Electronic Supplementary Material (ESI) for Nanoscale.


**Supporting Information**

# Template-directed conjugation of heterogeneous oligonucleotides to a homobifunctional molecule for programmable supramolecular assembly

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Table of Content

1- Abbreviations:

- CuAAC: copper-catalyzed azide-alkyne cycloaddition
- DMF: dimethylformamide
- DMT-MM: 4-(4, 6-dimethoxy-1, 3, 5-triazin-2-yl)-4-methylmorpholinium chloride
- DSS: disuccinimidyl suberate
- HPLC: high-performance liquid chromatography
- MOPS: N-[3-morpholinopropane]sulfonic acid
- MQ: Milli-Q water
- nt: nucleotide
- NT: non-templated
- T: templated
- PAGE: polyacrylamide gel electrophoresis
- PBS: phosphate-buffered saline
- PEG: polyethylene glycol
- TAE: tris-acetate-EDTA
- TAPS: [tris(hydroxymethyl)methylamino]propanesulfonic acid
- TBE: tris-borate-EDTA
- TCEP: tris(2-carboxyethyl)phosphine hydrochloride
- TEAA: triethylammonium acetate
- THPTA: tris(3-hydroxypropyltriazolylmethyl)amine
- rcf: relative centrifugal force
- rpm: rotations per minute

2- Materials:

Unless noted otherwise, all reagents and solvents were purchased from commercial sources and used as received.

2.1 Homobifunctional molecules

- PEG-N was supplied by Deepak Asthana as part of a collaboration with the laboratory of Professor Richard E. P. Winpenny, School of Chemistry, University of Manchester.
- PEG-5000, phthaldialdehyde, and biphenyl-4,4′-dicarboxylic acid: purchased from Sigma Aldrich.
- DSS: purchased from Thermo Scientific.
- Sulfo-cyanine5 bis-NHS ester: purchased from Lumiprobe
- N,N'-bis[2(iodoacetamido)ethyl]-N,N'-dimethylrhodamine dihydroiodide: purchased from Santa Cruz Biotechnology.

2.2 Other reagents

- DMT-MM: purchased from Fluka.
- All other chemicals were purchased from Sigma Aldrich.

2.3 DNA oligonucleotides and origami scaffold

- Oligos were purchased either from Integrated DNA Technologies (IDT) or Biomers, as specified in section (6).
- Scaffold p8064: purchased from tilibit nanosystems.

## 3- General Methods:

### 3.1 Conjugation of DNA adapters

In each reaction the concentration of each DNA adapter was 10 μM. In templated reactions, the template concentration was 10 μM. The annotation "n×" indicates the molar excess of the molecule over adapters (n:1:1). In all cases, molar equivalents specified are relative to the concentration of one DNA adapter, i.e. 10 μM.

CuAAC - PEG-N (Figures 1 and 2- main text):
PEG-N was dissolved in DMF.
For the templated reaction (T): DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in TBE buffer pH 8 with 11mM $MgCl_2$. PEG-N was mixed with the annealed DNA adapters in the stated molar ratios "n×" (2× - 256×) in the presence of 10% DMF.
For the non-templated reaction (NT): PEG-N was mixed with the DNA adapters in the stated molar ratios "n×" (2x-256x) in TBE pH 8 with 11mM $MgCl_2$ in the presence of 10% DMF.
To both reactions were added sodium ascorbate (600×), THPTA ligand (420×) and $CuSO_4$ (60×). The reaction was degassed and left covered overnight on a shaker at room temperature.

CuAAC - PEG-5000 (Figure 3 A- main text):
PEG-5000 was dissolved in DMF. DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in TBE buffer pH 8 with 11mM $MgCl_2$. 20 molar equivalents of PEG-5000 was mixed with the annealed DNA adapters in the presence of 10% DMF. To the reaction was added sodium ascorbate (600×), THPTA ligand (420×) and $CuSO_4$ (60×). The reaction was degassed and left covered on a shaker at room temperature overnight.

Reductive amination - phthaldialdehyde (Figure 3 B- main text):
Phthaldialdehyde was dissolved in DMF. Amine-labeled DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in TAPS buffer 100 mM pH 8.5 with 1M NaCl. To the annealed DNA adapters was added phthaldialdehyde (40×) then $NaBH_3CN$ to a final concentration of 80 mM. The reaction was carried out in a covered Eppendorf thermomixer at 25°C overnight, 300 rpm.

Amine acylation - Sulfo-Cyanine5 bis-NHS ester (Figure 3 C- main text):
Sulfo-cyanine5 bis-NHS ester was dissolved in MQ water. Amine-labeled DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in 100 mM PBS pH 8.75. Sulfo-cyanine5 bis-NHS ester (2×) was added to the annealed DNA. The reaction was carried out in a covered Eppendorf thermomixer at 25°C for 2 h, 300 rpm.

Amine acylation - DSS (Figure 4 D- main text):
DSS was dissolved in DMF. Amine-labeled DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in 100 mM PBS buffer pH 8. DSS (30×) was added to the annealed DNA in the presence of 15% DMF. The reaction was carried out for 30 min at room temperature.

Amine acylation- biphenyl-4,4′-dicarboxylic acid (Figure 3 E- main text):
Biphenyl-4,4′-dicarboxylic acid was dissolved in DMF. Amine-labeled DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in aqueous MOPS buffer 100mM pH 7.0 with 1M NaCl, 15% DMF. Biphenyl-4,4′-dicarboxylic acid (40×) was

added to the annealed DNA adapters. DMT-MM was added to the reaction mixture to a final concentration of 50mM. The reaction was carried out for 15 h at 25°C.

Alkylation - N,N'-bis[2 (iodoacetamido)ethyl]-N,N'-dimethylrhodamine dihydroiodide (Figure 3 F-main text):
Rhodamine was dissolved in DMF. Thiol-labeled DNA adapters were annealed (using the short annealing program, SI §3.2) to DNA template in 50mM PBS buffer pH 8 with 11mM $MgCl_2$ and containing 15%DMF. 40mM TCEP was added to a final concentration of 20 nM and left covered at room temperature for 1 h to reduce the templated thiol adapters. N,N'-bis[2 (iodoacetamido)ethyl]-N,N'-dimethylrhodamine dihydroiodide (50×) was added. in equal steps, each with half the final rhodamine volume. Between the two steps the reaction was left covered at room temperature for 30 min. The reaction was then carried out in the dark at 4°C overnight.

3.2 Short annealing program:

- Start: 96°C
- End 15°C
- -1°C/ 3 sec
- Hold: 15°C

3.3 Reaction product purification:

In cases of Cy5 and rhodamine conjugation, Biorad Micro Bio Spin column Bio-Gel® P-6 in Tris buffer was used to remove the unreacted molecule (unbound dye) following the manufacturer's instructions before HPLC purification. Other reactions were subjected directly to HPLC purification.

HPLC (Agilent 1200):

- Buffer A: 5% MeCN, 0.1 M TEAA
- Buffer B: 70% MeCN, 0.1 M TEAA
- Column: Waters XBridge® Oligonucleotide BEH C18 column, 130 Å, 2.5 µm 4.6×50 mm
- Temperature: 60°C

| Time / min | %B | Flow |
|---|---|---|
| 0.0 | 0.0 | 1 mL/min |
| 1.0 | 0.0 | 1 mL/min |
| 20.0 | 100.0 | 1 mL/min |
| 23.0 | 100.0 | 1 mL/min |
| 23.10 | 0.0 | 1 mL/min |

3.4 Denaturing PAGE gel:

- 20% PAGE (29:1acrylamide:bis-acrylamide) containing 25% formamide, 30% W/V urea in TBE.
- gels were pre-run for 30 min, 300 V.
- samples were heated to 95°C for 10 min then placed on ice before loading.
- 300 V, 50 min after sample loading.
- loading buffer: 80% formamide, 10% tris glycine, 10% urea.

3.5 Native PAGE gel:

- 10% PAGE (19:1acrylamide:bis-acrylamide) in TAE.
- 300 V, 15 min.

3.6 Gel scanning and analysis:

- All gels were scanned in each fluorophore fluorescence channel, then stained with SYBR® gold and scanned in the SYBR® gold channel.
- All gels were scanned using a Typhoon FLA 9500 gel scanner.
- Gel images were analysed using ImageJ.

3.7 Hetero-DNA-Cy5 hybrid integration into 3D origami structure (Figure 5 main text):

The long stem of the T-shaped origami comprises two layers of DNA helices with a gap between four helices (Figure 5 main text, Supporting Figure S13). The two DNA adapters of the hetero-DNA-Cy5 hybrid allow the Cy5 molecule to bridge the gap by hybridizing to the scaffold strand on either side of the gap (Figure 5 main text, Supporting Figure S13). The purified hetero-DNA-Cy5 hybrid was added either with the staple strands during the assembly or by annealing to the assembled origami structure. Samples were analysed on a 2% agarose gel. The coincidence of Cy5 fluorescence and the SYBR® gold-stained origami band confirms the integration of the Cy5 molecule into the assembled origami structure in both cases (Figure 5 main text lanes 3 and 5).

3.7.1 DNA origami Folding & hetero-DNA-Cy5 hybrid incorporation during assembly:
To fold the DNA origami template structure, 20 nM of p8064 scaffold was mixed with 200 nM of each unmodified staple oligonucleotide in 10 mM Tris, 1 mM EDTA (pH 8), 16 mM $MgCl_2$. The folding solution was heated to 65 °C for 15 min to denature all DNA strands and then slowly cooled to 15 °C over a period of 18 h using the origami assembling program.

- Origami assembling program:
  - Start: 65°C for 15 min
  - 65°C - 59°C > -1°C/ 5 min
  - 59°C - 35°C > -1°C/ 35 min
  - 35°C - 30°C > -1°C/ 10 min
  - 30°C - 15°C > -1°C/ 5 min
  - Hold: 15°C

3.7.2 Origami purification:
Free staples were removed by three rounds of PEG precipitation[1]. For each round an equal volume of 12.5 mM $MgCl_2$, 0.5 M NaCl, 15% PEG (w/v) and TAE was added and the samples were spun at 20,000 rcf for 30 minutes at 20°C.

3.7.3 Agarose gel:
After folding the DNA origami template structures, they were checked via gel electrophoresis.

- 2% agarose
  - 11 mM $MgCl_2$.
  - TAE 40 mM (Tris, 40 mM acetic acid, 1 mM EDTA, pH 8)
  - 60V for 2 h on ice.

3.7.4 Integration of Cy5 during the origami assembly:

Supporting Figure S13 D, lane 3: the hetero-DNA-Cy5 hybrid was added to the folding solution to a concentration of 40 nM before folding using the aforementioned origami assembling program.

3.7.5 Integration of Cy5 after origami assembly:

Supporting Figure S13 D, lane 5: the hetero-DNA-Cy5 hybrid was mixed with the PEG-purified origami (15 nM) (sample in lane 4, Figure 5 main text) in a 2:1 molar ratio of hetero-DNA-Cy5 hybrid to DNA origami using the origami post-assembly program.

