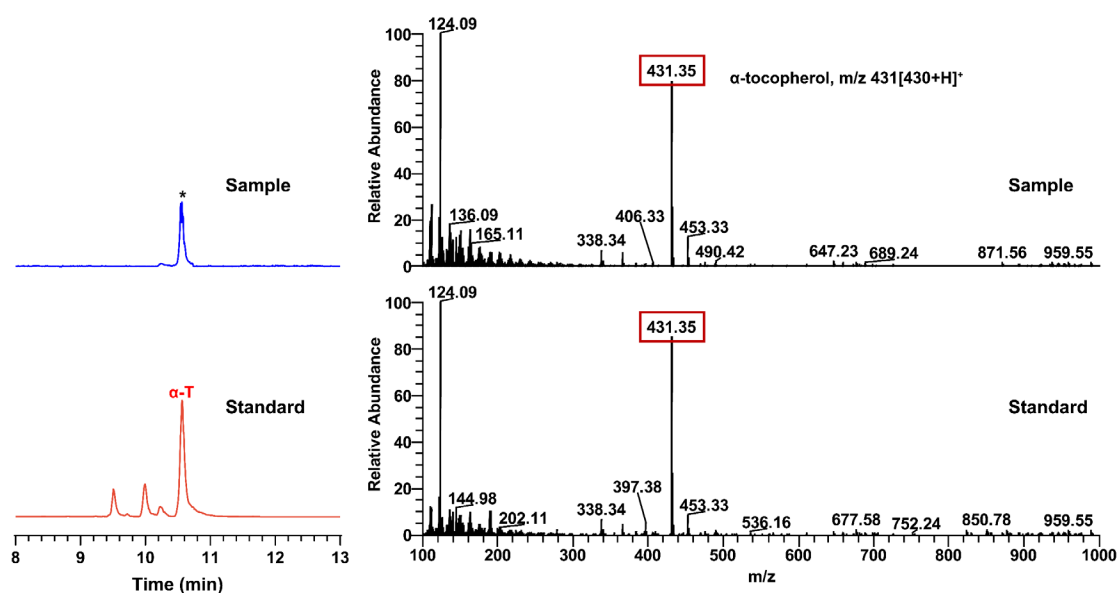

A non-classical biosynthetic route enables tocopherol synthesis in bacteria

In the format provided by the
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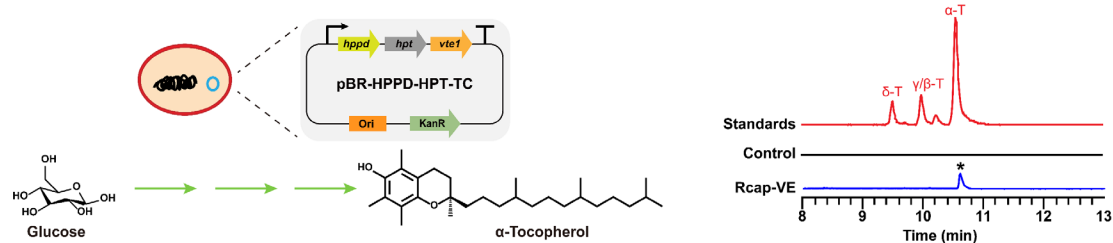
Table of contents

Supplementary Figures 1-15.....	2
Supplementary Tables 1-5.....	17
Supplementary References.....	31

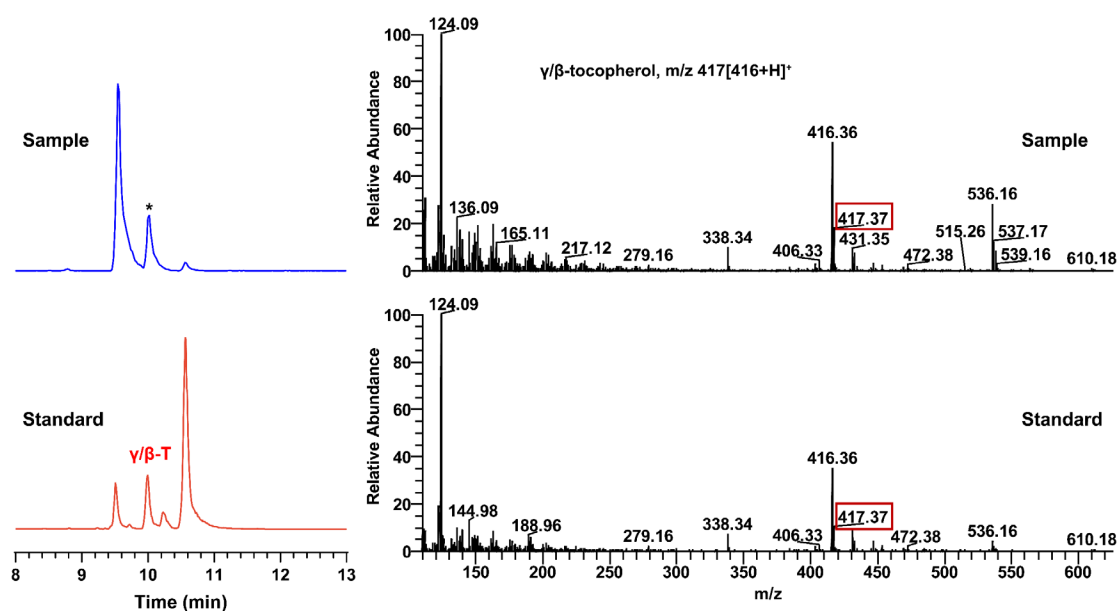


Supplementary Figure 1 Representative LC-MS results of mixed tocopherol standard and sample from strain Rsp-VE. The engineered *R. sphaeroides* Rsp-VE with the plasmid-based expression of *hppd-hpt-vte1* module was used. LC chromatograms were extracted at the ranges of 396-435 m/z. Asterisk (*) indicates the expected α -tocopherol product. Data are representative of experiments that were independently carried out in three biological repeats with similar results.

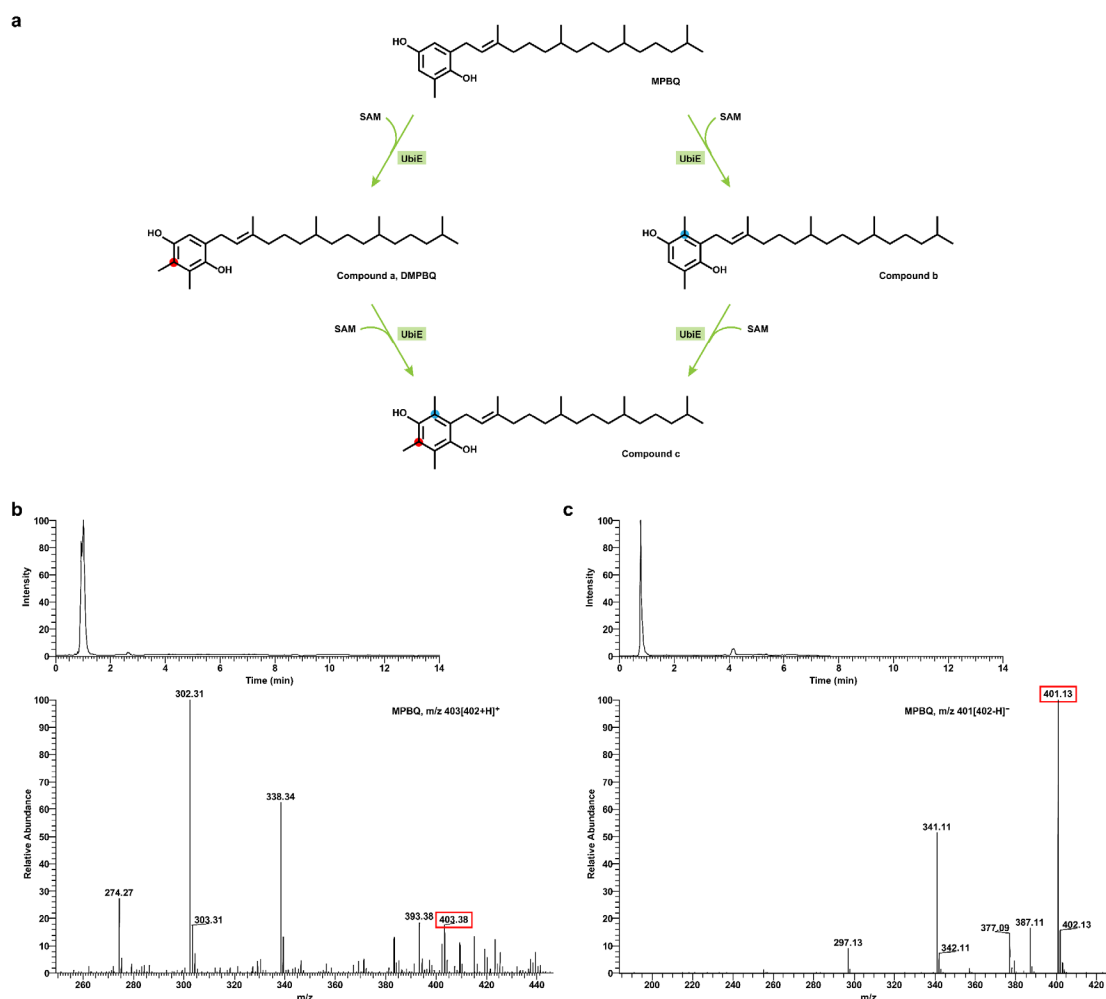
Microbial fermentation by *R. capsulatus*



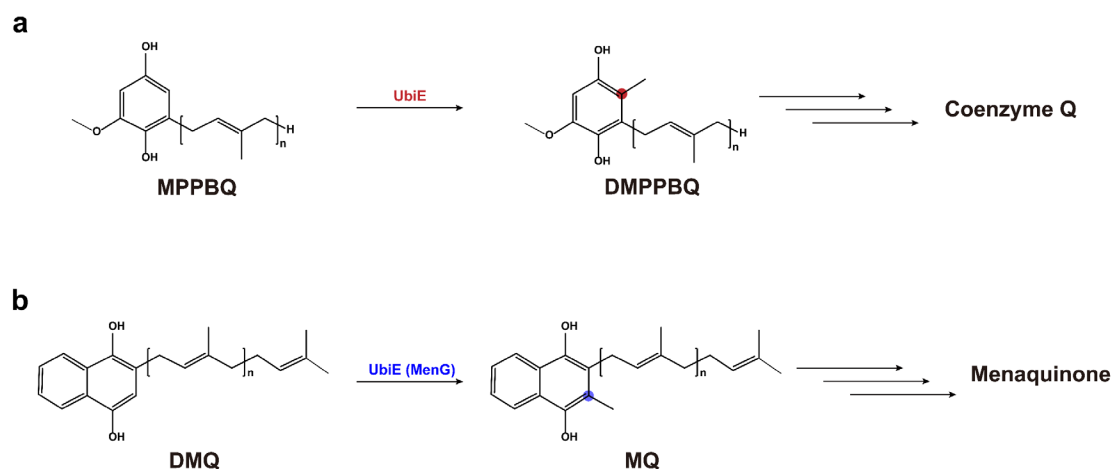
Supplementary Figure 2 Verifying the nonclassical α -tocopherol biosynthetic pathway in *R. capsulatus*. Representative LC-MS chromatograms from *R. capsulatus* Rcap-VE expressing the heterologous δ -tocopherol pathway. LC chromatograms were extracted at the ranges of 396-435 m/z. Control, *R. capsulatus* wild-type expressing the empty vector. δ -T, δ -tocopherol; γ/β -T, γ/β -tocopherols; α -T, α -tocopherol. Asterisk (*) indicates the expected α -tocopherol product. Data are representative of experiments that were independently carried out in three biological repeats with similar results.



