

Improved method for assembly of linear yeast expression cassettes using NEBuilder[®] HiFi DNA Assembly Master Mix

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Introduction

Heterologous protein production in yeast expression systems (i.e., *Kluyveromyces lactis* and *Pichia pastoris*) normally involves insertion of a linear expression cassette into a target locus in the host genome (1-3). Typically, an expression cassette is assembled in *E. coli* by first cloning a gene of interest into a circular expression vector (Figure 1A). The expression cassette comprises DNA encoding a strong yeast promoter upstream of a heterologous gene of interest, a downstream transcription terminator sequence and a selectable marker gene. The entire cassette is flanked by locus-specific targeting sequences on either end (Figure 1B). The assembled vector is then amplified by propagation of the host *E. coli* cells, isolated by standard DNA preparation techniques, and subjected to restriction digestion to create a linear expression cassette. The linear fragment is then introduced into yeast whereby it integrates into a target locus on the host chromosome (Figure 1C).

While this approach for expression strain construction has been accepted methodology for over two decades, it does have some limitations. For example, expression vector assembly using traditional cloning techniques is a multi-day process. Additionally, one is limited to the use of restriction sites that are present in the expression vector and the use of the expression machinery (i.e., promoter, terminator, locus targeting sequence, etc.) that is built into the vector. Finally, for cloning of a gene whose product is highly toxic to *E. coli*, serendipitous protein expression during vector assembly in bacteria can yield clones having deleterious mutations (1,4). The use of *in vitro* DNA assembly methods to construct linear expression cassettes suitable for direct introduction into yeast circumvents each of these limitations while shaving days off of expression strain construction time. In the presented method, we highlight the use of NEBuilder HiFi DNA Assembly Master Mix (NEB #E2621) to rapidly assemble expression cassettes for use with NEB's *K. lactis* Protein Expression Kit (NEB #E1000).

