g., viral infections, leading to a breakdown of the population or due to contaminations, it is of importance to have back-up cultures for fast reactivation from a state of dormancy. Therefore, studies on the storage of methanogens are inevitable to the successful functioning of an industrial bioprocess. In the microbiological lab, storing microbes in the fridge or freezer is common practice. After the pre-screening we analyzed how fast the vitality (OD and turnover) of mesophilic and (hyper-)thermophilic methanogens can be restored after they were in dormancy at 4° C or -80° C for a defined period. Our results show, that thermophilic (14 weeks at 4° C) and hyperthermophilic (>1 year at -80° C) methanogens possess a 50% higher turnoveraverage (60-88%) after dormancy compared to mesophilic methanogens (Supplementary Materials Table S1).

Methanogens	DSMZ	Medium	Growth temp.	Dormancy Period		Turnover	OD _{average}	Lowest pressure	Growth after dormancy
			°C	weeks (+4°C)	years (-80°C)	%	578nm	bar	
Methanobacterium lacus 17A1	DSM 24406	MM	30	16		2	0.04	1.916	no
Methanobacterium petrolearium Mic5c12T	DSM 22353	MM	35	25		15	-	1.376	yes
Methanobacterium bryantii M.o.H.	DSM 863	MM	37	25		1	-	1.644	no
		282c 0		71		56	0.28	0.632	yes
Methanobacterium palustre F	DSM 3108	MM	37	41		18	0.10	1.597	yes
		MM30		41		5	0.02	1.910	no
Methanohacterium suhterraneum∆&n	DSM 11074	MM	37	25		81	0.28	0.016	yes
	0510111074	MM30	57	25		22	0.31	1.355	yes
Methanobacterium arcticum M2	DSM 19844	MM	37	25		1	-	1.683	no
Methanosarcina sicliae TA/M	DSW 3028	MM	37	66		1	-	1.964	no
	05101 5020	MM30	37	66		0	-	1.985	no
Methanothermobacter thermophilus M	DSM 6529	MM	60	14		85	0.34	-0.078	yes
Methanobacterium thermaggregans	DSM 3266	MM	65	14		86	0.23	-0.107	yes
Methanothermobacter marburgensis Marburg	DSM 2133	MM	65	14		88	0.51	-0.159	yes
Methanothermobacter thermautotrophicus RMAS	DSM 23052	MM	65	14		45	0.20	0.745	yes
Methanothermobacter wolfeii	DSM 2970	MM	65		7		0.25	-	yes
Methanothermococcus okinawensis IH1	DSM 14208	282c 18	65		1	60	0.85	0.499	yes
Methanocaldococcus jannaschii JAL-1	DSM 2661	282c 30	80		1	79	0.80	-0.164	yes
Methanocaldococcus villosus KIN24-T80	DSM 22612	282c 30	80		1	84	0.13	-0.239	yes
Methanocaldococcus vulcanius M7	DSM 12094	282c 30	80		1	84	0.50	-0.265	yes

Table S1 Dormancy study with mesophilic, thermophilic and hyperthermophilic methanogens

Table S2 Cysteine requirements in the media of thermophilic and hyperthermophilic methaogens and the presence of cysteine biosynthesis machinery SepRS/SepCysS and cysteine metabolizing enzymes

Strains	Class	SepRS/ SepCysS	CDD	CDS	Cysteine addition	References
Methanocaldococcus jannaschii	Methanococci	+	+	-	+	11,12
Methanocaldococcus vulcanius	Methanococci	+	n.d.	n.d.	+	11
Methanotorris igneus	Methanococci	n.d.	+	-	+	11,12
Methanopyrus kandleri	Methanopyrus	+	-	+	- (vitamins)	11,12
Methanothermus fervidus	Methanobacteria	n.d.	-	+	+	12
Methanothermobacter marburgensis	Methanobacteria	n.d.	-	+	-	11,12
Methanothermobacter thermautotrophicus	Methanobacteria	+	-	+	-	11–13

n.d. not determinded

SepRS/SepCysS- cysteine production via t-RNA dependent pathway^{12,14}

Cysteine desulphidase (CDD)- cysteine and water are metabolized to H₂S, NH₄⁺, H⁺ and pyruvate¹⁵

Cysteine desulphurase (CSD)- cysteine is processed to L-alanine and is bound to the enzyme-S-sulfanylcysteine¹⁶