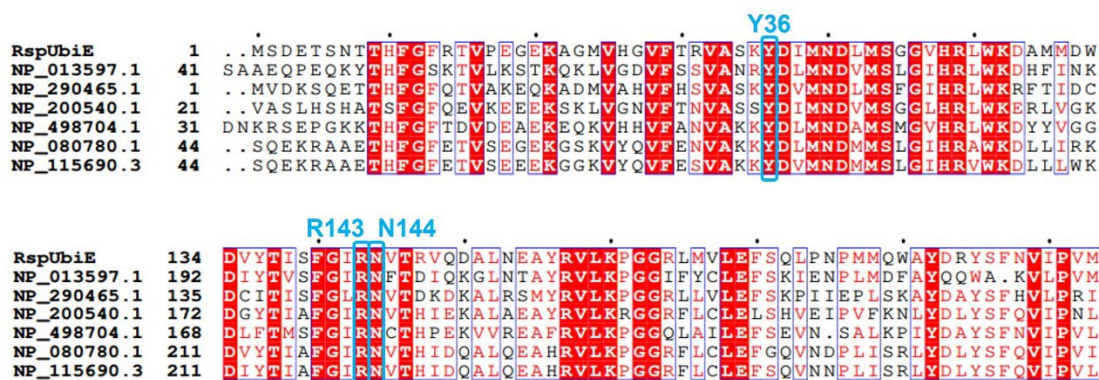
Supplementary Figure 3 Representative LC-MS results of mixed tocopherol standard and sample produced by the biotransformation of *R. sphaeroides*. The cell lysate of *R. sphaeroides* wild-type was reacted with 0.2 mM δ -tocopherol. LC chromatograms were extracted at the ranges of 396-435 m/z. Asterisk (*) indicates the expected γ/β -tocopherol product. Data are representative of experiments that were independently carried out in three biological repeats with similar results.



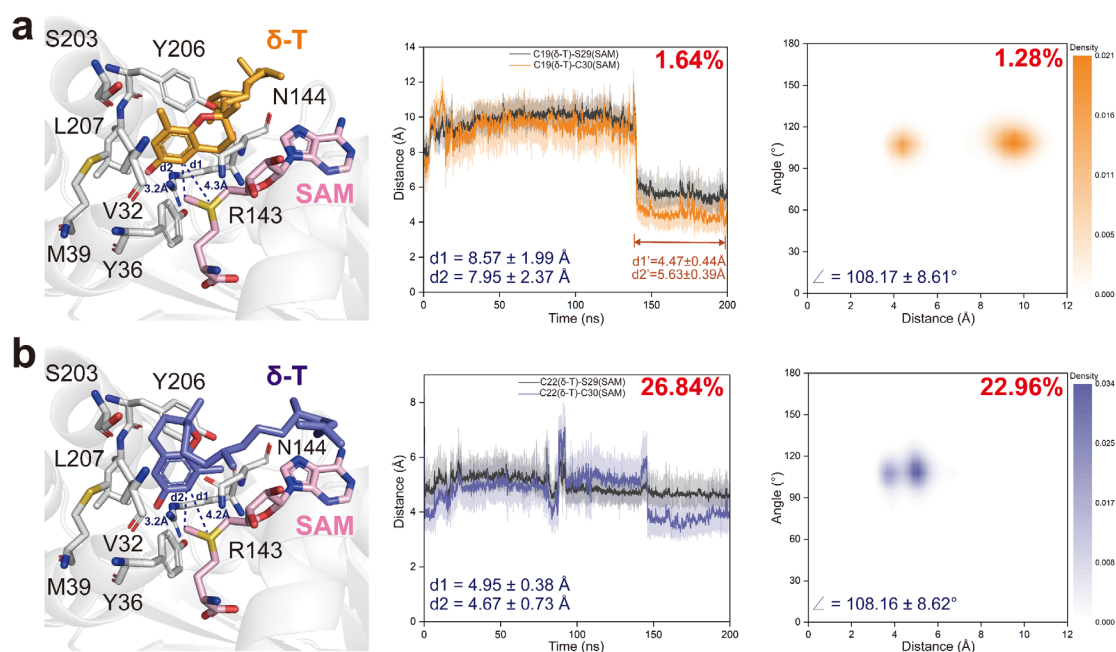
Supplementary Figure 4 Investigating the production of DMPBQ and its analogues by engineered *R. sphaeroides*. **a**, The biocatalytic routes of DMPBQ and its analogues from MPBQ. Compound b, 1,4-dimethyl-5-phytyl-1,4-benzoquinone; Compound c, 2,3,6-trimethyl-5-phytyl-1,4-benzoquinone; DMPBQ, 2,3-dimethyl-5-phytyl-1,4-benzoquinone; MPBQ, 2-methyl-6-phytyl-benzoquinone. LC-MS results showed MPBQ produced by the engineered *R. sphaeroides*, Rsp-MPBQ, which was obtained by transforming the *hppd-hpt* module into the wild-type *R. sphaeroides* via plasmid. LC chromatograms were extracted at the ranges of 396–435 m/z, and the m/z of the corresponding peak matched that of MPBQ in both positive (**b**) and negative (**c**) ion scanning modes. Data are representative of experiments that were independently carried out in three biological repeats with similar results.



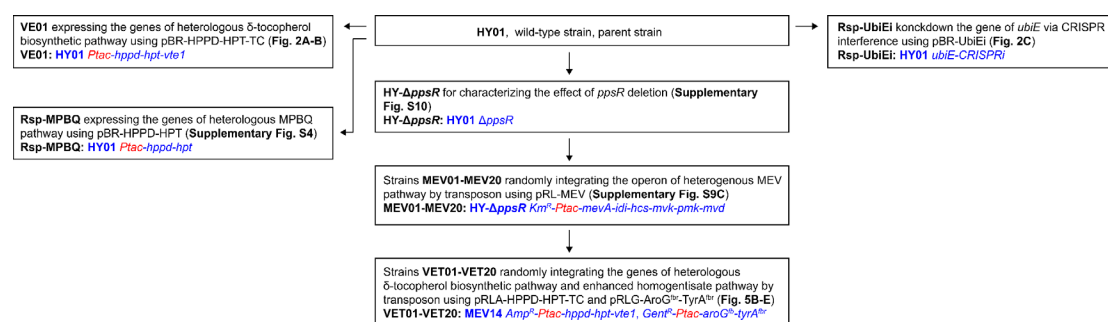
Supplementary Figure 5 The natural reactions catalyzed by UbiE. a, The reaction of UbiE-involved in coenzyme Q synthesis. **b,** The reaction of UbiE-related step in menaquinone synthesis. DMPPBQ, 6-methoxy-3-methyl-2-all-trans-polyprenyl-1,4-benzoquinol; DMQ, demethylmenaquinol; MPPBQ, 2-methoxy-6-all-trans-polyprenyl-1,4-benzoquinol; MQ, menaquinol.



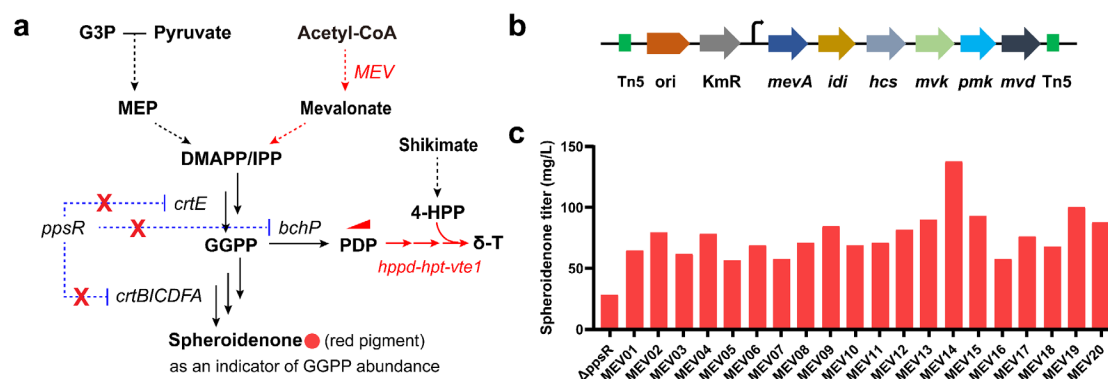
Supplementary Figure 6 Multiple sequence alignment of RspUbiE with other homologs. The putative residues responsible for substrate catalysis are indicated with blue boxes ¹. The sequences are (NCBI accession Nos. are given in parentheses) *S. cerevisiae* 2-hexaprenyl-6-methoxy-1,4-benzoquinone methyltransferase Coq5 (NP_013597.1), *E. coli* ubiquinone/menaquinone biosynthesis methyltransferase (NP_290465.1), *A. thaliana* 2-methoxy-6-polyprenyl-1,4-benzoquinol methylase (NP_200540.1), *Caenorhabditis elegans* Coq5 (NP_498704.1), *Mus musculus* 2-methoxy-6-polyprenyl-1,4-benzoquinol methylase (NP_080780.1) and *Homo sapiens* 2-methoxy-6-polyprenyl-1,4-benzoquinol methylase (NP_115690.3).