DNA CLONING

DNA AMPLIFICATION & PCR

EPIGENETICS

RNA ANALYSIS

LIBRARY PREP FOR NEXT GEN SEQUENCING

PROTEIN EXPRESSION & ANALYSIS

CELLULAR ANALYSIS

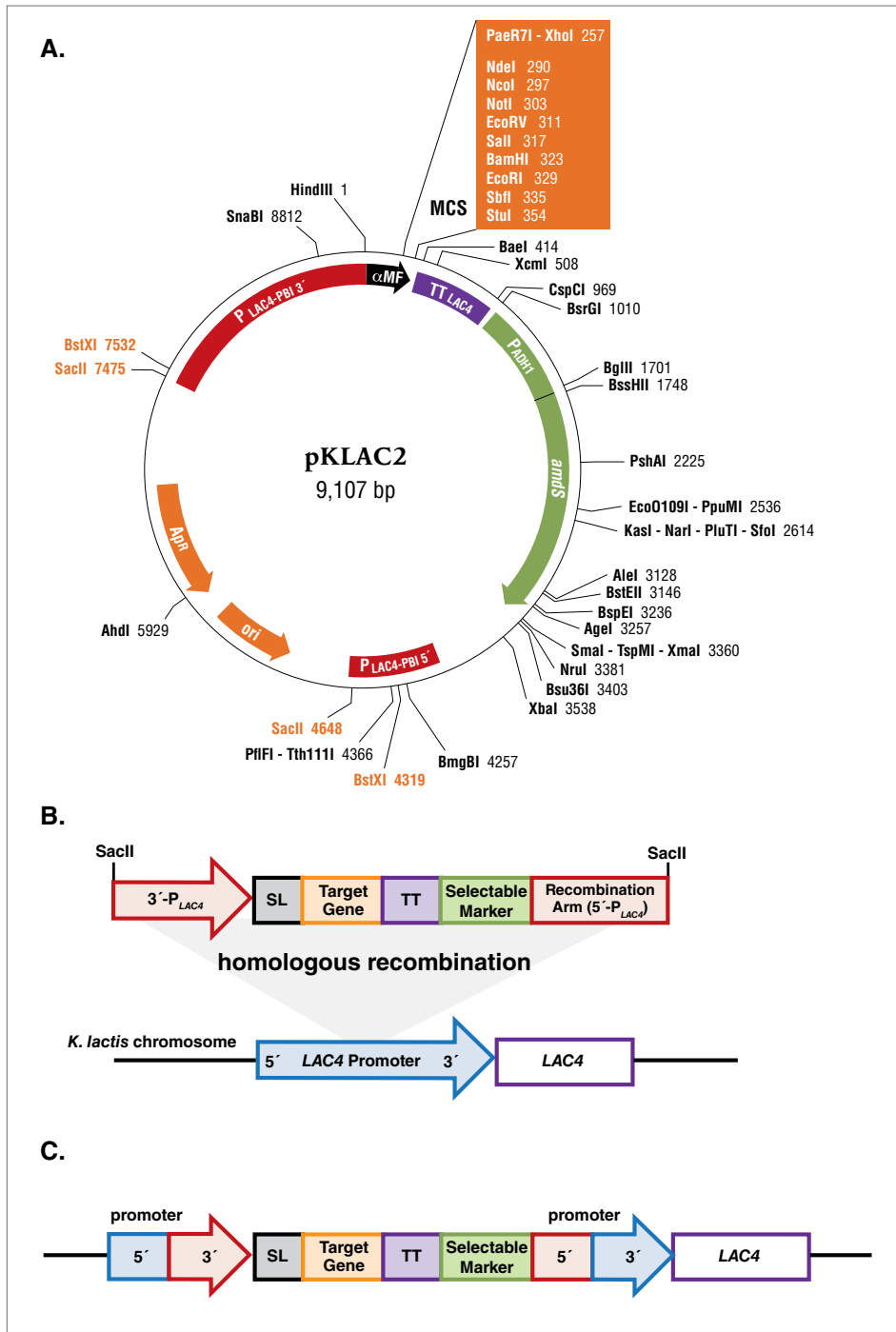
Materials

- NEBuilder HiFi DNA Assembly Master Mix
- Q5[®] Hot Start High-Fidelity 2X Master Mix
- Overlapping Primers
- NEBuilder Assembly Tool
- *K. lactis* Protein Expression Kit
- pKLAC2
- *K. lactis* GG799 Competent Cells
- Yeast Carbon Base Medium
- Biolum[®] *Gussia* Luciferase Assay Kit

References:

1. Colussi, P.A. and Taron, C.H. (2005) *Kluyveromyces lactis* *LAC4* promoter variants that lack function in bacteria but retain full function in *K. lactis*. *Appl. Environ. Microbiol.* 71:7092–7098.
2. van Ooyen, A.J.J., Dekker, P., Huang, M., Olsthoorn, M.M.A., Jacobs, D.I., Colussi P.A. and Taron, C.H. (2006) Heterologous protein production in the yeast *Kluyveromyces lactis*. *FEMS Yeast Res.* 6:381–392.
3. Read, J.D., Colussi, P.A., Ganatra, M.B. and Taron, C.H. (2007) Acetamide selection of *Kluyveromyces lactis* cells transformed with an integrative vector leads to high frequency formation of multicopy strains. *Appl. Environ. Microbiol.* 73:5088–5096.
4. Gibbs, M., Reeves, R.A., Sunna, A., and Bergquist, P.L. (2004) A yeast intron as a translational terminator in a plasmid shuttle vector. *FEMS Yeast Res.* 4:573–577.

Figure 1. Traditional yeast expression strain construction.



(A) The pKLAC2 integrative expression vector. A target gene is cloned into the multiple cloning site (optionally, in-frame with the mating factor alpha secretion leader for extracellular expression) using traditional techniques. Transcription is initiated and terminated by the LAC4 promoter ($P_{LAC4-PBI}$) and LAC4 transcription terminator (TT_{LAC4}) sequences, respectively. The *Saccharomyces cerevisiae* ADH1 promoter (P_{ADH1}) drives expression of a fungal acetamidase gene (*amdS*) for the selection of transformants by growth on acetamide-containing medium. *E. coli* vector sequence has been inserted into a unique *SacII* site in P_{LAC4} to allow for propagation in bacteria. (B) Targeted integration of a linear expression cassette. The vector is linearized by digestion with *SacII* or *BstXI* to permit subsequent insertion into the LAC4 promoter locus in the *K. lactis* genome. In the illustrated example, the fragment becomes inserted into the LAC4 promoter locus by recombination, mediated by homologous targeting sequences at either end of the fragment. The resulting chromosomal arrangement is shown in (C). Abbreviations: 3'- P_{LAC4} left targeting sequence; 5'- P_{LAC4} right targeting sequence; SL, secretion leader; TT_{LAC4} transcription terminator.