- Origami post-assembly program
  - Start: 40°C
  - -1°C/ 15 min
  - Hold: 15°C

3.8 Hetero-DNA-Cy5 hybrid programmable assembly (Figure 5 - main text):

3.8.1 Step 1- first template:

HPLC-purified hetero-DNA-Cy5 hybrid (at a final concentration of 125 nM) was mixed with the 3'-modified Cy3 oligo (1.5×) and the first template (2×)) in TBE buffer pH 8 with 16 mM $MgCl_2$ and annealed (using the short annealing program) in a total volume of 150 µl.

3.8.2 Step 2- second template:

After 10 min, to the mixture (step 1) we added the 2nd template (2.5× excess) (Supporting Figure S14, A-2).

3.8.3 Step 3- first template complement:

After 10 min, to the mixture (step 2) we added the complement to the 1st template (3× excess) (Supporting Figure S14, A-3).

3.8.4 Step 4- third template:

After 10 min, to the mixture (step 3) we added the complement to the 1st template (3.5× excess) (Supporting Figure S14, A-3).

After each step, the reaction was analysed using an Agilent Cary Eclipse Fluorescence Spectrometer (Supporting Figure S14, middle) using excitation – emission bands centred at the following wavelengths:
Cy5: 650-670
Cy3: 550-570
FRET: 550-670
Then 4 µl were collected for analysis on 10% native PAGE gel (Supporting Figure S14, bottom).

3.8.5 Following the same protocol, we tested two controls:

§Using a non-fluorescently labeled oligo with the same sequence as the 3' Cy3-modified oligo (Supporting Figure S14, B):

Upon the addition of each of the templates, bands with the same electrophoretic mobilities as in (Supporting Figure S14, A) were obtained. However, none of the assemblies showed any FRET signal, as expected.

§Using a 3'Cy3-modified oligo with a random sequence (Supporting Figure S14, C): No interaction between the Cy3 oligo and other reaction components was observed by either gel analysis or FRET, as expected

4- Calculation of yield:

Yields were estimated from the integrated Cy5 and Cy3 fluorescence intensities of the corresponding gel bands and are expressed relative to the concentration of DNA adapters of each type. The integrated intensity for a given fluorophore in each band was normalized to the total integrated intensity for that fluorophore in the entire lane (Cy3 and Cy5 fluorophore-labeled oligos were present in equal quantities in each reaction). This normalization procedure assumes that the quantum yield of a given fluorophore in all products is approximately the same. For the heterofunctionalized products the yields deduced from normalized intensities in Cy3 or the Cy5 channels were approximately equal, consistent with this assumption. Yields quoted in the main text are averages of these two measures.

For the templated reactions:

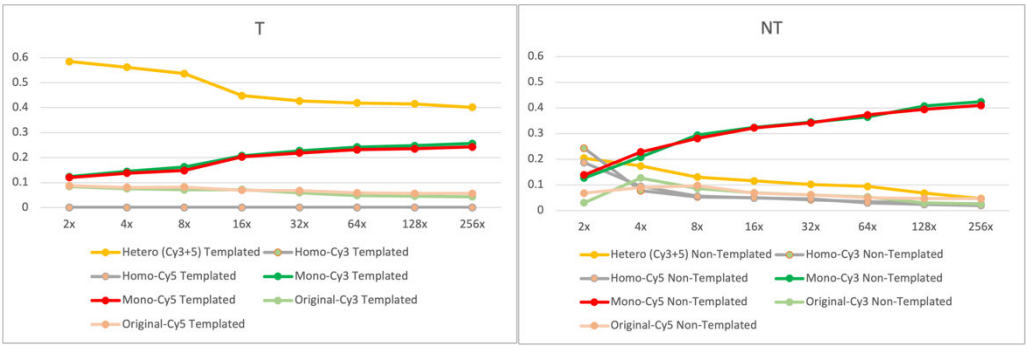
| Stoichiometry (n:1:1) | Normalized Hetero-PEG-N Cy3 channel | Normalized Hetero-PEG-N Cy5 channel | Average |
|---|---|---|---|
| 2 | 0.584 | 0.585 | 0.585 |
| 4 | 0.559 | 0.564 | 0.561 |
| 8 | 0.533 | 0.540 | 0.537 |
| 16 | 0.442 | 0.455 | 0.448 |
| 32 | 0.427 | 0.427 | 0.427 |
| 64 | 0.419 | 0.419 | 0.419 |
| 128 | 0.413 | 0.417 | 0.415 |
| 256 | 0.400 | 0.402 | 0.401 |

For the non-templated reactions:

| Stoichiometry (n:1:1) | Normalized Hetero-PEG-N Cy3 channel | Normalized Hetero-PEG-N Cy5 channel | Average |
|---|---|---|---|
| 2 | 0.198 | 0.210 | 0.204 |
| 4 | 0.173 | 0.175 | 0.174 |
| 8 | 0.132 | 0.130 | 0.131 |
| 16 | 0.112 | 0.120 | 0.116 |
| 32 | 0.102 | 0.102 | 0.102 |
| 64 | 0.094 | 0.094 | 0.094 |
| 128 | 0.067 | 0.069 | 0.068 |
| 256 | 0.047 | 0.048 | 0.047 |

5- Supporting Figures:

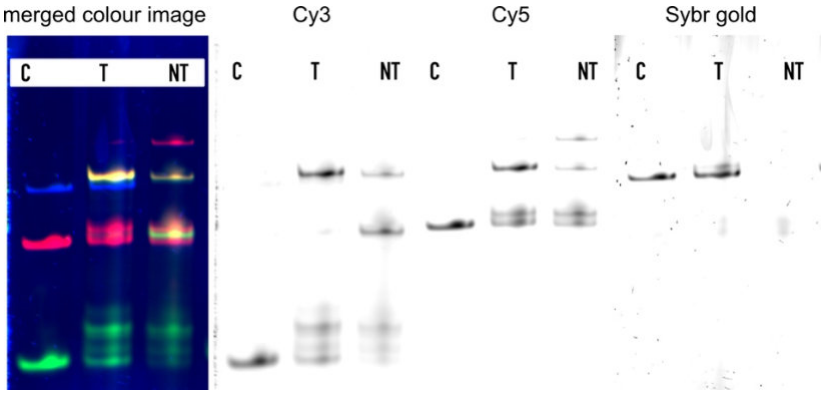
5.1 PEG-N reaction yields with different PEG-N concentrations:




Supporting Figure S1. Reaction yields, deduced from normalized fluorescence intensities, as functions of molar excess of PEG-N over each adapter. "T" and "NT" indicate templated and non-templated reactions, respectively.

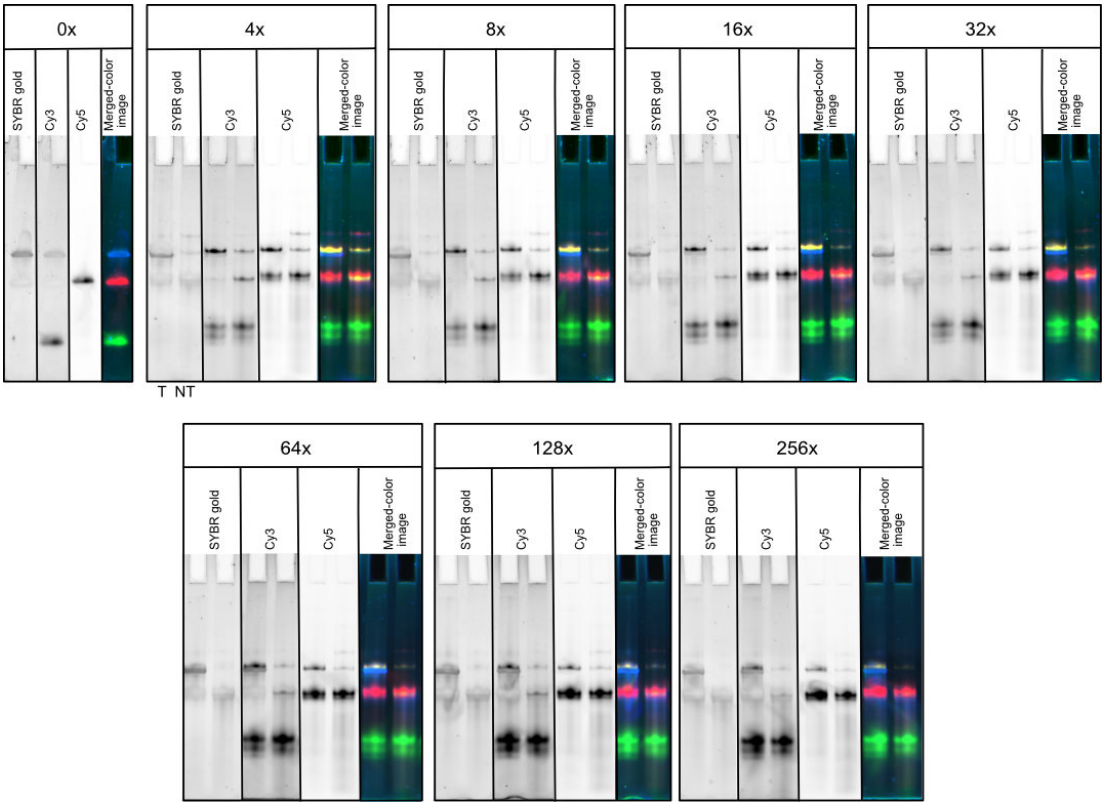
## 5.2 Single Color-Channel images:

### 5.2.1 Templated and Non-templated CuAAC - Figure 2 main text:



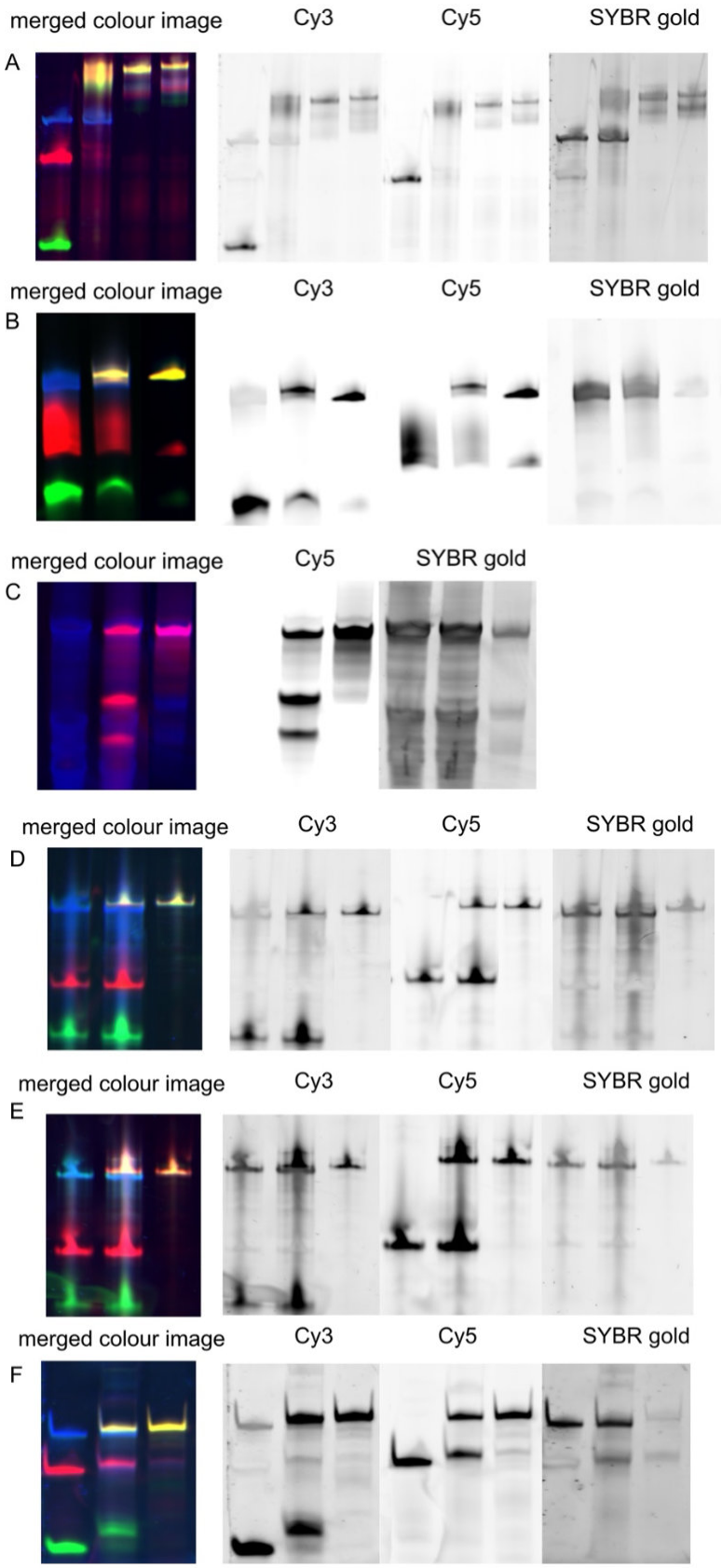

Supporting Figure S2. Templated and non-templated CuAAC reaction. Left: merged color image of 20% denaturing PAGE gel showing templated (T) and non-templated (NT) functionalization of alkyne-PEG-N-alkyne using two different azide-modified DNA adapters, as Figure 1B. To the right are the single-color-channel images of the same reactions from the Cy3, Cy5 and SYBR gold channels. Refer to the main text Figure 1B for key to the identities of bands.

### 5.2.2 Reaction yields as functions of PEG-N concentration - Figure 2 main text:



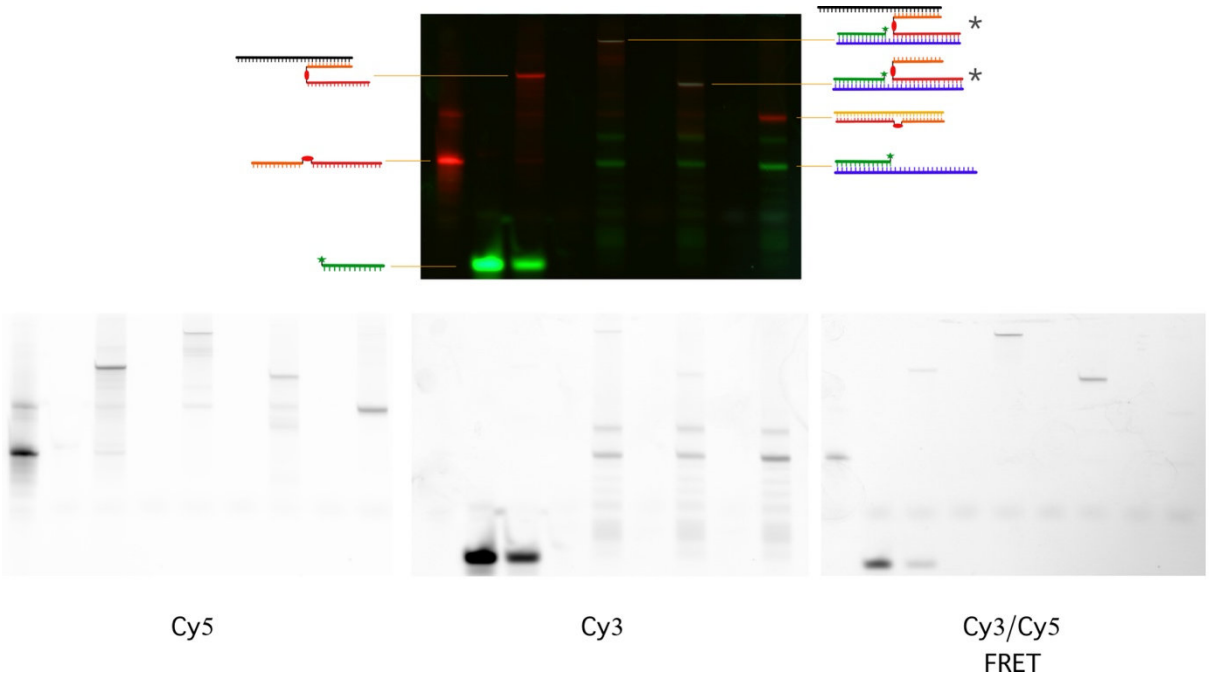

Supporting Figure S3. Reaction yields as functions of PEG-N concentration. For each gel, corresponding to the specified molar excess of PEG-N, the merged color image shown in main text Figure 2A is combined with single-color-channel images of the same reaction from the Cy3, Cy5 and SYBR gold channels.

5.2.3 Templated heterofunctionalization reactions of a wide range of target molecules - Figure 3 main text:




Supporting Figure S4. Templated heterofunctionalization of a wide range of target molecules. For each gel, corresponding to a different conjugation reaction, the merged color image shown in main text Figure 3A-F is combined with single-color-channel images of the same reaction from the Cy3, Cy5 and SYBR gold channels.

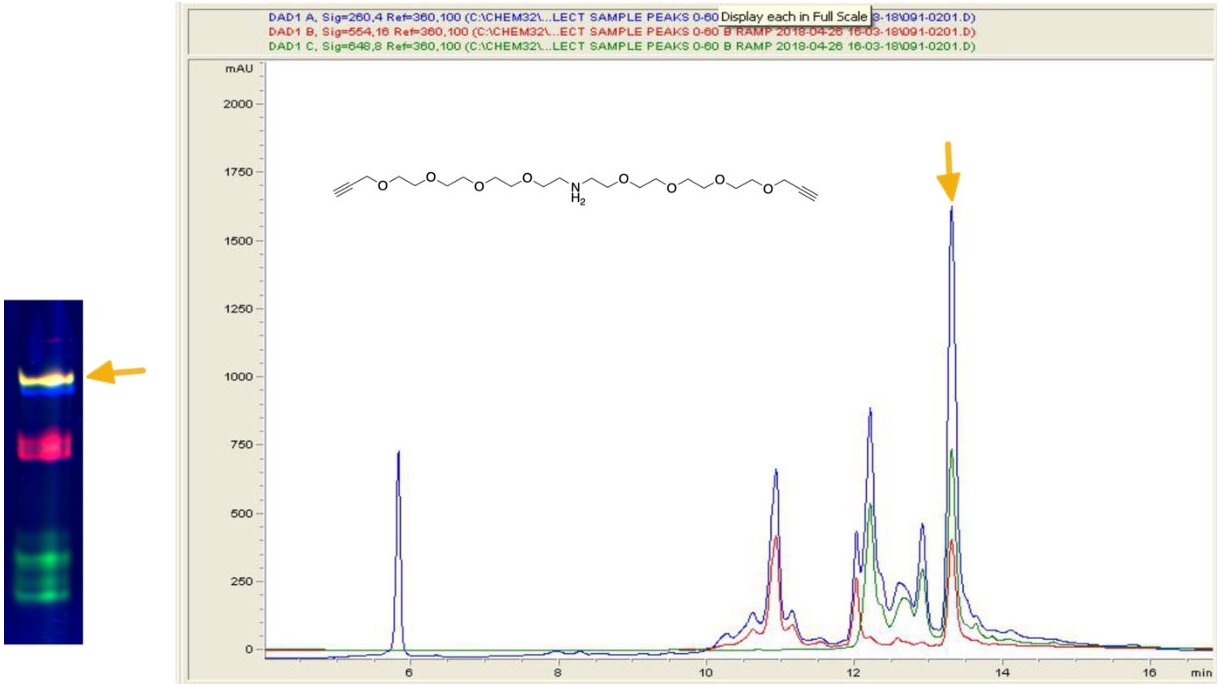
5.2.4 Hybridization reactions demonstrating programmed control of a hetero-DNA-Cy5 hybrid by means of the two oligonucleotide adapters - Figure 5 main text:




Supporting Figure S5. Hybridization reactions demonstrating programmed control of a hetero-DNA-Cy5 hybrid by means of the two oligonucleotide adapters. Top: 10% native PAGE gel showing reaction products imaged in Cy5 (red), Cy3 (green), and FRET (Cyan) fluorescence channels (main text Figure 5B). Yellow bands indicated by * correspond to products containing both fluorophores and FRET signal. Bottom: component single-color-channel images.