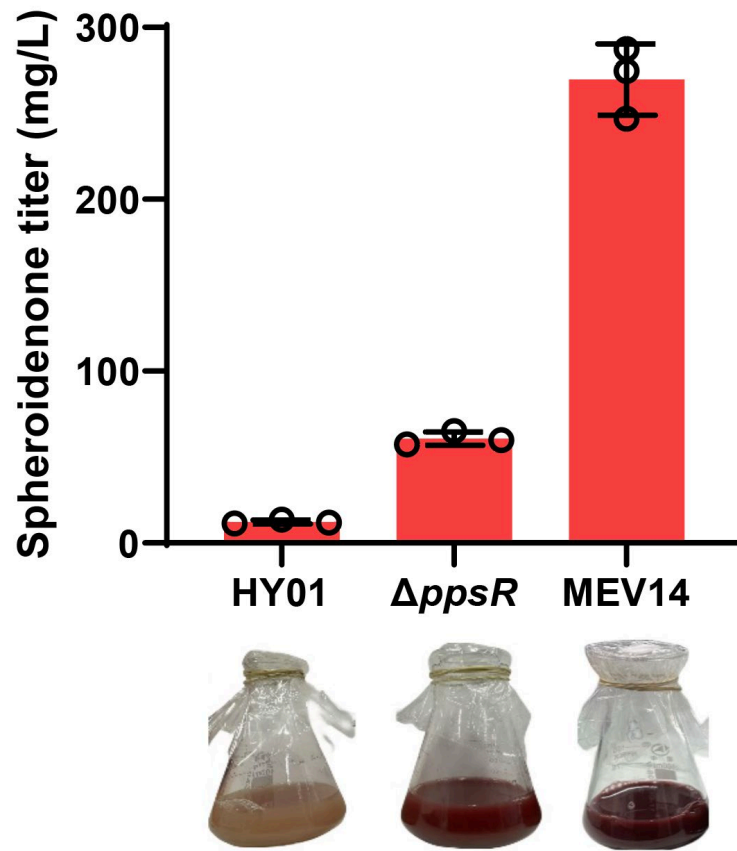
Supplementary Figure 7 Mechanism analysis of UbiE on δ -tocopherol through molecular docking and molecular dynamics (MD) simulations. **a**, Proposed binding conformation for catalyzing δ -T to β -T, catalytic distances between δ -T's C19 and SAM's S29 (d1) or methyl C30 (d2) during 200 ns MD simulations, and $S^{29}_{SAM}-C^{30}_{SAM}-C^{19}_{\delta-T}$ angle analysis for catalyzing δ -tocopherol to β -tocopherol. **b**, Proposed binding conformation for catalyzing δ -T to γ -T, catalytic distances between δ -T's C22 and SAM's S29 (d1) or methyl C30 (d2) during 200 ns MD simulations, and $S^{29}_{SAM}-C^{30}_{SAM}-C^{22}_{\delta-T}$ angle analysis for catalyzing δ -tocopherol to γ -tocopherol. The conformational fractions satisfying catalytic geometry ($d1 \leq 5.0 \text{ \AA}$ and $d2 \leq 4.0 \text{ \AA}$) are shown. The conformational fractions satisfying dual catalytic-geometric/angular criteria ($\geq 100^\circ$) are shown. Data are presented as mean values $\pm$ SD ($n=100,000$ frames of MD simulations).



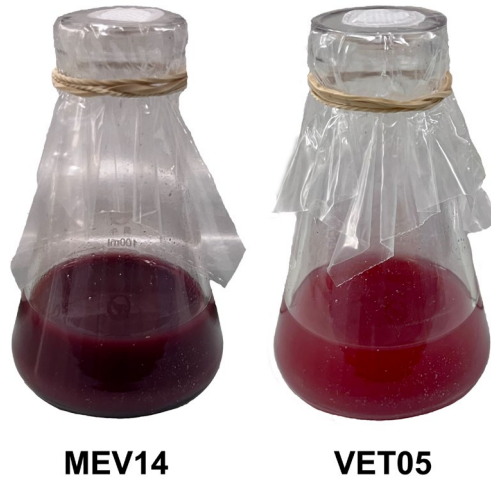
Supplementary Figure 8 The flowchart for constructing strains for tocopherol production. Names in bold and blue colour are the background strains, and genetic manipulations are highlighted in blue. Promoters are shown in red.



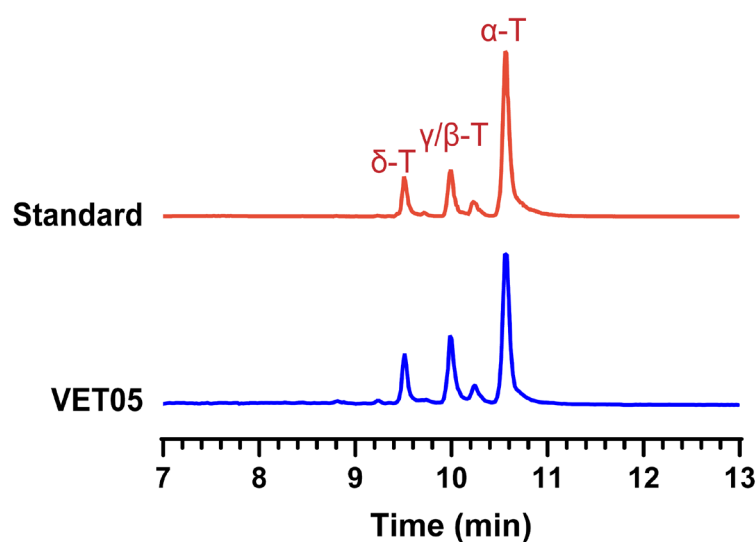
Supplementary Figure 9 Metabolic engineering for constructing GGPP/PDP-overproducing platform. **a**, Strategy for engineering the carotenoid pathway to enhance the precursor supply of GGPP via spheroidenone-based red colour. DMAPP, dimethylallyl pyrophosphate; 4-HPP, 4-hydroxyphenylpyruvate; IPP, isopentenyl pyrophosphate; GGPP, geranylgeranyl pyrophosphate; G3P, glyceraldehyde-3-phosphate; MEP, C-methyl-D-erythritol 4-phosphate; PDP, phytyl pyrophosphate; δ -T, δ -tocopherol; *ppsR*, a transcriptional regulator; *bchP*, GGPP reductase; *crtE*, GGPP synthase. **b**, Overview of the *MEV* operon from *P. zeaxanthinifaciens* used for integration via the mini Tn5 transposon system. Tn5, transposase recognition site; ori, λ pir protein-dependent replicator oriR6K; KmR, kanamycin resistance; HMG-CoA, S-3-hydroxy-3-methylglutaryl-CoA; *mevA*, HMG-CoA reductase gene; *idi*, isopentenyl-pyrophosphate isomerase gene; *hcs*, HMG-CoA synthase gene; *mvk*, mevalonate kinase gene; *pmk*, phosphomevalonate kinase gene; *mvd*, R-5-diphosphomevalonate decarboxylase gene. **c**, The spheroidenone production of HY01- Δ *ppsR* and transposon mutants MEV01-20 (random integration of *MEV* operon in HY01- Δ *ppsR*) in culture tubes. Data are from single experiment ($n = 1$).



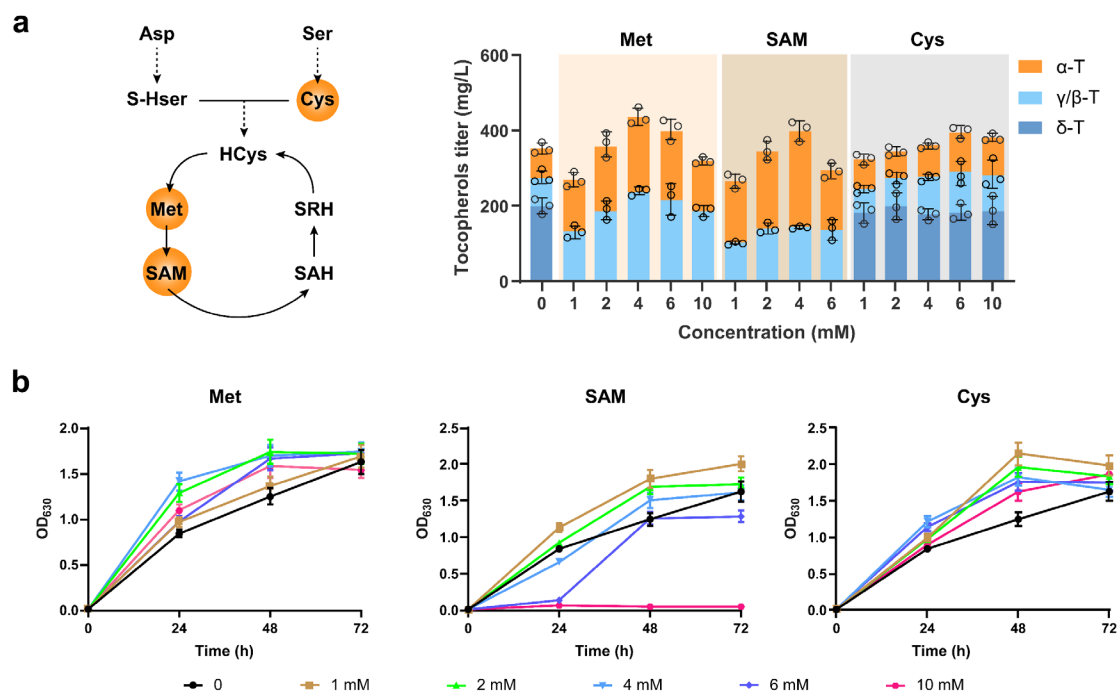
Supplementary Figure 10 The spheroidenone production of HY01- $\Delta ppsR$ and mutant MEV14 in shake flasks. Data are presented as mean values $\pm$ SD ($n = 3$ independent biological samples).



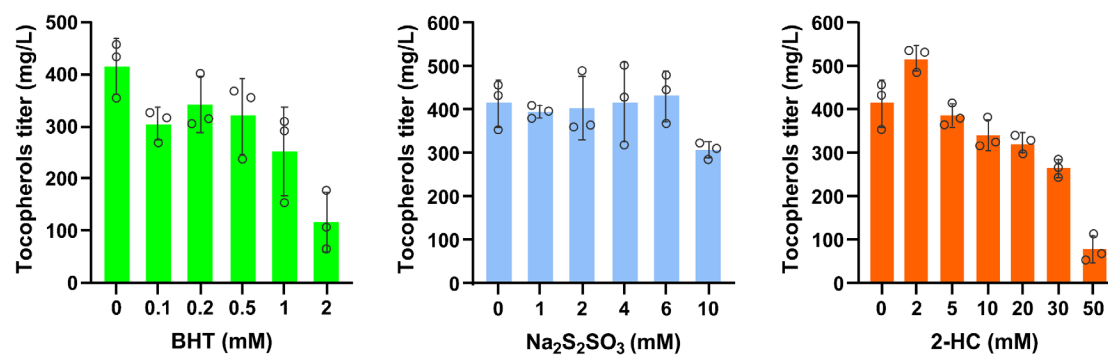
Supplementary Figure 11 The fermentation broth of recombinants for tocopherol production. Strain MEV14 is a strain HY01- $\Delta ppsR$ derivative with the transposon-integration of the *MEV* operon; strain VET05 is a MEV14 derivative with the transposon-integration of both a δ -tocopherol synthetic module (*hppd-hpt-vte1*) and a strengthened shikimate pathway module (*aroG*^{*}-*tyrA*^{*}).