Table S3 Core lipids of prioritized methanogens

Strains	Core lipids						
Strains	Archaeol	Tetraether lipids	Hydroxyarchaeol	Macrocyclic archaeol			
Methanococuss maripaludis S2	+	nd.	+	-	17–19		
Methanobacterium palustre F	+	+	-	-	17–19		
Methanobacterium subterraneum A8p	+	+	-	-	17–19		
Methanothermobacter marburgensis Marburg	+	GDGT-0 ^a	-	-	17–21		
Methanothermobacter thermophilus M	+	+	-	-	17–19		
Methanobacterium thermaggregans	+	+	-	-	17–19		
Methanothermobacter thermautotorphicus DeltaH	+	GDGT 75-83 mol%	-	-	17–21		
		3.7% GDGT-0					
Mathanatharmacaccus akingwansis 141	59% (mostly	1% GMGT-0		35% (mostly	19,22,23		
methanothermococcus okindwensis ini	monocyclic)	0.4% GMGT-0′,	-	monocyclic)			
		0.2% GTGT-0					
	18 % ^c	36%		46%			
	7 % ^d	52%		41%	17-19.24		
Methanocaldococcus Jannaschill JAL-1 **	0–2 % ^e	65%	-	35%			
	0–2 % ^f	64%		36%			
Methanocaldococcus vulcanius M7	+	+	-	+	17–19		
Methanocaldococcus villosus KIN24-T80	39% (mostly dicyclic)	4.3% GDGT-0 0.1% GMGT-0 1% GMGT-0' 0.2% GTGT-0	-	55% (mostly dicyclic)	19,23		
Methanotorris igneus Kol5	+	GDGT-0	-	+	17,18,25		
Methanothermus fervidus H9	+	GDGT-0 GTGT/ H-GDGT	-	-	17,21		
Methanopyrus kandleri AV19	+ ^h	GDGT-0, GDGT-1, GDGT-2, GDGT-3, GDGT-4, GTGT/ H-GDGT	÷	-	17–19,21		

a growth with detergent, increased caldarchaeols²⁶, b archaeols decline and caldarchaeols, macrocyclic archaeol polar lipids, increase as temperature and pressure rise²⁴ c 1 atm 1 bar and 75°C; d 1 atm 1 bar and 86°C; e 250 atm 253 bar and 86°C; f 500 atm 506 bar and 86°C, g mostly GDGT-0, h unsaturated archaeol-allyl ether type core lipids- geranylgeranyl group-containing archaeol