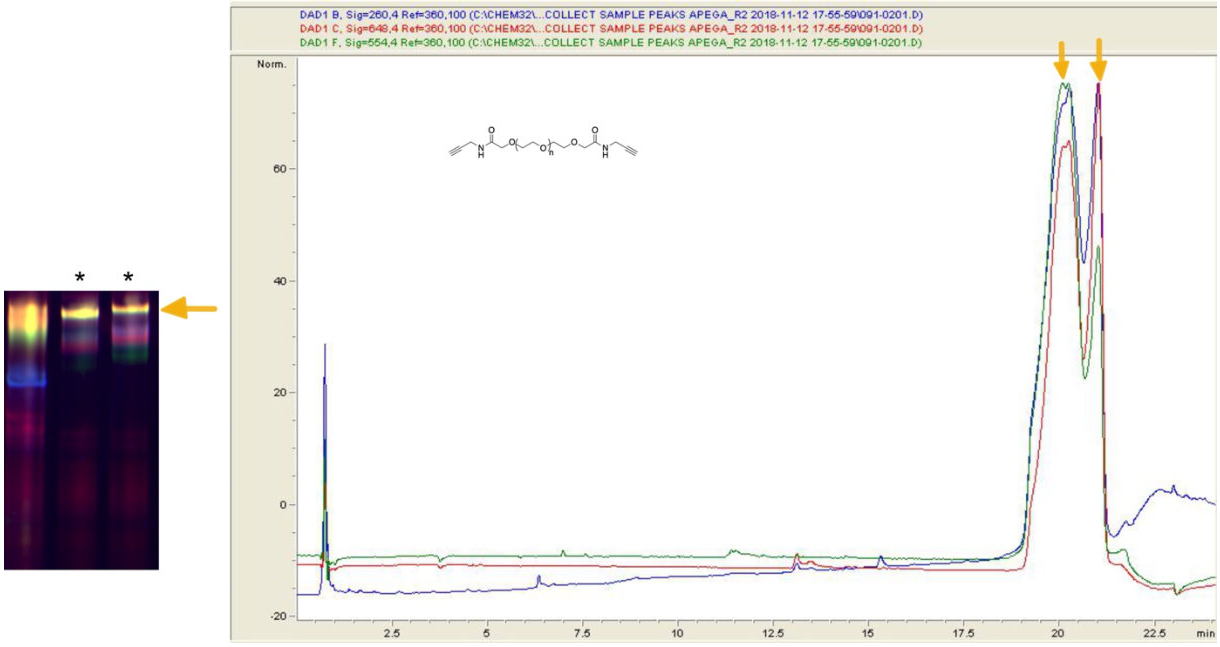
## 5.3 HPLC chromatograms of all tested reactions and molecules:

### 5.3.1 PEG-N “Figure 1- main text”



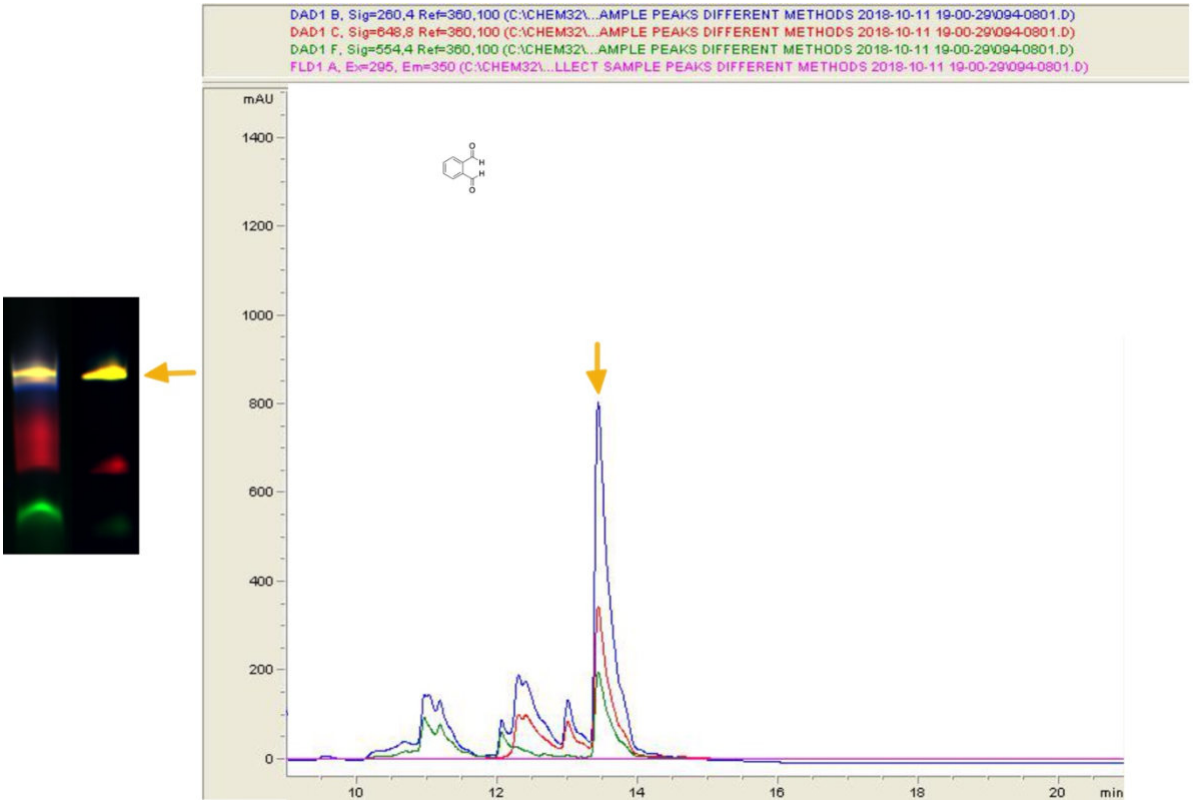

Supporting Figure S6. HPLC analysis of templated CuAAC reaction of PEG-N (gel from Figure 1B to the left) showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peak where all the three signals coincide (marked with the yellow arrow) corresponds to the hetero-DNA-functionalized product.

### 5.3.2 PEG-5000 “Figure 3 A- main text”



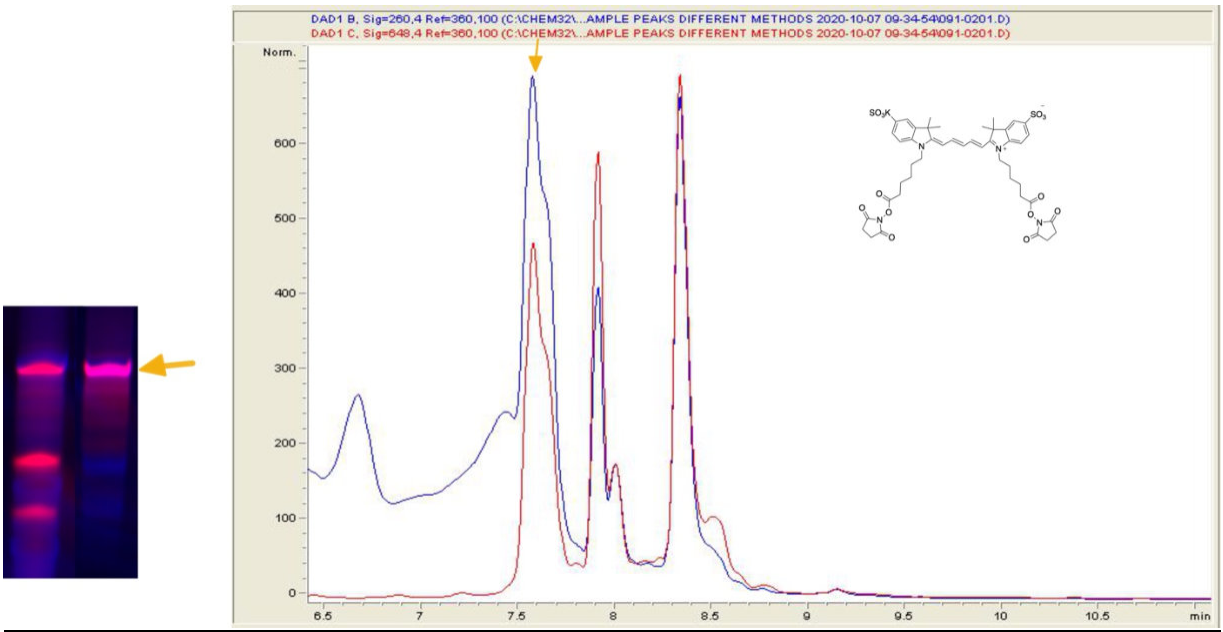

Supporting Figure S7. HPLC trace of Templated CuAAC reaction of PEG-5000 molecule (gel from Figure 3A to the left) showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peaks where all the three signals coincide (marked with the yellow arrow) correspond to the hetero-DNA-functionalized product.

### 5.3.3 Phthaldialdehyde “Figure 3 B- main text”



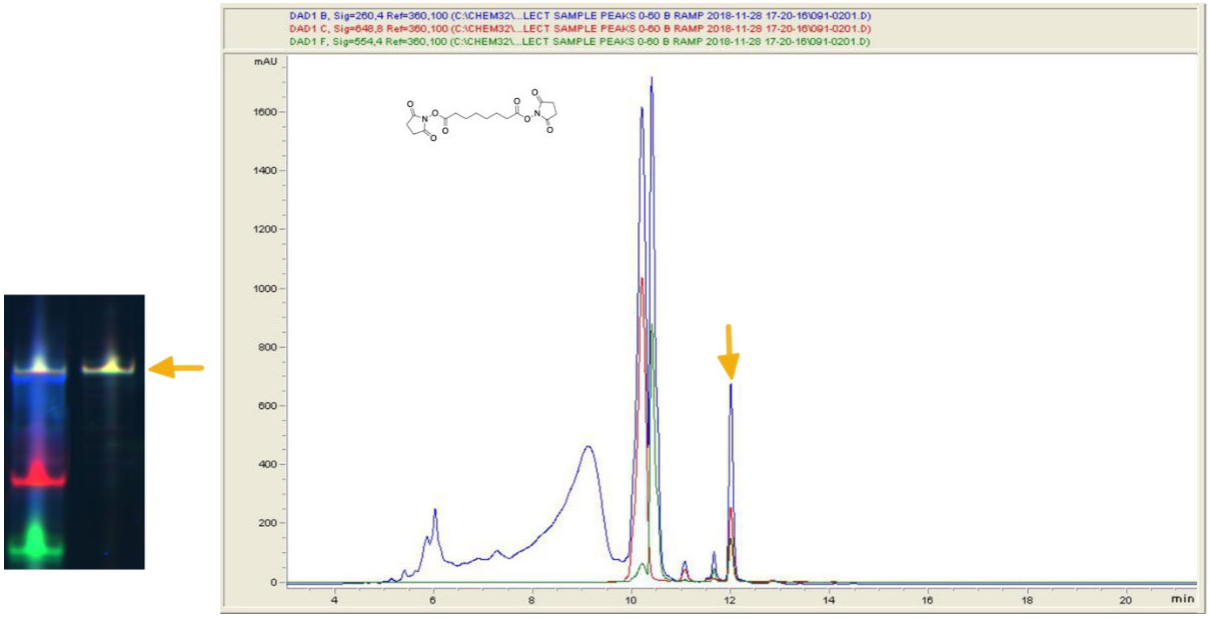

Supporting Figure S8. HPLC trace of templated reductive amination reaction of pthaldialdehyde (gel from Figure 3B to the left) showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peak where all the three signals coincide (marked with the yellow arrow) corresponds to the hetero-DNA-functionalized product.