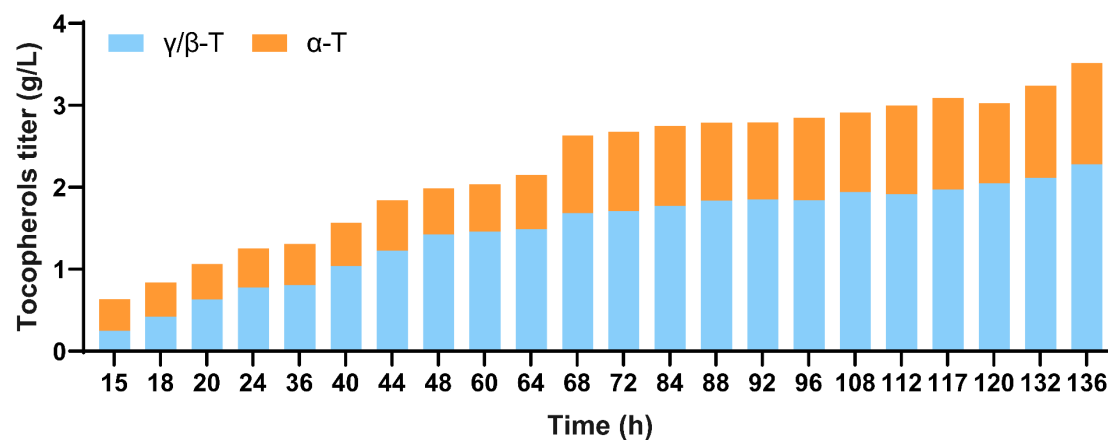
Supplementary Figure 12 Representative LC-MS result of mixed tocopherol standard and sample from strain VET05. LC chromatograms were extracted at the ranges of 396-435 m/z. Strain VET05 is a strain MEV14 derivative with the transposon-integration of both a δ -tocopherol synthetic module (*hppd-hpt-vteI*) and a strengthened shikimate pathway module (*aroG^{*}-tyrA^{*}*). Data are representative of experiments that were independently carried out in three biological repeats with similar results.



Supplementary Figure 13 The effect of *L*-methionine, *S*-adenosyl-*L*-methionine (SAM), and *L*-cysteine on tocopherol biosynthesis. Tocopherol production (a) and cell growth (b) by VET05 supplemented with different doses of methionine (Met), SAM, and cysteine (Cys). Experiments were carried out in 12 ml culture tubes. Data are presented as mean values $\pm$ SD ($n = 3$ independent biological samples).



Supplementary Figure 14 Tocopherol production by VET05 supplemented with antioxidants. Different doses of butylated hydroxytoluene (BHT), sodium thiosulphate, and 2-hydroxypropyl- β -cyclodextrin (2-HC) were added after 24 h of fermentation in culture tubes. Data are presented as mean values $\pm$ SD ($n = 3$ independent biological samples).



Supplementary Figure 15 Composition of tocopherols produced by VET05 during the fed-batch fermentation corresponding with Fig. 5e. Data are from single experiment ($n = 1$).

Supplementary Table 1 Comparison of vitamin E by microbial fermentation from the literatures

Host	Engineering strategies	Fermentation	Product	Source
<i>E. coli</i>	Heterologous expression of vitamin E biosynthetic genes	Shake-flasks	15 µg/g-DCW δ-tocotrienol	²
<i>S. cerevisiae</i>	Enhanced supply of precursor GGPP	Fermenter, fed-batch	4.1 mg/L δ-tocotrienol	³
<i>S. cerevisiae</i>	Systematically optimizing the supply of precursors, and employing a cold-shock-triggered temperature control system	Fermenter, fed-batch	320 mg/L tocotrienols	⁴
<i>S. cerevisiae</i>	Enhancing the MEV pathway and the shikimate pathway and promoting the product secretion	Shake-flasks	241.7 mg/L δ-tocotrienol	⁵
<i>Y. lipolytica</i>	Improving supplies of precursors HGA and GGPP, fusion expression of key enzymes, and semi-rational design of HGA phytyltransferase	Fermenter, fed-batch	466.8 mg/L δ-tocotrienol	⁶
<i>Y. lipolytica</i>	Enhancing supplies of precursors, identifying four membrane transporters, fusion expression of key enzymes, truncation of the N-terminal signal peptide of TC	Fermenter, fed-batch	617.23 mg/L δ-tocotrienol	⁷
<i>R. sphaeroides</i>	Transposon mutagenesis screen with the MEV pathway module, enhanced shikimate pathway module, and tocopherol biosynthetic pathway module	Fermenter, fed-batch	3.51 g/L tocopherols	This study

Supplementary Table 2 Plasmids used in this study

Plasmid	Description	Source
pBlu2SKP	Cloning vector, Amp ^R	Stratagene
pCDF-aroG ^{fbr} - tyrA ^{fbr}	Supply for <i>aroG</i> ^{D146N} and <i>tyrA</i> ^{M53I} from <i>E. coli</i>	8
pBRT	pBBR1MCS-2 derivative containing the new MCS and the terminator rrnB T1, Km ^R	9
pBBR-tacGFP	pBBR1MCS-2 derivative harboring the <i>Ptac</i> promoter	10
pZJD29c	Mobilizable suicide vector, Gent ^R	11
pRL27	Transposon plasmid, Km ^R	12
pK18mobsacB	Gene knockout vector for selecting double crossover, Km ^R	Invitrogen
pRSFDuet-1	T7 inducible expression vector, Km ^R	Novagen
pRSF-UibE	pRSFDuet-1 derivative harboring the codon-optimized <i>ubiE</i> from <i>R. sphaeroides</i>	This study
pRSF-UbiEmY36A	pRSF-UbiE derivative harboring the UbiE mutation of Y36A	This study
pRSF-UbiEmR143A	pRSF-UbiE derivative harboring the UbiE mutation of R143A	This study
pRSF-UbiEmN144A	pRSF-UbiE derivative harboring the UbiE mutation of N144A	This study
pRSF-Vte4	pRSFDuet-1 derivative harboring the <i>vte4</i> from <i>A. thaliana</i>	This study
pRSF-BchP	pRSFDuet-1 derivative harboring the <i>bchP</i> from <i>R. sphaeroides</i>	This study
pRSF-BchP-FdxA-Fdr	pRSFDuet-1 derivative harboring the <i>bchP</i> , <i>fdxA</i> , and <i>fdr</i> from <i>R. sphaeroides</i>	This study
pBRPtacT	pBRT derivative carrying the promoter <i>Ptac</i>	This study
pBR-HPPD-HPT-	pBRPtacT derivative harboring the <i>hppd</i> from <i>P. putida</i>	This study

TC	KT2440, <i>hpt</i> from <i>Synechocystis</i> sp. PCC6803, and <i>vteI</i> (TC) from <i>A. thaliana</i>	
pBR-HPPD-HPT	pBR-HPPD-HPT-TC derivative with partial removal of <i>vteI</i> (TC) from <i>A. thaliana</i> between <i>SacI</i> - <i>XhoI</i> .	This study
pBR-CRISPRi	pBRT derivative harboring the DNase-deactivated Cas12a of <i>Francisella novicida</i> driven by the promoter <i>Ppuc</i> from pRKucdCas12a ¹³	This study
pBR-UbiEi	pBR-CRISPRi derivative harboring the <i>ubiE</i> crRNA	This study
pK29mobsacB	pK18mobsacB derivative with the removal of two <i>KpnI</i> sites	This study
pK29-AppsR	pK29mobsacB derivative containing the up and downstream homologous arms of <i>ppsR</i>	This study
pRL27De	pRL27 derivative with the removal of <i>Esp3I</i> site	This study
pRL27Kan	pRL27De derivative with the introduction of the promoter <i>Ptac</i> and two <i>Esp3I</i> sites (cohesive ends of <i>Bam</i> HI and <i>Xho</i> I)	This study
pRL27Amp	pRL27Kan derivative with ampicillin resistance from pBlu2SKP instead of kanamycin resistance, Amp ^R	This study
pRL27Gen	pRL27Kan derivative with gentamycin resistance from pZJD29c instead of kanamycin resistance, Gent ^R	This study
pRL-MEV	pRL27Kan derivative carrying the cassette of MEV pathway operon from <i>P. zeaxanthinifaciens</i>	This study
pRLA-HPPD-HPT-TC	pRL27Amp derivative carrying the cassettes of <i>hppd</i> , <i>hpt</i> , and <i>vteI</i>	This study
pRLG-AroG ^{fbr} -TyrA ^{fbr}	pRL27Gen derivative carrying the cassettes of <i>aroG</i> ^{D146N} and <i>tyrA</i> ^{M53I} from pCDF-AroG ^{fbr} -TyrA ^{fbr}	This study