Protocol

Experimental Design – Linear expression cassette assembly

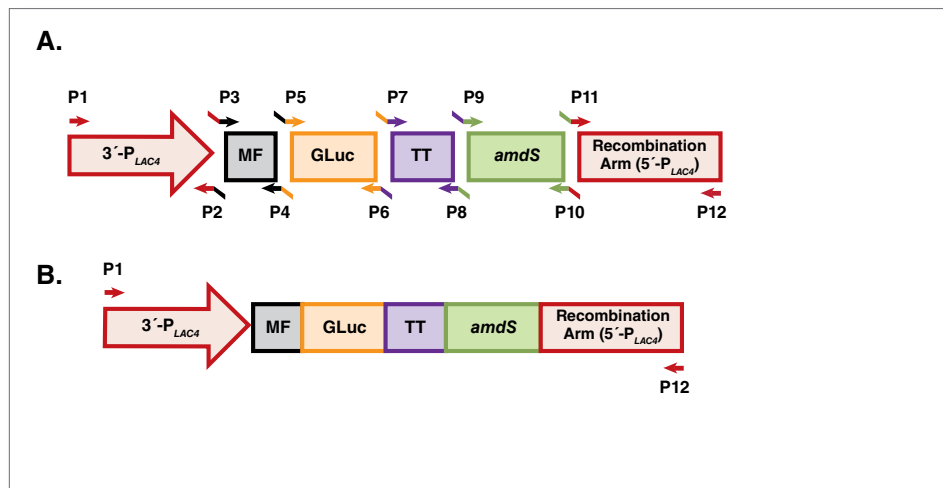
In this experiment, multiple pairs of primers were designed using the NEBuilder Assembly Tool (nebuilder.neb.com) to permit amplification of individual functional domains of an expression cassette (Table 1). Each resulting amplicon contained 22 bp overlaps with adjacent domains (Figure 2A). Purified PCR products were combined and treated with NEBuilder HiFi DNA Assembly Master Mix (NEB #E2621) and the fully assembled expression cassette was amplified using primers P1 and P12 (Figure 2B) to obtain sufficient quantities for introduction into *K. lactis* cells.

Table 1. Overlapping primers used for NEBuilder assembly of a linear *K. lactis* expression cassette.

PRIMER	SEQUENCE 5'→3'
P1	GATCGACTCATAAAATAGTAACC
P2	GAGAATTCATTTTTTCAAGCTTCTCGATG
P3	GCTTGAAAAAATGAAATCTCTACTATATTAGCCG
P4	TCGGTGGGCTTCTTTTCTCGAGATCATCC
P5	TCGAGAAAAGAAGCCCACCGAGAACAACG
P6	AAGGGGCCTGTTAGTCACCACCGGCCCC
P7	GTGGTGACTAACAGGCCCTTTTCCTTTG
P8	CACCCGAAACAGCTTGCAAATTAAGCCTTC
P9	ATTTGCAAGCTGTTCCGGGTGTACAATATG
P10	ATCTGTTCTTCTATGGAGTCACCACATTC
P11	TGACTCCATAGAAGGAACAGATAGATAAAATCCG
P12	CCGCGGAAA0TTTAGGAATTTAAAC

*Colors indicate DNA regions corresponding to the different functional domains shown in Figure 2A.

Figure 2. *In vitro* assembly of a linear expression cassette.



(A) Primer pairs P1 through P12 were used in PCR to amplify individual functional domains of the expression cassette. (B) The domains were then assembled using the NEBuilder HiFi DNA Assembly Master Mix and the assembled linear expression cassette was amplified by PCR using primers P1 and P12. In this experiment, the *CYC1* transcription terminator (TT) was used.

Fragment Preparation:

- The following reaction conditions were used to amplify individual functional domains of the expression cassette (schematic in Figure 2A, primers in Table 1).

COMPONENT	VOLUME (μl)	STEP	TEMP	TIME
Forward primer (40 μM)	1.25	Initial denaturation	98°C	30 seconds
Reverse primer (40 μM)	1.25	30 Cycles	98°C	10 seconds
DNA template (5 ng/μl)	1		58°C	30 seconds
ddH ₂ O	46.5		72°C	30 seconds or 1 minute
Q5 Hot Start High-Fidelity 2X Master Mix	50		Final extension	72°C
Total Volume	100	Hold	4°C	∞

- After thermocycling, each amplicon was purified by gel extraction.

Expression Cassette Assembly:

- The concentration of individual functional domain amplicons was determined by a Nanodrop™ instrument or estimated by agarose gel electrophoresis.
- NEBuilder HiFi DNA Assembly Master Mix (NEB #E2621) was thawed at room temperature.
- The DNA assembly reaction was set up as follows:
- The reaction was incubated at 50°C for 1 hour.