### 5.3.4 Sulfo-Cyanine5 bis-NHS ester “Figure 3 C- main text”:



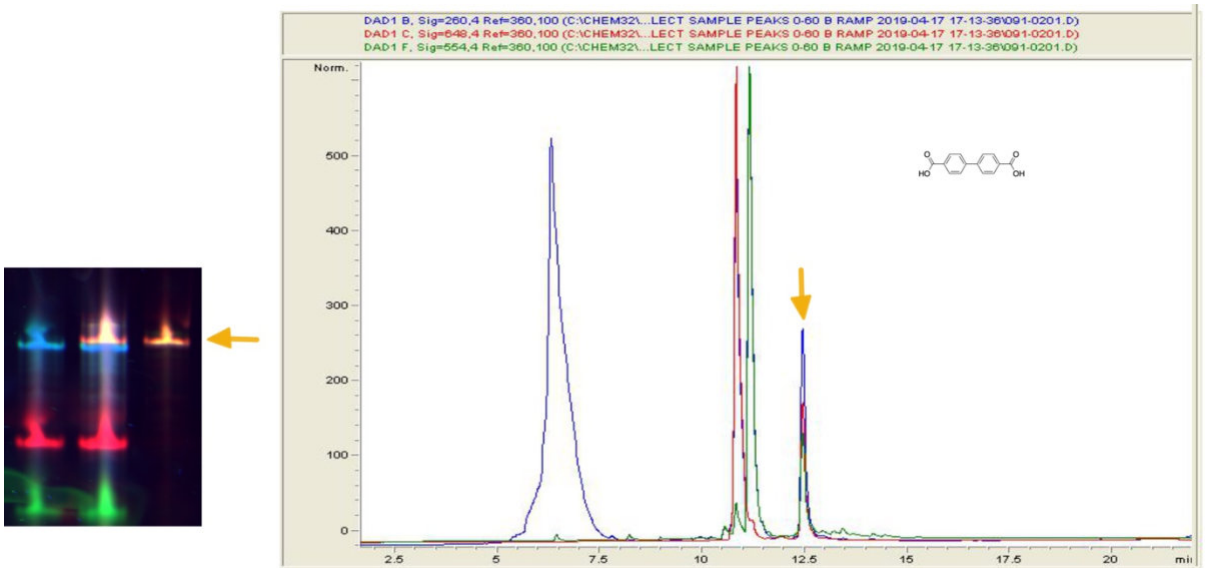

Supporting Figure S9. HPLC trace of templated amide bond formation reaction of Sulfo-Cyanine5 bis-NHS ester (gel from Figure 3C to the left) Showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peak where all the three signals coincide (marked with the yellow arrow) corresponds to the hetero-DNA-functionalized product.

### 5.3.5 DSS "Figure 3 D- main text":



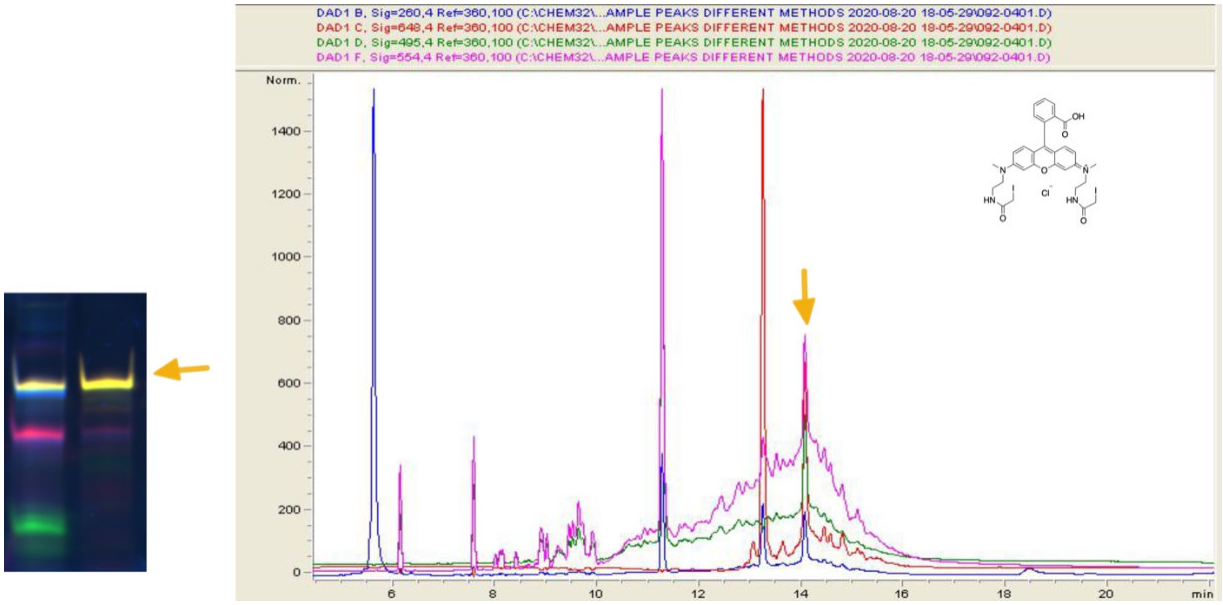

Supporting Figure S10. HPLC trace of templated amide bond formation reaction of DSS molecule (gel from Figure 3D to the left) Showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peak where all the three signals coincide (marked with the yellow arrow) corresponds to the hetero-DNA-functionalized product.

### 5.3.6 Biphenyl-4,4′-dicarboxylic acid "Figure 3 E- main text":

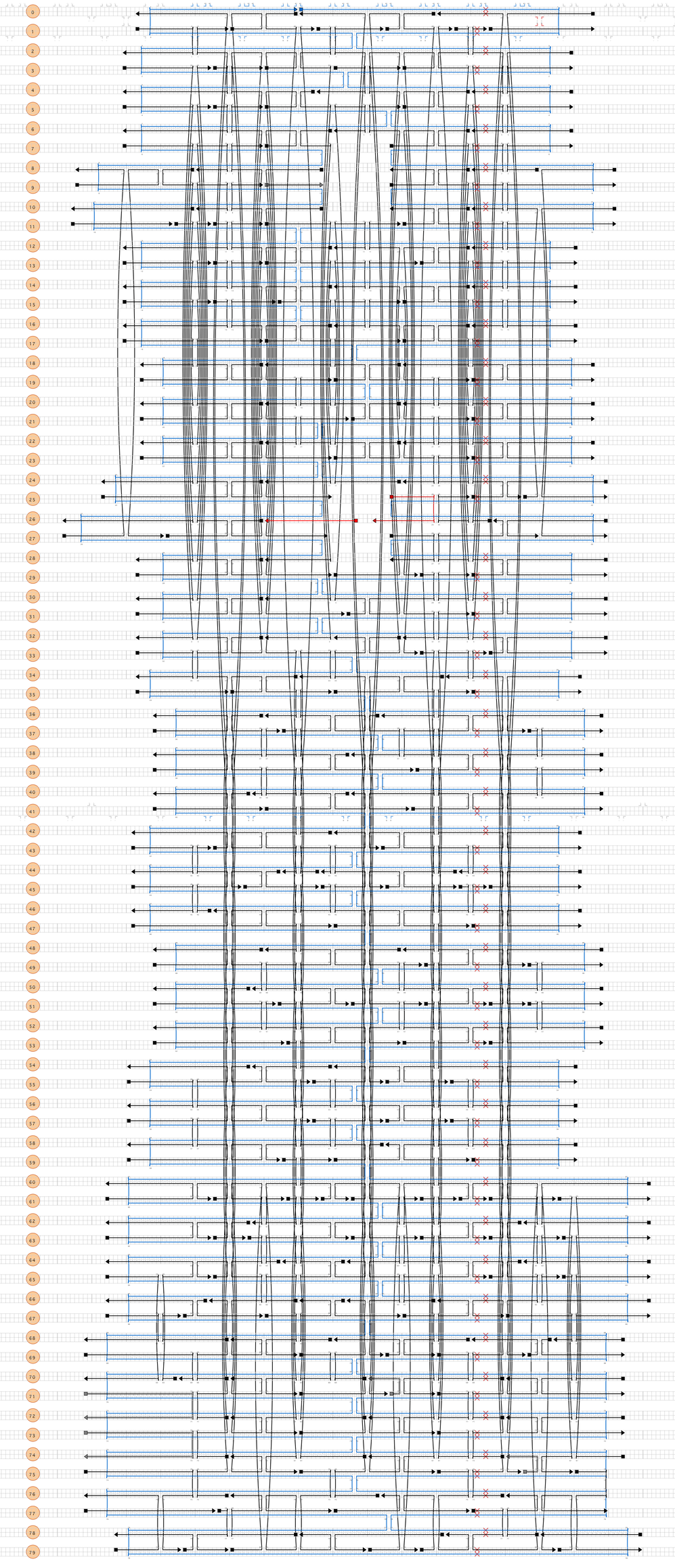



Supporting Figure S11. HPLC trace of templated amide bond formation reaction of Biphenyl-4,4′-dicarboxylicacid molecule (gel from Figure 3E to the left) showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peak where all the three signals coincide (marked with the yellow arrow) corresponds to the hetero-DNA-functionalized product.