Supplementary Table 3 Strains used in this study

Strain	Description	Source
<i>E. coli</i> Top10	<i>F-mcrA</i> Δ (<i>mrr-hsdRMS-mcrBC</i>) ϕ 80 <i>lacZ</i> Δ <i>M15</i> Δ <i>lacX74</i> <i>recA1</i> <i>ara</i> Δ 139 Δ (<i>ara-leu</i>)7697 <i>galU</i> <i>galK</i> <i>rpsL</i> (<i>Str^R</i>) <i>endA1</i> <i>nupG</i>	Weidi Biotech
<i>E. coli</i> DH5α λpir	<i>F-ϕ80</i> <i>lacZ</i> Δ <i>M15</i> Δ (<i>lacZYAargF</i>) <i>LAMpir</i> <i>U169</i> <i>endA1</i> <i>recA1</i> <i>hsdR17</i> (<i>r_k⁻,m_k⁺</i>) <i>supE44</i> λ - <i>thi-1</i> <i>gyrA96</i> <i>relA1</i> <i>phoA</i>	Weidi Biotech
<i>E. coli</i> S17-1	<i>thi</i> <i>pro</i> <i>hsdR</i> <i>hsdM⁺</i> <i>recA::</i> (RP4-2-Tc::Mu-Km::Tn7) λ pir, Sm ^R	Weidi Biotech
<i>E. coli</i> BL21 (DE3)	Strain used for IPTG-induced expression of T7 promoter	Lab Stock
Ec-UbiE	BL21 (DE3) harboring the plasmid pRSF-UbiE	This study
Ec-UbiEmY36A	BL21 (DE3) harboring the plasmid pRSF-UbiEmY36A	This study
Ec-UbiEmR143A	BL21 (DE3) harboring the plasmid pRSF-UbiEmR143A	This study
Ec-UbiEmN144A	BL21 (DE3) harboring the plasmid pRSF-UbiEmN144A	This study
Ec-Vte4	BL21 (DE3) harboring the plasmid pRSF-Vte4	This study
Ec-BchP	BL21 (DE3) harboring the plasmid pRSF-BchP	This study
Ec-BchP-FdxA-Fdr	BL21 (DE3) harboring the plasmid pRSF-BchP-FdxA-Fdr	This study
<i>R. capsulatus</i> SB1003	Wild type, Rif ^R	14
Rcap-VE	SB1003 harboring the plasmid pBR-HPPD-HPT-TC	This study
<i>R. sphaeroides</i> HY01	Wild type, parental strain	15
Rsp-VE	HY01 harboring the plasmid pBR-HPPD-HPT-TC	This study
Rsp-MPBQ	HY01 harboring the plasmid pBR-HPPD-HPT	This study
Rsp-UbiEi	HY01 harboring the plasmid pBR-UbiEi	This study
HY01-ΔppsR	HY01 derivative with the <i>ppsR</i> gene deletion	This study
MEV01-MEV20	HY01-ΔppsR derivative with the transposon mutagenesis by the plasmid pRL-MEV	This study
VET01-VET20	MEV14 derivative with the transposon mutagenesis by the plasmids pRLA- HPPD-HPT-TC and pRLG-AroG ^{fbr} -TyrA ^{fbr}	This study

Supplementary Table 4 Oligonucleotides used in this study

Name	Sequence (5' → 3')	Purpose
Ptac-F	CGGAATTCGGTTCTGGCAAATATTC	Clone the promoter <i>Ptac</i>
Ptac-R	TTGGTACCTTATCCGCTCACAATTCC	
HPPD-F	TTGGTCTCGGATCCCATCAACGGAGGTTACAT	Clone <i>hppd</i>
	ATGGCTGATATCTTTGAAAATC	
HPPD-R	TTGGTCTCATCAGTCTGTGCTCAGCACGC	
HPT-F	TTGGTCTCACTGACATCAACGGAGGTTACATA	Clone <i>hpt</i>
	TGGCAACTATCCAAGCTTTTGT	
HPT-R	TTGGTCTCGGATGCTAAAAAATAGTATTAGAA	
	AAATTAGG	
TC-F	TTGGTCTCACATCAACGGAGGTTACATATGCG	Clone <i>vteI</i> and remove the <i>BsaI</i>
	CTCCATTTCTAGGGTTTCGG	site of <i>vteI</i>
TCoe-R	catttccatgtctcagtcgaac	
TCoe-F	gactgagacatatgaaatgctgc	
TC-R	TTGGTCTCCTCGAGTTACAGACCCGGTGGCTT	
	GAAG	
sacB-F	GTACATAAAAAAGGAGACATGAACGATGAAC	Replace the <i>sacB</i> of
	ATCA	pK18mobsacB with the <i>sacB</i>
sacB-R	CTCGATACCCATCGGCATTTTCTTTTGCGTTTT	from pJD29c
	TATTTG	
ppsRup-F	GCTCTAGATTGATGGTCGGTTCCTCGTCG	Clone the upstream fragment of
ppsRup-OE-R	TCCCGTCCCTCGCTCCGCTCTCGCTGTCGCGG	<i>ppsR</i>
	CAGTC	
ppsRdown-OE-F	TGCCGCGACAGCGAGAGCGGAGCGAGGGAC	Clone the downstream
	GGGAGGC	fragment of <i>ppsR</i>
ppsRdown-R	TTGGTACCGCAGAGAGACAGGGCGGGG	
De-F	TTCGTCTCAACTCGCTCAGGCGCAATCAC	Remove the <i>Esp3I</i> site of
De-R	TTCGTCTCAGAGTCGAAATACGCGATCGCTGT	pRL27
	TAA	
Ur-F	TATCAACGGAGGACGGATCCGAGACGTTCTGT	Introduce the promoter <i>Ptac</i>
	CTCCTCGAGCTTCTTCACGAGGCAGACC	and two <i>Esp3I</i> sites (cohesive
Pr-R	CGGGATCCGTGTTGCTGACTCATACCA	ends of <i>BamHI</i> and <i>XhoI</i>) into
Pr-F	CGGGATCCCTTGACAATTAATCATCGGCTCGTAT	pRLDe
	AATGTATCAACGGAGGACGGATCC	
Amp-F	acagtaatacaaggggtgttATGAGTATTCAACATTTCCG	Replace the kanamycin
	TG	resistance of pRL27Kan with
Amp-R	aaccaattaaccaattctgaTTACCAATGCTTAATCAGTG	the ampicillin resistance
	AG	
Gen-F1	acagtaatacaaggggtgttATGTTACGCAGCAGCAACG	Replace the kanamycin
	ATG	resistance of pRL27Kan with
Gen-OE-R1	gctgatgttgGGAGTAGGTGGCTACGTCGC	the gentamycin resistance

Gen-OE-F2	cacctactccCAACATCAGCCGGACTCCGATTAC	
Gen-R2	aaccaattaaccaattctgaTTAGGTGGCGGTACTTGGGT C	
AroG-F	TTGGTCTCGGATCCTTTCCGGAGGTTACATATG AATTATCAGAACGACGA	Clone <i>aroG</i> ^{D146N} - <i>tyrA</i> ^{M53I}
TyrA-R	TTGGTCTCCTCGAGTTACTGGCGATTGTCATTG G	
LD-U1-F	TTGGTCTCACTAATGCAAACCTTAGTCTTTATG	Forward primer for crRNA
dUbiE-gRNA-R	TTGGTCTCAAAAAGCTTCCGGAACCGTCCGGA AGCCATCTACAACAGTAGAAATT	Reverse primer for <i>ubiE</i> interference crRNA
UbiE-F	AGAGGATCCGATGAGTGATGAACTAGCAATA CCA	Clone the wild-type UbiE
UbiE-R	AGAGACTCGAGTTAGATCTTCCAACCGCTATG C	
UbiEY36A-OE-R	TTGCATCTAAGgcCGATATCATG	Clone the UbiE mutant with Y36A
UbiEY36A-OE-F	CATGATATCGgcCTTAGATGCAA	
UbiER143A-OE-R	CTTTGGTATCgcAAATGTTACCC	Clone the UbiE mutant with R143A
UbiER143A-OE-F	GGGTAACATTTgcGATACCAAAG	
UbiEN144A-OE-R	CTTTGGTATCAGAgcTGTTACCC	Clone the UbiE mutant with N144A
UbiEN144A-OE-F	GGGTAACAgcTCTGATACCAAAG	
BchP-F	AGAGGATCCGATGGCCTATGATGTCTTCGTAG TGG	Clone <i>bchP</i> for digestion and ligation
BchP-R	AGAGACTCGAGTCAGGTCCATTGCGGCGAGA	
pRSF-F	cgggatctaaCTCGAGTCTGGTAAAGAAACCG	Clone vector backbone of pRSFDuet-1 for homologous recombination
pRSF-R	cgggatctaaCTCGAGTCTGGTAAAGAAACCG	
BchP-F2	gccaggatccGATGGCCTATGATGTCTTCGTAGTGG	Clone <i>bchP</i> for homologous recombination
BchP-R2	aactcctttaTCAGGTCCATTGCGGCGAGA	
FdxA-F	atggacctgaTAAAGGAGTTACATATGACCTATGTG GTGACCGACAACCTGCATCG	Clone <i>fdxA</i> for homologous recombination
FdxA-R	aactccttaaTCAACCGCCCTCGCCGGGCT	
Fdr-F	gggcggttgaTTAAGGAGTTACATATGAACCAGAA CGCCGCCATTG	Clone <i>fdr</i> for homologous recombination
Fdr-R	cagactcgagTTAGATCCCGTCGCCGACGAA	
Vte4-F	AGAGGATCCGATGACGACAACGCGTGGAAC	Clone <i>vte4</i>
Vte4-R	AGAGACTCGAGTTAGAGTGGCTTCTGGCAAG	