COMPONENT	AMOUNT
PCR Amplicons	0.03 pmol (each)
2X NEBuilder HiFi DNA Assembly Master Mix	10 μl
ddH ₂ O	x μl
Total volume	20 μl

- A 2 μl aliquot of the reaction was used as template in a fresh PCR reaction using primers P1 and P12 to amplify the assembled cassette. (Note: occasionally, more than one 100 μl reaction is needed to generate enough pooled assembled product for introduction into yeast).
- Following thermocycling, the amplicon was purified by gel extraction.

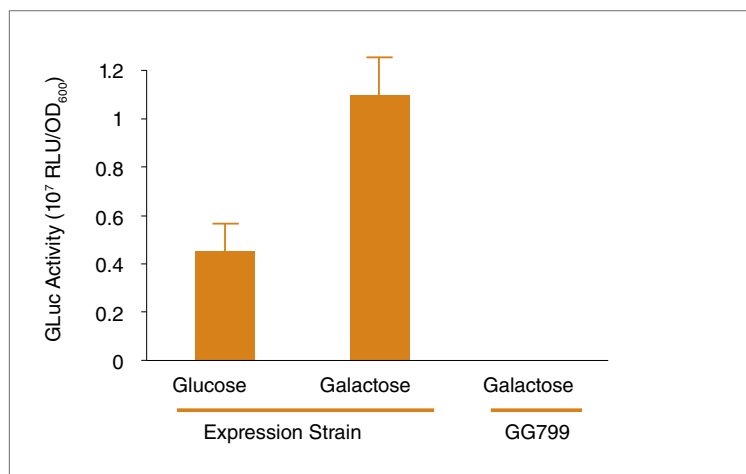
COMPONENT	VOLUME (μl)	STEP	TEMP	TIME
Forward primer (40 μM)	1.25	Initial denaturation	98°C	30 seconds
Reverse primer (40 μM)	1.25	30 Cycles	98°C	10 seconds
DNA Template (fragment assembly mix)	2		58°C	30 seconds
ddH ₂ O	45.5		72°C	3 minutes
Q5 High-Fidelity 2X Master Mix	50		Final extension	72°C
Total Volume	100	Hold	4°C	∞

- An aliquot containing 0.1–1 μg of the assembled linear expression cassette was used to transform *K. lactis* GG799 Competent Cells (NEB #C1001). The transformation reaction was plated on Yeast Carbon Base Medium (NEB #B9017) containing 5 mM acetamide and incubated for 3–4 days at 30°C until colonies formed. Targeted integration of the linear expression cassette into the *K. lactis* genome was confirmed by colony PCR using standard techniques described in the *K. lactis* Protein Expression Kit Manual (NEB #E1000).

Results:

A transformation efficiency of about 8×10^3 colonies/ μg DNA was obtained with the *in vitro* assembled expression construct, a similar efficiency to that observed when using a cloned expression cassette liberated from a pKLAC2 expression construct. *K. lactis* cells harboring at least one integrated copy of the *in vitro* assembled expression cassette successfully secreted *Gaussia princeps* luciferase (GLuc) into the growth medium (Figure 3).

Figure 3. Expression of *Gaussia princeps* luciferase (GLuc) in *K. lactis* GG799 cells.



The NEBuilder-assembled linear expression cassette (shown in Figure 2B) was used to transform *K. lactis* GG799 cells. A representative transformant was cultured in triplicate in rich medium (yeast extract/peptone) supplemented with glucose or galactose as a carbon source. Untransformed GG799 cells were grown in medium containing galactose as a negative control. GLuc enzyme activity secreted into the growth medium was measured using the BioLux *Gaussia* Luciferase Assay Kit (NEB #E3300). GLuc expression from the LAC4 promoter is repressed in the presence of glucose, but is de-repressed in galactose, as expected (1-3).

Conclusions:

In this application note, the use of NEBuilder HiFi DNA Assembly Master Mix (NEB #E2621) to rapidly assemble a linear expression fragment for introduction into *K. lactis* was demonstrated. The method permits fast preparation of linear expression cassettes in 1-2 days whereas the classical *E. coli* cloning approach takes at least 4-5 days. The *in vitro* assembly method is also suitable for the cloning of toxic genes because it eliminates the potential for accumulation of deleterious mutations during expression vector construction steps in bacteria. Moreover, NEBuilder HiFi DNA assembly permits more flexibility in the creation of constructs having different promoters, signal sequences, reporter genes and integration sites compared to using pKLAC2 in the *K. lactis* Protein Expression Kit (NEB #E1000). The general methodology outlined in this application note can also be applied more widely to assemble linear DNAs containing expression machinery for introduction into other yeasts (e.g. *Pichia pastoris*), fungi, bacteria, plant cells or animal cells.

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