5.3.7 N,N'-bis[2(iodoacetamido)ethyl]-N,N'-dimethylrhodamine dihydroiodide "Figure 3 F-main text":

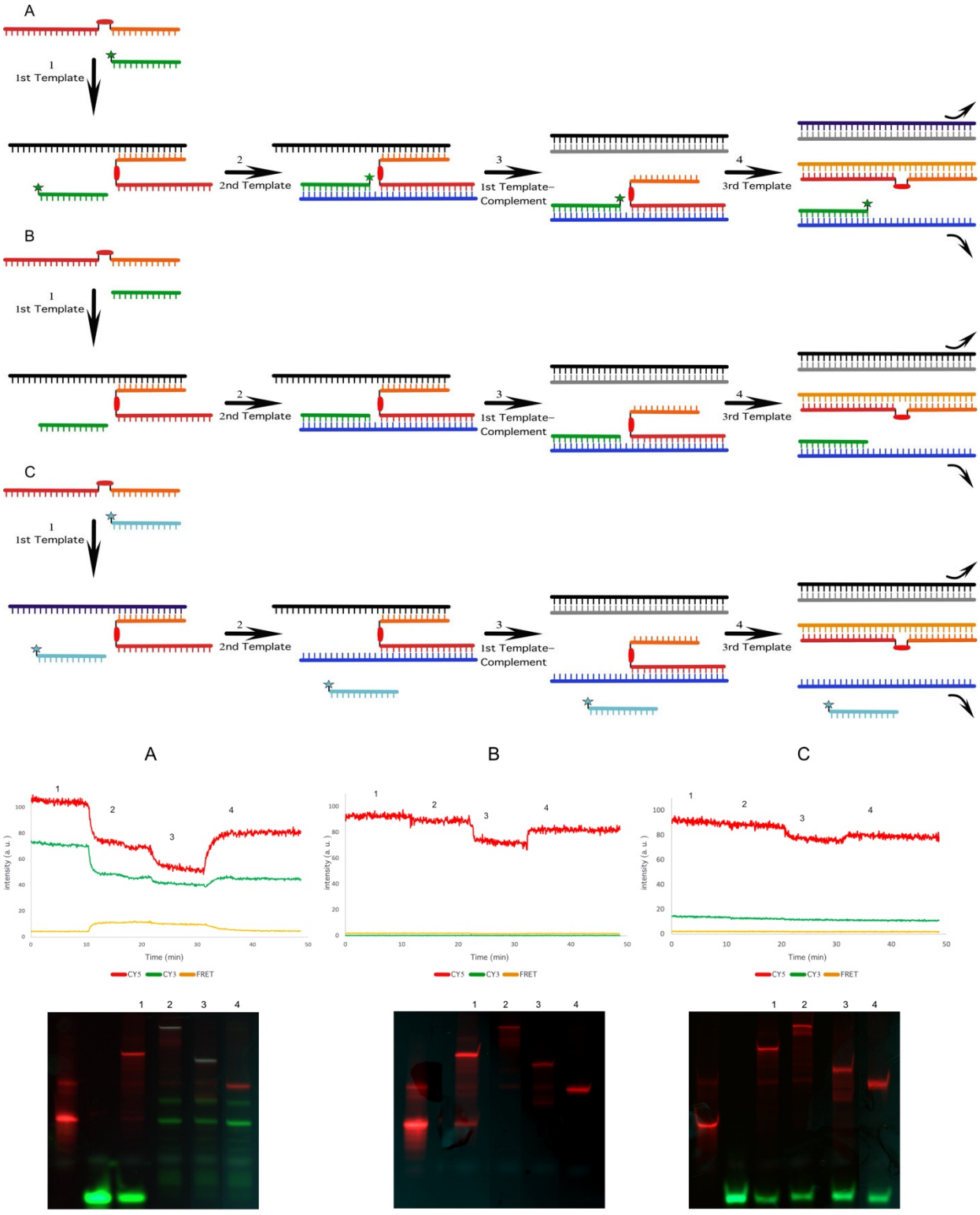



Supporting Figure S12. HPLC trace of templated amide bond formation reaction of N,N'-Bis[2 (iodoacetamido)ethyl]-N,N'-dimethylrhodamine dihydroiodide (gel from Figure 3F to the left) showing the 260 nm absorption of DNA in blue, 648 nm Cy5 fluorescence in green and 554 nm Cy3 fluorescence in red. The peak where all the three signals coincide (marked with the yellow arrow) corresponds to the hetero-DNA-functionalized product.



Supporting Figure S13. DNA origami design. CaDNAno[2] image of the DNA origami structure displaying scaffold (blue), staple oligonucleotides (black) and oligo adapters conjugated to the Cy5 fluorophore (red). The hetero-functionalized DNA-Cy5 hybrid bridges a gap in the structure: it is held in place by hybridization of the two conjugated DNA strands to scaffold domains on either side.

## 5.5 Programmable assembly of hetero-Cy5 – Controls:




Supporting Figure S14. Hybridization reactions demonstrating programmed control of a hetero-DNA-Cy5 hybrid by means of the two oligonucleotide adapters. Top: reaction schemes. Bottom: intensity trajectories of Cy5 (red) and Cy3 (green) fluorescence and Cy3-Cy5 FRET (yellow); merged-color image of a 10% native PAGE gel constructed from Cy5 (red), Cy3 (green), and Cy3-Cy5 FRET (cyan) channels for each assembly. Interval between steps: 10 min. A) As Figure 5. B) As Figure 5 but with Cy3 fluorophore omitted. C) As Figure 5 but with random (non-complementary) sequence for Cy3-modified oligo.

6- Oligo Sequences:

- "Figure 1 and 2 - main text": Oligos were purchased from IDT

1- /5Cy5/ATCGGATGGATTATTTACATTAAAAGGGACATTCTG/3AzideN/
2- /5AzideN/CAACAGAGATAGAAC/3Cy3Sp/
3- TCCTGTTCTATCTCTGTTGCCCAGAATGTCCCTTTTAATGTAAATAATCCATCCGATTCCT

- "Figure 3 A - main text": Oligos were purchased from IDT

1- /5Cy5/ATCGGATGGATTATTTACATTAAAAGGGACATTCTG/3AzideN/
2- /5AzideN/CAACAGAGATAGAAC/3Cy3Sp/
3- TCCTGTTCTATCTCTGTTGCCAGAATGTCCCTTTTAATGTAAATAATCCATCCGATTCCT

- "Figure 3 B - main text": Oligos were purchased from IDT

1- /5Cy5/CACCGCTGGTAGCGGTGAGTATTTGGTATCTGCGCTCTGC/3AmMO/
2- /5AmMC6/GAAGCCAGATCCGGCAAACAAAC/3Cy3Sp/
3- TCTGTTTGTTTGCCGGATCTGGCTTCCGCAGAGCGCAGATACCAAATACTCACCGCTACCAGCGGTGT

- "Figure 3 C - main text": Oligos were purchased from Biomers

1- CTCACCGGAAAGAACGGATAACTTTTT/3AmMC3/
2- /5AmMC3/TTTTTTTTTTCCTGATTATCAG
3- TACACTCTGATAATCAGGAAAAAAAAAACCAAAAAGTTATCCGTTCTTTCCGGTGAG

- "Figure 3 D - main text": Oligos were purchased from IDT

1- /5Cy5/CACCGCTGGTAGCGGTGAGTATTTGGTATCTGCGCTCTGC/3AmMO/
2- /5AmMC6/GAAGCCAGATCCGGCAAACAAAC/3Cy3Sp/
3- TCTGTTTGTTTGCCGGATCTGGCTTCCCGCAGAGCGCAGATACCAAATACTCACCGCTACCAGCGGTGT

- "Figure 3 E - main text": Oligos were purchased from IDT

1- /5Cy5/AACCATCGCCTTTAATTGTATCGG/3AmMO/
2- /5AmMC6/ATGGATTATTTACATT/3Cy3Sp/
3- TCCTAATGTAAATAATCCATGACCGATACAATTAAAGGCGATGGTTTCCT

- "Figure 3 F - main text": Oligos were purchased from IDT

1- /5Cy5/CACCGCTGGTAGCGGTGAGTATTTGGTATCTGCGCTCTGC/3ThioMC6/
2- /5ThioMC6/GAAGCCAGATCCGGCAAACAAAC/3Cy3Sp/
3- TCTGTTTGTTTGCCGGATCTGGCTTCCCGCAGAGCGCAGATACCAAATACTCACCGCTACCAGCGGTGT

- Hetero-DNA-Cy5 hybrid programmable assembly (Figure 6- main text): Templates were purchased from Biomers, other oligos from IDT

- Figure 4- main text, and Supporting Figure S5& S6 A:

b) 1st template:
TACAACTTATCAAAAAGAGTATTGACTTAAAGTCTACAAAAAGTTATCCGT
TCTTTCCGGTGAG
c) 2nd template: CTGATAATCAGGAAAAAAAAAACCGGGTTGGACTCAA
d) 1st template complement:
CTCACCGGAAAGAACGGATAACTTTTTGTAGACTTTAAGTCAATACTCTTT
TTGATAAGTTGT
e) Hetero-DNA-Cy5 Hybrid complement:
TACACTCTGATAATCAGGAAAAAAAAAACCAAAAAGTTATCCGTTCTTTC
CGGTGAG
f) 3' Cy3-modified oligo:
TTGAGTCCAACCCGG/3Cy3Sp/

- SI 5.5.1 Supporting Figure S6 B (1st control):

g) TTGAGTCCAACCCGG

- SI 5.5.2 Supporting Figure S6 C (2nd control):

h) CAACAGAGATAGAAC/3Cy3Sp/

- Origami staples: were purchased from IDT

| Start | | End | | Sequence |
|---|---|---|---|---|
| 0 | [236] | 41 | [238] | TACACTCAAGAGTCCACTACAGTCAAATCACCATCAATTACACT |
| 0 | [167] | 44 | [164] | GGGCGATGAAGCACTAATTTAATGAAAACTTTTAAT |
| 0 | [199] | 43 | [186] | TCCAACGTGCCCGAGACCGGAGAGGGTAGATTTGC |
| 1 | [172] | 32 | [160] | GGAAAGCCCCCGGGGCGCTGCGCCAATTACCTGAGC |
| 1 | [130] | 2 | [127] | TACACTCAAGTTTTTTGGGCGAACGTGGCGTACACT |
| 1 | [152] | 41 | [159] | GTGCCGTAGCCCACTATAAATAAG |
| 1 | [212] | 1 | [236] | GTTGTTCCAGTTTGGAATACACT |
| 1 | [204] | 31 | [207] | GTTGTCCGAAATACGCTGGTGTAATGGGGGGGACGA |
| 1 | [188] | 41 | [193] | AATACAAAGGGCAAAGATTCAA |
| 2 | [231] | 43 | [233] | TACACTATCCTGTTTGACAGGTCATCCGTTCTATAAAAATTTTTAGTACACT |
| 3 | [160] | 37 | [163] | GGGCGCTAATTTAGAGTAACAATTACTATATGTCTG |
| 3 | [192] | 33 | [195] | AGCGGTCCCGGCAAAACATT |
| 3 | [148] | 4 | [127] | AGCGACCACACCCGCCGCGCTTAATTACACT |
| 3 | [176] | 4 | [172] | GCAGAGAGCCTGAAGTGTAG |
| 3 | [127] | 32 | [130] | TACACTAGAAAGGAAGGGAACAAACATTACACT |
| 4 | [171] | 30 | [160] | CGGTAGCACGTAGCCAGAAACAATAACG |
| 4 | [207] | 29 | [207] | GCTGATTGGGGCGCCACACCGCTTGGGAAGGG |
| 4 | [231] | 3 | [231] | TACACTCCAGTGAGACGAGCAGGCGAAATACACT |
| 5 | [127] | 30 | [130] | TACACTGCGCCGCTACAGGTTGAATACTACACT |
| 5 | [148] | 6 | [127] | GTACTTAAAGGGATTTTAGACAGGATACACT |
| 5 | [192] | 32 | [192] | TGCGTATTCCCTTCACCAGTTTGAATAGGTCA |