Supplementary Table 5 List of genes used in this study

Gene	Sequence
<i>hppd</i> from <i>P. putida</i>	ATGGCTGATATCTTTGAAAATCCAATGGGCCTGATGGGCTTCGAATTCATCG AACTGGCTTCGCCGACCCAGGCGTACTAGAGCCTGTATTCCAGATACTGG GCTTCACCAAAGTGGCCACCCACCGTTCCAAGGATGTGCACCTGTATCGCC AGGGTGGCATCAACCTGATCCTGAACAATGAACCCAAGAGCATCGCTTCGT ATTTCGCCGCTGAACACGGCCCGTCGGTATGTGGCATGGCTTTTCGCGTGC GCAATGCCCATGAGGCTTATGCCC GCGCCCTGGA ACTGGGCGCTCAGCCGG TAGAAATCGAAACCGGCCCGATGGAATTGCGCCTGCCGGCGATCAAGGGTA TCGGGGGGGCACCGCTCTATCTGATCGACCGCTTCGAGGAAGGCAGCTCTA TCTACGACATCGACTTCAACTTCATCGAAGGCGTGGATCGCAACCCGGTAG GGGCCGCGCTGAAAATCATCGACCACCTACCCATAACGTCTACCGTGGGC GTATGGCCTACTGGGCCGGGTCTACGAGAAGCTGTTCAACTTCCGCGAAA TCCGCTACTTCGATATCAAGGGCGAATACACCGGCCTGACCTCCAAGGCCA TGACTGCGCCTGATGGCATGATCCGCATCCCGCTCAACGAAGAGTCATCCA AGGGTGCAGGGCAGATCGAAGAGTTCCTGATGCAGTTCAACGGTGAAGGT ATCCAGCACGTGGCCTTCCTGACCGATGACCTGCTCAAGACCTGGGATGCG CTGAAGGGGCTGGGCATGCGCTTCATGACCGCGCCACCGCAAACCTACTAC GAAATGCTCGAAGAGCGCCTGCCGGGCCATGGTGAGCCGGTCGACCAACT GCAAGCGCGTGGCATCCTGCTCGATGGCGCCTCGCAGCCCGGAGACAAGC GCCTGCTGCTGCAGATTTTCTCGGAAACCCTGCTTGGCCCGGTCTTCTTCGA GTTTCATCCAGCGCAAAGGTGACGATGGCTTCGGTGAAGGCAACTTCAAGG CGCTGTTTGAATCCATCGAGCGTGACCAGGTACGCCGCGGCGTGCTGAGCA CAGACTGA
<i>hpt</i> from <i>Synechocystis sp.</i>	ATGGCAACTATCCAAGCTTTTTGGCGCTTCTCCCGCCCCCATACCATCATTG GTACAACCTCTGAGCGTCTGGGCTGTGTATCTGTAACTATTCTCGGGGATGG AAACTCAGTTAACTCCCCTGCTTCCCTGGATTAGTGTTGCGCGCTTGGCTG GCCTGCCTGTTGGGTAATGTGTACATTGTCGGCCTCAACCAATTGTGGGATG TGGACATTGACCGCATCAATAAGCCGAATTTGCCCTAGCTAACGGAGATT TTCTATCGCCCAGGGCCGTTGGATTGTGGGACTTTGTGGCGTTGCTTCCTTG GCGATCGCCTGGGGATTAGGGCTATGGCTGGGGCTAACGGTGGGCATTAGT TTGATTATTGGCACGGCCTATTGCGTGCCGCCAGTGAGGTTAAAGCGCTTTT CCCTGCTGGCGGCCCTGTGTATTCTGACGGTGCGGGGAATTGTGGTTAACTT GGGCTATTTTTATTTTTAGAAATTGGTTTAGGTTATCCCCCACTTTAATAAC CCCCATCTGGGTTTTGACTTTATTATCTTAGTTTTACCGTGGCGATCGCCA TTTTTAAAGATGTGCCAGATATGGAAGGCGATCGGCAATTTAAGATTCAAAC TTTAACTTTGCAAATCGGCAAACAAAACGTTTTTCGGGGAACCTTAATTTTA CTCACTGGTTGTTATTTAGCCATGGCAATCTGGGGCTTATGGGCGGCTATGC CTTTAAATACTGCTTTCTTGATTGTTTCCCATTTGTGCTTATTAGCCTTACTCT GGTGGCGGAGTCGAGATGTACACTTAGAAAGCAAAACCGAAATTGCTAGTT TTTATCAGTTTATTTGGAAGCTATTTTTCTTAGAGTACTTGCTGTATCCCTTGG

	CTCTGTGGTTACCTAATTTTCTAATACTATTTTGTAG
<i>vte1</i> from <i>A. thaliana</i>	ATGGAGATACGGAGCTTGATTGTTTCTATGAACCCTAATTTATCTTCCTTTGA GCTCTCTCGCCCTGTATCTCCTCTCACTCGCTCACTAGTTCCGTTCCGATCG ACTAAACTAGTTCCCCGCTCCATTTCTAGGGTTTCGGCGTCGATCTCCACCC CGAATAGTGAAACTGACAAGATCTCCGTAAACCTGTTTACGTCCCGACGT CTCCCAATCGCGAACTCCGGACTCCTCACAGTGGATACCATTTCGATGGAA CACCTCGGAAGTTCTTCGAGGGATGGTATTTACAGGGTTTCCATCCCAGAGA AGAGGGAGAGTTTTTGTGTTTATGTATTCTGTGGAGAATCCTGCATTTTCGGCA GAGTTTGTCAACCATTGGAAGTGGCTCTATATGGACCTAGATTCACTGGTGTT GGAGCTCAGATTCTTGGCGCTAATGATAAATATTTATGCCAATACGAACAAG ACTCTCACAATTTCTGGGGAGATCGACATGAGCTAGTTTGGGGAATACTTT TAGTGCTGTGCCAGGCGCAAAGGCTCCAAACAAGGAGGTTCCACCAGAGG AATTTAACAGAAGAGTGTCCGAAGGGTTCCAAGCTACTCCATTTTGGCATC AAGGTCACATTTGCGATGATGGCCGTAAGTACTGACTATGCGGAACTGTGAAAT CTGCTCGTTGGGAGTATAGTACTCGTCCCGTTTACGGTTGGGGTGATGTTGG GGCCAAACAGAAGTCAACTGCAGGCTGGCCTGCAGCTTTTCCTGTATTTGA GCCTCATTGGCAGATATGCATGGCAGGAGGCCTTTCCACAGGGTGGATAGA ATGGGGCGGTGAAAGGTTTGAGTTTCGGGATGCACCTTCTTATTCAGAGAA GAATTGGGGTGGAGGCTTCCCAAGAAAATGGTTTTGGGTCCAGTGTAATGT CTTTGAAGGGGCAACTGGAGAAGTTGCTTTAACCGCAGGTGGCGGGTTGA GGCAATTGCCTGGATTGACTGAGACATATGAAAATGCTGCACTGGTTTGTGT ACACTATGATGGAAAAATGTACGAGTTTGTTCCTTGAATGGTGTTGTAGA TGGGAAATGTCTCCCTGGGGTTATTGGTATATAACTGCAGAGAACGAAAAC CATGTGGTGGAAC TAGAGGCAAGAACAAATGAAGCGGGTACACCTCTGCG TGCTCCTACCACAGAAGTTGGGCTAGCTACGGCTTGCAGAGATAGTTGTTA CGGTGAATTGAAGTTGCAGATATGGGAACGGCTATATGATGGAAGTAAAGG CAAGGTGATATTAGAGACAAAGAGCTCAATGGCAGCAGTGGAGATAGGAG GAGGACCGTGGTTTGGGACATGGAAAGGAGATACGAGCAACACGCCCCGAG CTACTAAACAGGCTCTTCAGGTCCCATTGGATCTTGAAAGCGCCTTAGGTT TGGTCCCTTTCTTCAAGCCACCGGGTCTGTAA
<i>aroG^{D146N}</i> from <i>E. coli</i>	ATGAATTATCAGAACGACGATTTACGCATCAAAGAAATCAAAGAGTTACTTC CTCCTGTGCGATTGCTGGAAAAATTCCCCGCTACTGAAAATGCCGCGAATAC GGTTGCCCATGCCCCGAAAAGCGATCCATAAGATCCTGAAAGGTAATGATGA TCGCCTGTTGGTTGTGATTGGCCCATGCTCAATTCATGATCCTGTGCGGGCA AAAGAGTATGCCACTCGCTTGCTGGCGCTGCGTGAAGAGCTGAAAGATGA GCTGGAAATCGTAATGCGCGTCTATTTTGAAAAGCCGCGTACCACGGTGGG CTGGAAAGGGCTGATTAACGATCCGCATATGGATAATAGCTTCCAGATCAAC GACGGTCTGCGTATAGCCCCGTAAATTGCTGCTTGATATTAACGACAGCGGTC TGCCAGCGGCAGGTGAGTTTCTCAATATGATCACCCACAAATATCTCGTGGA CCTGATGAGCTGGGGCGCAATTGGCGCACGTACCACCGAATCGCAGGTGCA CCGCGAACTGGCATCAGGGCTTTCTTGTCCGGTCGGCTCAAAAATGGCAC CGACGGTACGATTAAAGTGGCTATCGATGCCATTAATGCCGCCGGTGCGCCC

			CACTGCTTCCTGTCCGTAACGAAATGGGGGCATTGCGCGATTGTGAATACC AGCGGTAACGGCGATTGCCATATCATTCTGCGCGGCGGTAAAGAGCCTAAC TACAGCGCGAAGCACGTTGCTGAAGTGAAAGAAGGGCTGAACAAAGCAG GCCTGCCAGCACAGGTGATGATCGATTTCAGCCATGCTAACTCGTCCAAAC AATTCAAAAAGCAGATGGATGTTTGTGCTGACGTTTGCCAGCAGATTGCCG GTGGCGAAAAGGCCATTATTGGCGTGATGGTGGAAGCCATCTGGTGGAAG GCAATCAGAGCCTCGAGAGCGGGGAGCCGCTGGCCTACGGTAAGAGCATC ACCGATGCCTGCATCGGCTGGGAAGATACCGATGCTCTGTTACGTCAACTG GCGAATGCAGTAAAAGCGCGTTCGCGGGTAA
<i>tyrA^{M53I}</i>	from <i>E. coli</i>		ATGGTTGCTGAATTGACCGCATTACGCGATCAAATTGATGAAGTCGATAAAG CGCTGCTGAATTTATTAGCGAAGCGTCTGGAAGTGGTTGCTGAAGTGGGCG AGGTGAAAAGCCGCTTTGGACTGCCTATTTATGTTCCGAGCGCGAGGCAT CTATTTTGGCCTCGCGTCGTGCAGAGGCGGAAGCTCTGGGTGTACCGCCAG ATCTGATTGAGGATGTTTTGCGTCGGGTGATGCGTGAATCTTACTCCAGTGA AAACGACAAAGGATTTAAACACTTTGTCCGTCACTGCGTCCGGTGGTTAT CGTCGGCGGTGGCGGTGAGATGGGACGCCTGTTTCGAGAAGATGCTGACCC TCTCGGGTTATCAGGTGCGGATTCTGGAGCAACATGACTGGGATCGAGCGG CTGATATTGTTGCCGATGCCGGAATGGTGATTGTTAGTGTGCCAATCCACGT TACTGAGCAAGTTATTGGCAAATTACCGCCTTTACCGAAAGATTGTATTCTG GTCGATCTGGCATCAGTGAAAAATGGGCCATTACAGGCCATGCTGGTGCGG CATGATGGTCCGGTGCTGGGGCTACACCCGATGTTCCGGTCCGGACAGCGGT AGCCTGGCAAAGCAAGTTGTGGTCTGGTGTGATGGACGTAAACCGGAAGC ATACCAATGGTTTCTGGAGCAAATTCAGGTCTGGGGCGCTCGGCTGCATCG TATTAGCGCCGTCGAGCACGATCAGAATATGGCGTTTATTACGGCACTGCGC CACTTTGCTACTTTTGCTTACGGGCTGCACCTGGCAGAAAGAAAATGTTACG CTTGAGCAACTTCTGGCGCTCTCTTCGCCGATTTACCGCCTTGAGCTGGCG ATGGTCGGGCGACTGTTTGCTCAGGATCCGCAGCTTTATGCCGACATCATT TGTCGTCAGAGCGTAATCTGGCGTTAATCAAACGTTACTATAAGCGTTTCGG CGAGGCGATTGAGTTGCTGGAGCAGGGCGATAAGCAGGCGTTTATTGACAG TTTCCGCAAGGTGGAGCACTGGTTCGGCGATTACGTACAGCGTTTTCAGAG TGAAAGCCGCGTGTTATTGCGTCAGGCGAATGACAATCGCCAGTAA
<i>bchP</i>	from <i>R. sphaeroides</i>		ATGGCCTATGATGTCTTCGTAGTGGGTGGCGGCCCCGTCGGGCGCCACGGCG GCCGACGAGCTGGCCCCGTGCCGGCAAGAGCGTGCGCTTCTCGACCGTGC CGGGCGGATCAAGCCCTGCGGCGGCGCGATCCCGCCGCGCCTGATCGAGG ATTCGACATCCCCGACAGCCAGATCGTGCGCGCATCCGCACCGCGCGGA TGATCTCGCCACCGGCCGCAAGGTGACATCCCGATCGAGGGCGGCTTCG TCGGCATGGTGGACCGCGAGCATTTCGACGAATGGCTCCGCCGCCGCGCCG CCAAGGCCGGGGCCGAGCGGCTGACGGGCACCTTCCTGCGCGTCGAGCGC GACAGCTTCCACACCTATGTCGTCTGGCGCGAGAAGGCGACGGGCGAGGA GAAACGGTCCGAGACCAAGCTCGTGATCGGTGCCGACGGCGCGAAATCCG ACGTGGCACGCGCCGAGGTGCCCGGGGCGACAAGATCCCGATGGTGATC GCCTACCACGAGATCATCAAGCCGCCGACCAGCTCGGTGATCGACTACGAC