Supplementary references

- 1. Bryant, M. P., Wolin, E. A., Wolin, M. J. & Wolfe, R. S. *Methanobacillus omelianskii*, a symbiotic association of two species of bacteria. *Archiv für Mikrobiologie* **59**, 20–31 (1967).
- 2. Balch, W. E., Fox, G. E., Magrum, L. J., Woese, C. R. & Wolfe, R. S. Methanogens: reevaluation of a unique biological group. *Microbiological Reviews* **43**, 260–296 (1979).
- 3. Ermler, U., Grabarse, W., Shima, S., Goubeaud, M. & Thauer, R. K. Crystal structure of methyl-coenzyme M reductase: the key enzyme of biological methane formation. *Science* **278**, 1457–1462 (1997).
- 4. Borrel, G., Adam, P. S., McKay, L. J., Chen, L.-X., Sierra-García, I. N., Sieber, C. M., Letourneur, Q., Ghozlane, A., Andersen, G. L. & Li, W.-J. Wide diversity of methane and short-chain alkane metabolisms in uncultured archaea. *Nature microbiology* **4**, 603–613 (2019).
- Pappenreiter, P. A., Zwirtmayr, S., Mauerhofer, L.-M., Rittmann, S. K.-M. R. & Paulik, C. Development of a simultaneous bioreactor system for characterization of gas production kinetics of methanogenic archaea at high pressure. *Engineering in Life Sciences* 19, 537–544 (2019).
- 6. UniProt: a worldwide hub of protein knowledge. Nucleic Acids Res 47, D506–D515 (2019).
- El-Gebali, S., Mistry, J., Bateman, A., Eddy, S. R., Luciani, A., Potter, S. C., Qureshi, M., Richardson, L. J., Salazar, G. A., Smart, A., Sonnhammer, E. L. L., Hirsh, L., Paladin, L., Piovesan, D., Tosatto, S. C. E. & Finn, R. D. The Pfam protein families database in 2019. *Nucleic Acids Res* 47, D427–D432 (2019).
 P. H. L. A. C. Handridt, C. B. M. Chang, C. L. C. Martin, C. M. C. B. M.
- 8. Bellack, A. Cell architecture and flagella of hyperthermophilic Archaea. (2011).
- 9. Bellack, A., Huber, H., Rachel, R., Wanner, G. & Wirth, R. *Methanocaldococcus villosus* sp. nov., a heavily flagellated archaeon that adheres to surfaces and forms cell–cell contacts. *International journal of systematic and evolutionary microbiology* **61**, 1239–1245 (2011).
- 10. König, H., Rachel, R. & Claus, H. in Archaea 315–340 (American Society of Microbiology, 2007).
- 11. Hidese, R., Inoue, T., Imanaka, T. & Fujiwara, S. Cysteine desulphurase plays an important role in environmental adaptation of the hyperthermophilic archaeon *Thermococcus kodakarensis*. *Molecular Microbiology* **93**, 331–345 (2014).
- 12. Liu, Y., Sieprawska-Lupa, M., Whitman, W. B. & White, R. H. Cysteine Is Not the Sulfur Source for Iron-Sulfur Cluster and Methionine Biosynthesis in the Methanogenic Archaeon *Methanococcus maripaludis*. *Journal of Biological Chemistry* **285**, 31923–31929 (2010).
- Kärcher, U., Schröder, H., Haslinger, E., Allmaier, G., Schreiner, R., Wieland, F., Haselbeck, A. & König, H. Primary structure of the heterosaccharide of the surface glycoprotein of *Methanothermus fervidus*. *Journal* of Biological Chemistry 268, 26821–26826 (1993).
- 14. Klipcan, L., Frenkel-Morgenstern, M. & Safro, M. G. Presence of tRNA-dependent pathways correlates with high cysteine content in methanogenic Archaea. *Trends in Genetics* **24**, 59–63 (2008).
- Tchong, S.-I., Xu, H. & White, R. H. l-Cysteine Desulfidase: An [4Fe-4S] Enzyme Isolated from *Methanocaldococcus jannaschii* That Catalyzes the Breakdown of l-Cysteine into Pyruvate, Ammonia, and Sulfide. *Biochemistry* 44, 1659–1670 (2005).
- 16. Zheng, L., White, R. H., Cash, V. L., Jack, R. F. & Dean, D. R. Cysteine desulfurase activity indicates a role for NIFS in metallocluster biosynthesis. *Proc Natl Acad Sci USA* **90**, 2754 (1993).
- Koga, Y., Nishihara, M., Morii, H. & Akagawa-Matsushita, M. Ether polar lipids of methanogenic bacteria: structures, comparative aspects, and biosyntheses. *Microbiology and Molecular Biology Reviews* 57, 164– 182 (1993).
- Koga, Y., Morii, H., Akagawa-Matsushita, M. & Ohga, M. Correlation of Polar Lipid Composition with 16S rRNA Phylogeny in Methanogens. Further Analysis of Lipid Component Parts. *Bioscience, Biotechnology,* and Biochemistry 62, 230–236 (1998).
- Koga, Y. & Morii, H. Recent Advances in Structural Research on Ether Lipids from Archaea Including Comparative and Physiological Aspects. *Bioscience, Biotechnology, and Biochemistry* 69, 2019–2034 (2005).
 Knappy, C. S. Mass spectrometric studies of ether lipids in Archaea and sediments. (2010).
- 21. Schouten, S., Hopmans, E. C. & Sinninghe Damsté, J. S. The organic geochemistry of glycerol dialkyl glycerol tetraether lipids: A review. *Organic Geochemistry* 54, 19–61 (2013).
- 22. Taubner, R.-S., Baumann, L. M., Bauersachs, T., Clifford, E. L., Mähnert, B., Reischl, B., Seifert, R., Peckmann, J., Rittmann, S. K.-M. & Birgel, D. Membrane Lipid Composition and Amino Acid Excretion Patterns of *Methanothermococcus okinawensis* Grown in the Presence of Inhibitors Detected in the Enceladian Plume. *Life* **9**, 85 (2019).
- Baumann, L. M. F., Taubner, R.-S., Bauersachs, T., Steiner, M., Schleper, C., Peckmann, J., Rittmann, S. K.-M. R. & Birgel, D. Intact polar lipid and core lipid inventory of the hydrothermal vent methanogens *Methanocaldococcus villosus* and *Methanothermococcus okinawensis*. Organic Geochemistry 126, 33–42 (2018).
- 24. Kaneshiro, S. M. & Clark, D. S. Pressure effects on the composition and thermal behavior of lipids from the deep-sea thermophile *Methanococcus jannaschii*. J. Bacteriol. **177**, 3668 (1995).

- 25. Trincone, A., Nicolaus, B., Palmieri, G., De Rosa, M., Huber, R., Huber, G., Stetter, K. O. & Gambacorta, A. Distribution of complex and core lipids within new hyperthermophilic members of the Archaea domain. *Systematic and applied microbiology* **15**, 11–17 (1992).
- 26. Gräther, O. W., Arigoni, D. & Jaun, B. Zur Struktur und Biosynthese der Tetraetherlipide der Archaea. (1994). doi:10.3929/ethz-a-001377425