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|---|---|---|---|---|
| 5 | [160] | 31 | [178] | CTTTGACGCACGCTGCGAATTATTCATTTATCGTA |
| 6 | [207] | 26 | [213] | CAACGCGCTCCAGTCGGATGTGCTCGCCAGGGTTTTCCCAGGT |
| 6 | [175] | 28 | [160] | AGCGGGAGAGTGAGCCCCAGAAATAAAGAAAT |
| 6 | [231] | 5 | [231] | TACACTCTGCATTAATGTTTTCTTTTCATACACT |
| 7 | [127] | 28 | [130] | TACACTACGGTACGCCAGATTTAACGTTACACT |
| 7 | [160] | 29 | [175] | TTATAATCCTAAACAGCTTTTACATCGGGATT |
| 7 | [189] | 29 | [195] | ACTGCCCGCTTGGGGAGAGCAAC |
| 8 | [223] | 7 | [231] | GAGTGAGCTGTCGTGCCAGTACACT |
| 8 | [241] | 27 | [239] | TACACTTGGGGTGCCTAATGTTGTAAAACGACTACACT |
| 8 | [173] | 27 | [174] | GCCACCGAGTAAAATTTGCACGTAAAAC? |
| 8 | [143] | 26 | [113] | CAAATTAATAACATCAAATATAATCCTGATTGTTTGGATTATATACACT |
| 8 | [207] | 25 | [207] | CATTAATTCACAACATCGCCACGGCAATCGGC |
| 9 | [189] | 8 | [189] | TCACAATTCCAGCGTTGCGCTC |
| 9 | [116] | 27 | [136] | TACACTTTCTTTGATTAGTAACCGTTGTATGGAAGGGT |
| 9 | [160] | 9 | [173] | AACTCAAACTATCG |
| 10 | [241] | 25 | [239] | TACACTTTCGTAATCATGGATGTTTACCAGTCTACACT |
| 10 | [207] | 23 | [207] | GTGTGAAACCTCACAGCGTGGTGATCTGCTCA |
| 10 | [143] | 10 | [115] | CCGCCAGCCATTGCAACAGGAAAATACACT |
| 10 | [173] | 25 | [175] | GCCTTGCTGGTAATGAATTATCATCATA?? |
| 11 | [192] | 10 | [189] | GTGAGCCTTTGTTATCCGC |
| 11 | [115] | 11 | [138] | TACACTACGCTCATGGAAATACCTA |
| 11 | [148] | 12 | [127] | GCTCATTCACCAGTCACACGACCAGTACACT |
| 11 | [139] | 24 | [122] | CATTTAAAGTTTGAGTAACATTATTACACT |
| 11 | [160] | 24 | [160] | GAAATGGACACGCGTGGACAATCCTTTGCCCG |
| 12 | [175] | 21 | [179] | TCTGCCAGGGTGCCCCTGAAGAGCAGATTTGAAGGG |
| 12 | [232] | 11 | [241] | TACACTGTGCTGCGGCCTCCCCGGGTACCGAGCTCGAATACACT |
| 12 | [207] | 21 | [207] | GGCGGGCCGTCACTGCCCCGTAAATGCCGTTC |
| 13 | [160] | 23 | [175] | ATAGAACCTTATTTACACAACTCGTATTAGCA |
| 13 | [127] | 22 | [131] | TACACTTAATAAAAGGGACATTTAGAATACACT |
| 13 | [196] | 24 | [192] | CAGTGTTTTCACCTTAAATTAGGGATAG |
| 13 | [148] | 14 | [127] | TGGCGTAAGAATACGTGGCACAGACTACACT |
| 14 | [175] | 19 | [175] | GCGGTGCCCCTGCGGCGTTGGCAAAAACCCTC |
| 14 | [207] | 19 | [207] | AACGGCATCTCGTCATCCAGAGCAAACGTCAG |
| 14 | [232] | 13 | [232] | TACACTTGTGTTCAGCATGCACTCTGTGTACACT |
| 15 | [127] | 20 | [131] | TACACTAATATTTTTGAATAAGGTTATTACACT |
| 15 | [163] | 22 | [160] | GCGAACTTCTGACCAACTAATCGTCAATA |
| 15 | [192] | 22 | [192] | TTTCTTTGCAGATGCCATGCTGATAAAAGCCG |
| 15 | [148] | 16 | [127] | ATTAATCGCCATTAAAAATACCGAATACACT |
| 16 | [207] | 18 | [192] | CCGCCGGGTGTCCAGCGCACCGTCGGTGGTGC |
| 16 | [232] | 15 | [232] | TACACTGGCGCTTTCGCCCTTACACTGGTACACT |
| 16 | [175] | 18 | [160] | ACTGTTGCTCAGTATTGCAACAGTGCCACGCT |
| 17 | [127] | 18 | [131] | TACACTCGAACCACCAGCATGAAAAATTACACT |
| 17 | [192] | 20 | [192] | GCTGGAGGCGCGGTTGACTTGTAGCATCCTCA |
| 17 | [160] | 20 | [160] | TGAGGCGGCTGATAGCCAAATATCATCAACAG |
| 18 | [236] | 19 | [236] | TACACTCAACCGCAAGAATGCCCTGGTCTGGTCAGCAGTACACT |
| 18 | [191] | 15 | [191] | CATCCCACCGTGCCGGCGGTATGAGGTAAAGG |
| 18 | [159] | 15 | [162] | GAGAGCCACTGAACCTCCTAAAACGTCTTTAATGC |

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|---|---|---|---|---|
| 19 | [131] | 17 | [159] | TACACTCTAAAGCATCACCTTGGCAGCAAAGAAGATAAAACAGAGG |
| 19 | [176] | 17 | [191] | AATCAATAGCACGCCTAACACACCAGCTTACG |
| 19 | [208] | 17 | [232] | CGTGGTGAACGGCAATCAGCGGGGTCATTGCATACACT |
| 20 | [236] | 21 | [236] | TACACTGTCTCGTCGCTGGCAGCGCGGTCCGTTTTTTCTACACT |
| 20 | [159] | 13 | [159] | TTGAAAGGAGCACTAACTGAAAGCCAACAGAG |
| 20 | [191] | 13 | [195] | TAACGGAAGTTAAACGGGGTTACCGACGATCCAGCG |
| 21 | [180] | 16 | [176] | TAAATCTGGTCATGGTAATGGCCGGGTC |
| 21 | [208] | 16 | [208] | CGGCAAACCTCCGGAAACATCACTCAAT |
| 21 | [131] | 15 | [147] | TACACTCTAAAATATCTTTAGGAATTGAGGGGCT |
| 22 | [191] | 11 | [191] | CACAGGCGGGATCAAAGGTCATACTCGCGTCC |
| 22 | [159] | 11 | [159] | GATAATACACAATTCGATTGGCAGAATCGTCT |
| 22 | [236] | 23 | [236] | TACACTTGTGTACATCGACATACCAGCAGTTGGGCGGTTACACT |
| 23 | [208] | 14 | [208] | TTTGCCGAAAAAATGCGCCTGAATCGTT |
| 23 | [131] | 13 | [147] | TACACTGTATTAGACTTTACAAATTTGAGGATTC |
| 23 | [176] | 14 | [176] | GAAACAGCGCCTTTAGCTGCATCATGCAGCCA |
| 24 | [191] | 12 | [176] | CTCTCACGGAAAAAGACCTGTTCTCGGGGGTT |
| 24 | [239] | 25 | [219] | TACACTCCGGAATTTGTGAGAGATAGAACAG |
| 24 | [159] | 9 | [159] | AACGTTATAAGGAGCGATCCAGAAAGTAGAAG |
| 25 | [220] | 9 | [241] | CGCCTCATAGCTGGAAGCATAAAGTGTAAAGCCTACACT |
| 25 | [208] | 12 | [208] | GAAACGTCTTTCTCTTGAGGAAGAATGC |
| 25 | [122] | 11 | [147] | TACACTCATTTTGCGGAACAAAGAAACCACCAGTAATTTTATGAC |
| 25 | [189] | 26 | [185] | CTCACCGGAAAGAACGGATAACTTTTT |
| 26 | [159] | 7 | [159] | ATGATGGCCAAAATTAGAGTCTGTAAGTGTTT |
| 26 | [212] | 10 | [208] | GGAGCACGAGCCGTTTCCT |
| 26 | [181] | 26 | [160] | TTTTTTTTTTCCTGATTATCAG |
| 26 | [239] | 27 | [223] | TACACTGGCCAGTGCCAAGCTTTCAGAGTCACGAC |
| 27 | [113] | 8 | [116] | TACACTCTTCTGAATAAGCAATACTACACT |
| 27 | [137] | 10 | [144] | TAGAACCTACCATATAATTCATCCTTGCCTGCAATATTA |
| 27 | [189] | 28 | [189] | AAGTTGGGTAAGCAAGGCGATT |
| 28 | [159] | 5 | [159] | TGCGTAGAAACAGTACGAGGCCGATATGGTTG |
| 28 | [239] | 29 | [239] | TACACTATTACGCCAGCTGGCGTGCGGGCCTCTTCGCTTACACT |
| 29 | [176] | 5 | [191] | CGCCATTCAGGCTGCGGCGTCGTTTTTCCGTT |
| 29 | [130] | 8 | [144] | TACACTCAGATGAATATACAGTTTTTCAGGATCCTGAGCCATCACG |
| 29 | [208] | 8 | [208] | CGATCGGAAAGGGGGGAAACCTAACTCA |
| 29 | [196] | 3 | [191] | TGTTCTGGTGCCGGAAACCAGCATCTGCCGCCTGGCTTGCAGCA |
| 30 | [239] | 31 | [239] | TACACTTCGCACTCCAGCCAGCATCGGCCTCAGGAAGATACACT |
| 30 | [159] | 3 | [159] | GATTCGCCGCAGAGGCGCGTAACCAAAGGAGC |
| 31 | [179] | 6 | [176] | ACCGTGGCAAAGCTAACGTGCAGAATCAG |
| 31 | [130] | 5 | [147] | TACACTCAAGTTACAAAATCGCTGATTGCTGCGC |
| 31 | [208] | 6 | [208] | CGACAGTTTTCCGGGGGTGGTAATCGGC |
| 32 | [159] | 40 | [157] | AAAAGAAGATTACATTCTTGACGGAACGCGAGGTT |
| 32 | [239] | 33 | [239] | TACACTTGGGAACAAACGGCGGCCCGTCGGATTCTCCGTACACT |
| 32 | [191] | 39 | [194] | CGTTGGTGTTCATCAATCCCTTATTTACTATTTTT |
| 33 | [130] | 34 | [130] | TACACTCAAGAAAAGAGTGAATAACTACACT |
| 33 | [212] | 4 | [208] | ACAAATTGACCTTGCCCCGGCAACA |
| 33 | [196] | 48 | [192] | AAATGTAAAACTTCATATGTTTAACATCAGCTATATTCGCAAAT |
| 34 | [201] | 36 | [187] | CGTCTGGCCTATTAAATTCGTTAATATTTTG |