			CCTACCCGCTGCGACGTGATCTACGACGGCCGGGTCAGCCCCGATTCTAC GGCTGGATCTTCCCGCATGGCGAGACCGCCTCGGTGCGCATGGGCACGGGC ATCCTCGGCTTCGACCTGAAGGAGGCGACTGCGCTCCTGCGCCGGCAGGC CGGGCTCGACCAGTGCGAGACGATCCGCAAGGAGGGCGCGCCGATCCCGC TGCAGCCGCTGGAGAAGTGGGACAACGGCAAGGACGTGGTGCTTGCGGGC GATGCGGCGGGGGTCGTGCGACCCCTCGTCGGGCGAGGGGATCTACTATGCC TTCGTGCGGTGGCCAGGTCGCGGCCAGGGCCTGCCTCGCCGCGCTGAAATCG GGCCGGGCGACCGACCTCCAACCTCGCGCGCAAGATGTTATGGCCGACCA CAAGACCGTGTTCAAGGTTCTCCGCTCGATGCAGGATGCCTATTATCGCGAC GACGAGCGGCGCGAGCGGTTCTGTGAGCCTGTGCCACGACACCGACGTTCA GCGCCTGACCTTCGAGTCTACATGAACAAGAACTGACGAGCAAACAGC CCTGGGCCCATATCAAGATCGGGTTCAAGAACGTGATGCACCTGACGCGGC TCGTCTCGCCGCAATGGACCTGA
<i>fdxA</i> <i>sphaeroides</i>	from	R.	ATGACCTATGTGGTGACCGACAACCTGCATCGCCTGCAAATACACCGACTGC GTGGAAGTCTGTCCGGTGGACTGCTTCTACGAAGGCGAGAACATGCTGGTC ATCCACCCGGACGAATGCATCGACTGCGGCGTCTGCGAACCAGGAATGCCCCG GCCGATGCGATCCGCCCCGACACCGAGCCCGACATGGAAAGCTGGGTCTGA GCTGAACCGGAAATATGCCGAGGTCTGGCCGGTTATCGTGACCAAGAAGGA CCCCTGCCCCGAGGCGACCGATCTCGACGGCCAGCCCGCAAGCTCGCCA CGCATTTCTCCGAAAAGCCCGGCGAGGGCGGTTGA
<i>fdx</i> <i>sphaeroides</i>	from	R.	ATGAACCAGAACGCCGCCATTGTGAAGACCCTGCCCCGATGCGCAGACCGT GACCTCGGTGCAGCATTGGACGGACCGTCTCTTTTCCTTCCGCGTGACCCG TCCGCAGTCGCTGCGGTTCCGCTCGGGCGAGTTCGTGATGATCGGGCTGCT CGACGAGCGCGGCAAGCCGATCATGCGCGCCTATTCCATCGCCTCGCCAA CTGGGACGAAGAGCTCGAATTCTACTCGATCAAGGTGCCGGACGGTCCGCT GACCTCGCGGCTCCAGCATATCCAGCCCGGCGACCAGATCATCTGCGTCC GAAGCCGGTGGGGACGCTCGTTCTCGACGCGCTTCTGCCCCGCAAGCGGA TCTGGTTCCTCGCCACCGGCACCGGCATCGCGCCCTTCGCCTCGCTGATGC GCGACCCCGAGACCTACGAGCGCTACGAGCAGGTCATCATGATGCACACCT GCCGCGAGCAGGCCGAGCTCGAATATGGCCGCCAACTGGTTCGAGAGCCTG AAGGACGATCCGCTGATCGGCGAGATGGTGGGCGACAAGCTGCTCTACTAT CCCACCACCGCGCGAGACCTCGGACCGGATGGGTGCGATCACCGACAA CCTCAGCTCGGGCAAGGTGTTTCGAGGATCTGGGCGTGCCGAAGATGAACC TCGAGGAAGACCGCGCGATGGTCTGCGGCTCGCTCCAGTTCAACCTCGAC GTCAAGACCGTGCTCGAGAGCTTCGGCCTGCGCGAGGGCGCGAACTCGGA ACCGCTGCAATATGTGGTCGAGAAGGCCTTCGTGCGGCGACGGGATCTAA
<i>vte4</i> from <i>A. thaliana</i>			ATGACGACAACGCGTGGAACGTGGCTGTGGCGGCTGCTGCTACATCCACT GAGGCGCTAAGAAAAGGAATAGCGGAGTTCTACAATGAAACTTCGGGTTT GTGGGAAGAGATTGGGGAGATCATATGCATCATGGCTTTTATGACCCTGAT TCTTCTGTTCAACTTTCTGATTCTGGTCACAAGGAAGCTCAGATCCGTATGA TTGAAGAGTCTCTCCGTTTTGCCGGTGTTACTGATGAAGAGGAGGAGAAAA AGATAAAGAAAGTAGTGGATGTTGGGTGTGGGATTGGAGGAAGCTCAAGA

		TATCTTGCCTCTAAATTTGGAGCTGAATGCATTGGCATTACTCTCAGCCCTGT TCAGGCCAAGAGAGCCAATGATCTCGCGGCTGCTCAATCACTCGCTCATAA GGCTTCCTTCCAAGTTGCGGATGCGTTGGATCAGCCATTCGAAGATGGAAA ATTCGATCTAGTGTGGTCGATGGAGAGTGGTGAGCATATGCCTGACAAGGC CAAGTTTGTA AAAAGAGTTGGTACGTGTGGCGGCTCCAGGAGGTAGGATAAT AATAGTGACATGGTGCCATAGAAATCTATCTGCGGGGGAGGAAGCTTTGCA GCCGTGGGAGCAAAACATCTTGGACAAAATCTGTAAGACGTTCTATCTCCC GGCTTGGTGCTCCACCGATGATTATGTCAACTTGCTTCAATCCCATCTCTCC AGGATATTAAGTGTGCGGATTGGTCAGAGAACGTAGCTCCTTTCTGGCCTG CGGTTATACGGACTGCATTAACATGGAAGGGCCTTGTGTCTCTGCTTCGTAG TGGTATGAAAAGTATTAAAGGAGCATTGACAATGCCATTGATGATTGAAGGT TACAAGAAAGGTGTCATTAAGTTTGGTATCATCACTTGCCAGAAGCCACTCT AA
MEV pathway operon from <i>zeaxanthinifaciens</i>	<i>P.</i>	ATGAAAGACCAGATGATTTCCCATACCCCGGTGCCACGCAATGGGTGCGC CCGATCCTGTTCCGCGGCCCCGTCGTCGAGGGCCCGATCAGCGCGCCGCTG GCCACCTACGAGACGCCGCTCTGGCCCTCGACCGCGCGGGGGGCGAGGGGT TTCCCGGCATTGCGGGCGGGATCCAGGTGTCGCTGGTCGACGAACGCATGAG CCGCTCGATCGCGCTGCGGGCGCATGACGGGGCGGCGGCGACCGCCGCCT GGCAGTCGATCAAGGCCCGCCAGGAAGAGGTGCGCGGCCGTGGTCGCCACC ACCAGCCGCTTCGCCCCGCCTTGTGAGCTGAATCGCCAGATCGTGGGCAAC CTGCTTTACATCCGCATCGAATGCGTGACGGGCGACGCCTCGGGTCACAAC ATGGTCACCAAGGCCCGCCGAGGCCGTGCAGGGCTGGATCCTGTGCGAATAC CCGATGCTGGCCTATTCCACGATCTCGGGGAACCTGTGCACCGACAAGAAG GCGTCGGCGGTCAACGGCATCCTGGGCCGCGGCAATACGCCGTCGCCGA GGTCGAGATCCCGCGCAAGATCCTGACCCGCGTGCTGCGCACCAGCGCCG AGAAGATGGTCCGCCTGAACTACGAGAAGAACTATGTGCGGGGTACGCTG GCGGGGTGCTGCGCAGTGCGAACGCGCATTTGCGCAACATGCTGCTGGGC TTCTACCTGGCGACGGGGCAGGACGCGGCCAACATCATCGAGGCCAGCCA GGGCTTCGTCCATTGCGAGGCCCCGCGGCGAGGATCTGTATTTCTCGTGAC GCTGCCCAACCTCATCATGGGCTCGGTGCGGTGCCGGCAAGGGCATCCCCCTC GATCGAGGAGAACCTGTGCGGATGGGCTGCCGCCAGCCGGGCGCAACCCG GCGACAACGCGCGCCGTCTTGCGGCGATCTGCGCGGGCGTCGTGCTGTGTG GTGAATTGTCGCTGCTTGCGGCCAGACCAACCCCGAGAGTTGGTCCGCA CCCACATGGAGATGGAGCGATGACCGACAGCAAGGATCACCATGTCGCGG GGCGCAAGCTGGACCATCTGCGTGCAATTGGACGACGATGCGGATATCGACC GGGGCGACAGCGGCTTCGACCGCATCGCGCTGACCCATCGCGCCCTGCCCC AGGTGGATTTGACGCCATCGACACGGCGACCAGCTTCCTGGGCCGTGAAC TGTCCTTCCCGCTGCTGATCTCGTCCATGACCGGCGGCACCGGCGAGGAGA TCGAGCGCATCAACCGCAACCTGGCCGCTGGTGCCGAGGAGGCCCGCGTC GCCATGGCGGTGGGCTCGCAGCGCGTGATGTTACCGACCCCTCGGCGCGG GCCAGCTTCGACCTGCGCGCCCATGCGCCCACCGTGCCGCTGCTGGCCAAT ATCGGCGCGGTGCAGCTGAACATGGGGCTGGGGCTGAAGGAATGCCTGGC

CGCGATCGAGGTGCTGCAGGCGGACGGCCTGTATCTGCACCTGAACCCCT
GCAAGAGGCCGTCCAGCCGAGGGGATCGCGACTTTGCCGATCTGGGCA
GCAAGATCGCGGCCATCGCCCGGACGTTCCCGTGCCCGTCTGTGAAGG
AGGTGGGCTGCGGCCTGTCGGCGGCCGATATCGCCATCGGGCTGCGCGCCG
GGATCCGGCATTTCGACGTGGCCGGTCGCGGCGGCACATCCTGGAGCCGGA
TCGAGTATCGCCGCCGCCAGCGGGCCGATGACGACCTGGGCCTGGTCTTCC
AGGACTGGGGCCTGCAGACCGTGGACGCCCTGCGCGAGGCGCGGCCCGCG
CTTGCGGCCCATGATGGAACCAGCGTGCTGATCGCCAGCGGCGGCATCCGC
AACGGTGTGACATGGCGAAATGCGTCATCCTGGGGGCCGACATGTGCGGG
GTCGCCGCGCCCCTGCTGAAAGCGGCCAAAACTCGCGCGAGGCGGTTGT
ATCCGCCATCCGGAACCTGCATCTGGAGTTCGGGACAGCCATGTTCTCTCT
GGGTTGCGGCACGCTTGCCGACCTGAAGGACAATTCCTCGCTTATCCGTCA
ATGAAAGTGCCTAAGATGACCGTGACAGGAATCGAAGCGATCAGCTTCTAC
ACCCCCAGAACTACGTGGGACTGGATATCCTTGCCGCGCATCACGGGATC
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CCGCGACGGCGGCGCTGCAGATGGCCTGCGCGCATGTGCCCCGAAGCCC
GACCGCAAGGTGCTGGTGATCGCGTCCGATGTGCGCGCTATGACCGCGAA
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CGCCGATCCCAAGGTGGCCGAGATCGGCACCGTCTCGGGGCTGTTACCGA
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CGGCAAGGCATCGACGCTGCGCTATCTGAACGCGCTGGTCGAGGCGTGGA
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GCTATCACGTGCCGTTCTCGCGGATGGGCGAGAAGGCGAACAGCCACCTG
GCCAAGGCGAACAAGACGCCGGTGGACATGGGGCAGGTGCAGACGGGCC
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GTCGGTCTGTTAGCTATGGCTCGGGTGCGACGGGCGAATTCATGCGC
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ACGAGATCGACCTGACGCAGGGCGCGCCCGACAAGGCGCGCGGTGCTTTC
AGGCTGGCAGGTATCGAGGACGAGAAGCGCATCTATGTGACCGGCAGGC
CTGAAGCAGGCGCCCATGCCCCGGGCAAGCTGATCCTGTCCGGGGAACATT
CCGTGCTCTATGGTGCGCCCGCGCTTGCCATGGCCATCGCCGCTATAACGA
GGTGTGGTTACGCCGCTTGGCATTGGCGAGGGGATACGCACGACATTCGC
CAATCTCTCGGGCGGGGCGACCTATTCGCTGAAGCTGCTGTGCGGGTTCAA
GTCGCGGCTGGACCGCCGGTTGAGCAGTTCCTGAACGGCGACCTAAAGG
TGCACAAGGTCCTGACCCATCCCGACGATCTGGCGGTCTATGCGCTGGCGT
CGCTTCTGCACGACAAGCCGCCGGGACCGCCGCGATGCCGGGCATCGGC

GCGATGCACCACTGCCGCGACCGGGTGAGCTGGGCAGCCGGACGGAGCT
GCCCATCGGCGCGGGCATGGGGTCGTCTGCGGCCATCGTCGCGGCCACCAC
GGTCTGTTCGAGACGCTGCTGGACCGGCCCAAGACGCCCCGAACAGCGCT
TCGACCGCGTCCGCTTCTGCGAGCGGTTGAAGCACGGCAAGGCCGGTCCC
ATCGACGCGGCCAGCGTCGTGCGCGGCGGGCTTGTCCGCGTGGGCGGGAA
CGGGCCGGGTTTCGATCAGCAGCTTCGATTTGCCCCAGGATCACGACCTTGT
CGCGGGACGCGGCTGGTACTGGGTACTGCACGGGCGCCCCGTCAGCGGGA
CCGGCGAATGCGTCAGCGCGGTGCGGGCGGCGCATGGTCGCGATGCGGCG
CTGTGGGACGCCCTTCGACGCCTGCACCCGCGCGTTGGAGGCCGCGCTGCT
GTCTGGGGGCAGCCCCGACGCCGCCATCACCGAGAACCAGCGCCTGCTGG
AACGCATCGGCGTCGTGCCGGCAGCGACGCAGGCCCTCGTGGCCCAGATC
GAGGAGGCGGGTGGCGCGGCCAAGATCTGCGGCGCAGGTTCCGTGCGGGG
CGATCACGGCGGGGCGGTCTCTGTGCGGATTGACGACGCGCAGGCGATGG
CTTCGGTCATGGCGGCCATCCCCGACCTCGACTGGGCGCCCCGTCGCGATGT
CGCGCACGGGGGCGGCACCCGCGCCCCGCGCCGCGTGCGAACCGCTGCCG
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CGGCCAGCCTGCATGGCGGCTTCGTGCGCTATCGCGCGCCCGATGGCGGTG
CCGCGCAGATCGAGGCGCTTCCGGTGCCGCGGGGCCGTTTCGGCCTGCGCT
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GGATGGCGGGCAACGAGGCCGCTTTCGACGCGCTCTACTCCCGGATGGGC
GCAAGCGCAGATGCCGCGATCCGCGCGGCGCAAGGGCTGGACTGGGCTGC
ATTCCACGACGCGCTGAACGAATACCAGCGCCTGATGGAGCAGCTGGGCGT
GTCCGACGACACGCTGGACGCGATCATCCGCGAGGCGCGCGACGCGGGCG
CCGCAGTCGCCAAGATCTCCGGCTCGGGGCTGGGGGATTGCGTGCTGGCAC
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CTTGTTTTTCGATGACTGATGCCGTCCGCGACATGATCGCCCGTGCCATGGCG
GGCGCGACCGACATCCGAGCAGCCGAGGCTTATGCGCCCAGCAACATCGC
GCTGTGCAAATACTGGGGCAAGCGCGACGCCGCGCGGAACCTTCCGCTGA
ACAGCTCCGTCTCGATCTCGTTGGCGAACTGGGGCTCTCATACGCGGGTCG
AGGGGTCCGGCACGGGCCACGACGAGGTGCATCACAACGGCACGCTGCTG
GATCCGGGCGACGCCTTCGCGCGCCGCGCGTTGGCATTGCTGACCTGTTC
CGGGGGGGGAGGCACCTGCCGCTGCGGATCACGACGCAGAACTCGATCCC
GACGGCGGCGGGGCTTGCTCGTCGGCCTCGGGGTTCGCGGCGCTGACCC
GTGCGCTGGCGGGGGCGTTTCGGGTGGATCTGGACGACACGGATCTGAGC

		CGCATCGCCCGGATCGGCAGTGGCAGCGCCGCCCGCTCGATCTGGCACGGC
		TTCGTCCGCTGGAACCGGGGCGAGGCCGAGGATGGGCATGACAGCCACGG
		CGTCCCGCTGGACCTGCGCTGGCCCGGCTTCCGCATCGCGATCGTGGCCGT
		GGACAAGGGGGCCCAAGCCTTTCAGTTCGCGCGACGGCATGAACCACACGG
		TCGAGACCAGCCCGCTGTTCCCGCCCTGGCCTGCGCAGGCGGAAGCGGAT
		TGCCGCGTCATCGAGGATGCGATCGCCGCCCGCGACATGGCCGCCCTGGGT
		CCGCGGGTCGAGGCGAACGCCCTTGCGATGCACGCCACGATGATGGCCGC
		GCGCCCGCCGCTCTGCTACCTGACGGGCGGCAGCTGGCAGGTGCTGGAAC
		GCCTGTGGCAGGCGCGCGGACGGGCTTGCGGCCCTTGCGACGATGGAT
		GCCGGCCCGAACGTCAAGCTGATCTTCGAGGAAAGCAGCGCCGCCGACGT
		GCTGTACCTGTTCCCGACGCCAGCCTGATCGCGCCGTTTCGAGGGGCGTTG
		A
Codon-optimized		ATGAGTGATGAAACTAGCAATACCACCCATTTCGGTTTCAGAACTGTTCCAG
<i>ubiE</i>	from	AAGGTGAAAAGGCTGGTATGGTTCACGGTGTTTTACCCGTGTTGCATCTA
<i>sphaeroides</i>	<i>R.</i>	AGTACGATATCATGAACGATTTGATGTCCGGTGGTGTCCACAGATTGTGGAA
		AGATGCCATGATGGACTGGCTAGCACCGCGTCCTGGCCAGAACTGCTGGA
		TGTCGCCGGTGGTACAGGTGACATTTCTTTCCGTTTTCTGAAACGTGCTCCA
		GGTGCTGAAGCAACCGTTTGTGATATGACTGAATCCATGTTAGTTGAAGGTC
		GTCAAAGAGCTGATGCTGCTCAAATGGCCGATCGTCTGGATTGGGTTGTTG
		GTGATGCAATGGCACTGCCGTTTGCAAGCAATACCTTTGATGTTTATACCAT
		TAGCTTTGGTATCAGAAATGTTACCCGTGTGCAGGATGCTTTGAACGAAGC
		CTACAGAGTTTTGAAACCGGGTGGTCGGTTGATGGTTTTGGAATTTAGCCA
		GCTGCCAAACCCAATGATGCAATGGGCTTACGACAGATACTCTTTCAACGTT
		ATTCCGGTTATGGGTCAAATCGTTGCCAACGACCGTGATAGCTATCAGTATT
		TAGTCGAATCCATTAGAAAGTTCCCAGACCAAGAAACCTTTGCGGACATGA
		TTCGTAAAGCAGGATTTGGTCTGGTGAAATATCGTAATCTGTCTTTGGGTATT
		GCAGCACTGCATAGCGGTTGGAAGATCTAA

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