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|---|---|---|---|---|
| 34 | [233] | 37 | [220] | TACACTATAGGAACGCCATCAGAA |
| 34 | [167] | 36 | [160] | AACAGTACTTAATTTTTAGATTAA |
| 35 | [130] | 35 | [151] | TACACTCTTGCTTCTGTAAATCGTC |
| 35 | [208] | 35 | [233] | ATCAGCTCATTTTTTAACCATACACT |
| 35 | [176] | 45 | [187] | ATCCTTGAAAATTCGCTCCTGTAGCCGGTCAAAGCATGCTGGCA |
| 35 | [152] | 45 | [154] | GCTATTAAATAAATCAATCATAGGTAAATGCTAAA |
| 36 | [159] | 50 | [157] | GACGCTGAAAGAAAAACTAATGCAAAACCAAGTAC |
| 36 | [238] | 47 | [233] | TACACTGGAAGATTGTATAAGCAAAGAGCTGAAAAGGTTACACT |
| 36 | [186] | 57 | [187] | TTAACCTGTTTCAATAAATAGCGTGTCGTACGCGTGTTT |
| 37 | [134] | 3 | [147] | TACACTTGAATTTATCAAAATATATGTCAAAATTAATGATGAAAGAA |
| 37 | [164] | 48 | [160] | AGAGATGTTCAGTAATATCCAATAATCG |
| 37 | [221] | 45 | [233] | AAGAAGAGAATTAAAGCCTCAGAGTACACT |
| 38 | [179] | 1 | [187] | TTGGTATTTTAGAAAAAGGGCCCTATCAAAAG |
| 38 | [238] | 37 | [238] | TACACTCTGGAGCAAACCCCCAAAAACATACACT |
| 39 | [134] | 1 | [151] | TACACTTCGCAAGACAAAGGGAAAGCCGGGTCGAG |
| 39 | [195] | 49 | [196] | GAGAGCATTATGAAAAGAATTCAACTAAATGGAA |
| 40 | [179] | 0 | [168] | CTTCATAATTACGAAAAACCGTCTATCA |
| 40 | [156] | 53 | [164] | TGAAAAGGGCTTAATGCGTTAGCACCCAGCTACA |
| 40 | [238] | 39 | [238] | TACACTATGATATTCAATGCCTGAGAGTTACACT |
| 41 | [194] | 51 | [196] | AAGGGTTGAGTAATAAGCCTTTTTTAATTGTAAGA |
| 41 | [160] | 51 | [162] | AATAAACAAGTATCATATTGAGAACGGGAGGTCCG |
| 41 | [134] | 0 | [130] | TACACTATAAATAAGGCGTCGTGAACCATCACCCAAATTACACT |
| 42 | [233] | 53 | [238] | TACACTAACCCTCATATATCAAAGCGAACCAGACCGGATACACT |
| 42 | [175] | 1 | [171] | GCCTGTTTCCGGAATCTGACCTAAAATC |
| 43 | [129] | 44 | [129] | TACACTAAAGCCAACGCGCCAGTAATAATACACT |
| 43 | [148] | 40 | [134] | CAGTTACCGACCGTGTGTACACT |
| 43 | [187] | 53 | [191] | GGGAGGTGTAGGTGACTTCAA |
| 44 | [163] | 59 | [163] | TTAGAAGTAATTGGAATCATTACCGCACGAGCGCTAAACA |
| 44 | [233] | 51 | [220] | TACACTCATAAAGCTAAATCTTAG |
| 44 | [172] | 34 | [168] | ACATGTTCAAATAGTTATATATCATTTGATTAATGGA |
| 44 | [204] | 34 | [202] | AAAAAATCTACAACGGTAATCGTGAGCGAAATTCG |
| 45 | [188] | 55 | [187] | AGGCCCCTGTAATTTTTTGACTCCTTAGCCAT |
| 45 | [212] | 1 | [211] | GCAACGATGAAAGGCTATTGGTGGTAGT |
| 45 | [155] | 54 | [157] | AGGTAGCAGAGGCAGGCTTATTTTGAAGCAATCCAAAAGC |
| 45 | [129] | 46 | [129] | TACACTGAGAATATAAACTGTTTATCAATACACT |
| 45 | [173] | 35 | [175] | CAGTAAACAACACTACCTTCGATAGCTCCCTTAGA |
| 45 | [205] | 35 | [207] | AATTAGTAGCAACCCCGGTATTGTAAATTTGTTAA |
| 46 | [147] | 38 | [134] | GCGCGTACCGACGATGCAAATCCAATACACT |
| 46 | [233] | 49 | [220] | TACACTGGCATCAATTCTAGTTGA |
| 47 | [129] | 36 | [134] | TACACTCAATAGATAAGTCCTGAACGAAGAGTCAATAGTACACT |
| 47 | [176] | 32 | [176] | TTTACGAGAAACATAGTTTAACCTCCACTTTTATTACGCTTAGATGGG |
| 47 | [208] | 33 | [211] | GGGGCGCTATTTAATGATAATCAAAAATGTA |
| 48 | [238] | 59 | [232] | TACACTAACGAGTAGATTTAGTTTGAAAAACCAAAATATACACT |
| 48 | [159] | 62 | [157] | GCTGTCTTGAGCAAGAATATCAGACGGAATACAGA |
| 48 | [191] | 58 | [188] | GGTCAATACTATCATAGGTA |
| 49 | [197] | 79 | [195] | GTTCCAGAGGGACCCTCGTCATAGTAACACC |
| 49 | [134] | 46 | [148] | TACACTAAGAACGGGTATTGAAC |

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|---|---|---|---|---|
| 49 | [221] | 57 | [232] | TTCTAGCTCAAATCGTCATAAATATACACT |
| 50 | [238] | 49 | [238] | TACACTATATAATGCTGCCAATTCTGCGTACACT |
| 50 | [156] | 63 | [155] | CGCGCGGAGAATTGCCTTTACATAA |
| 51 | [180] | 40 | [180] | GGCGTACCAACGTTTAATTTTCAT |
| 51 | [134] | 43 | [147] | TACACTAATCAGATATAGAATTTTCGATCAA |
| 51 | [163] | 61 | [164] | GTATTAAATAGCAAACTGAACGCAAACGTCCAAA |
| 51 | [221] | 55 | [232] | AGCACAGGTCACTATTATAGTCAGTACACT |
| 51 | [197] | 61 | [195] | GGTACAGTTCATGGATAGCAATAAAACAACA |
| 51 | [212] | 0 | [200] | ATGGCGGTTGTGCAAGGAGCTGATACCGGAGATTAAAGAACGTGGAC |
| 52 | [238] | 51 | [238] | TACACTAGCAAACTCCATTAATTGCTGATACACT |
| 53 | [165] | 64 | [164] | ATTCTTTCCAGTAAGAAACAGAC |
| 53 | [192] | 63 | [195] | ATATCGCGAAGAGGAACAAAAATCTAAATTGGGTTT |
| 53 | [134] | 42 | [129] | TACACTTAGTTGCTATTTTTACAAATTCTTACCAGTATTACACT |
| 53 | [212] | 1 | [203] | GCTTTTTAAATGCAATGCCGAGAAAGGAATTAATGTAGG |
| 54 | [175] | 44 | [173] | ACGAGCGTTTATCCTGCCGACTTGTCGCCATACCA |
| 54 | [156] | 68 | [152] | CTAATTAAAGGTGCAGTAGCAATCACCGGCGCGTTTT |
| 54 | [232] | 69 | [220] | TACACTAAGCAAAGCGGATCCCAAATCACCAGGCGCGCGA |
| 55 | [188] | 69 | [187] | AAATGCCCGAAACCAAATCTAGAGTTTTCTCA |
| 55 | [203] | 45 | [204] | TCTTTTGCTTTAACATTTTTGTAAATATGAGCAA |
| 55 | [128] | 56 | [128] | TACACTCAGCCATATTATAACATAAAAATACACT |
| 55 | [171] | 45 | [172] | TTTTTAAAAATGACTAAGAACTCATCGTACTGTC |
| 56 | [232] | 64 | [220] | TACACTTTCATTGAATCCCGTGAATTAACGA |
| 57 | [128] | 58 | [128] | TACACTCAGGGAAGCGCCCACAAGAATTTACACT |
| 57 | [171] | 47 | [175] | CTGAAGGGTAATTTCATCGAGAACCAATCCATCCTAA |
| 57 | [203] | 47 | [207] | CAATAAAGTTTTGTCATTCCAGATACATTTTTCATTT |
| 57 | [188] | 71 | [188] | AGACGAAAACGATCAAGATGGCTTGTATGCTTT |
| 58 | [187] | 72 | [184] | ATAGCTCAACGGGAACTCTTCATAACCGCAACGGCT |
| 58 | [232] | 62 | [220] | TACACTGCGAGAGGCTTTTGATTCATCCGTT |
| 59 | [176] | 38 | [180] | TAGCTATCCATGTAGAAACAAGCACATGACAAACGACACATAGG |
| 59 | [208] | 45 | [211] | CGACGATACCATTATATAACACTAATAGTAA |
| 59 | [164] | 77 | [175] | ATGATAAGAAAAAGGAACCCCTCCTCAATAGCCCGGAATAGGTG |
| 59 | [128] | 48 | [134] | TACACTGAGTTAAGCCCAATAATAATCCTTATCATTCCTACACT |
| 60 | [249] | 79 | [227] | TACACTCATTCAACTAATGCAGATACACCAC |
| 61 | [123] | 60 | [123] | TACACTGAAACCGAGGAAACGCACAAAGTTACCAGAAGTACACT |
| 61 | [212] | 51 | [211] | GAAAGCAAAAGCTGCGGACATGTTTCGG |
| 61 | [148] | 50 | [134] | ATAAGAGATAACATTAGACGCCAATAGCAAGCATACACT |
| 61 | [173] | 59 | [175] | CATGCCCTTTTAATAGCAA |
| 61 | [228] | 75 | [231] | GAGAAAACAGCTGCTTGCTT |
| 61 | [180] | 51 | [179] | AAGATAATCAGACAAAGAATTTTTATTTGCGA |
| 61 | [165] | 75 | [167] | AGATAATAAGTTATTCTGA |
| 61 | [196] | 75 | [199] | ACATATGACAACAAAAGGAG |
| 61 | [205] | 59 | [207] | CAGTTACGAGGTTACCAGA |
| 62 | [219] | 72 | [216] | GGGACAGGGAGTGCAGCGAA |
| 62 | [249] | 61 | [227] | TACACTGGCTCATTATACCAGTCAGGAAGTT |
| 62 | [156] | 72 | [152] | AAATATAAGCGTCTCACAAAC |
| 63 | [196] | 73 | [199] | AATTGAGGGTAGATATATTC |
| 63 | [229] | 73 | [243] | TGCCACCCTCATAAAGGCCGCTTTTGCTACACT |

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|---|---|---|---|---|
| 63 | [212] | 53 | [211] | CATTCCTCAAAACCCTGAGGATTAGCGA |
| 63 | [123] | 62 | [123] | TACACTAAAGAAACGCAAAGACAAGGTGGCAACATATATACACT |
| 63 | [156] | 70 | [152] | GTTTGGGCGACACGCCAGCACCTCAGAA |
| 63 | [180] | 42 | [176] | AAATGAAACGTCGTTTATGACGAACCTCAATCTTACTAGAAAAA |
| 63 | [148] | 52 | [134] | CGGAAGAGAGAATTTATCCCCTTAAATCAAGATTACACT |
| 64 | [163] | 73 | [167] | AAAAATTTTGTCCTTGATATATACATGG |
| 64 | [219] | 70 | [216] | GAAAAGTTTCCAAGGCACCA |
| 64 | [178] | 54 | [176] | ACCGACTTGAGCAACGCTA |
| 64 | [249] | 63 | [228] | TACACTCAGTGAATAAGGCTTGCCCTGCCTTA |
| 65 | [212] | 44 | [205] | ATTATGCATCAAAAAGATTTTTTAATTAGAGTACCATTTCAACACC |
| 65 | [123] | 70 | [118] | TACACTTAAATATTCACCACCCTCAGATACACT |
| 65 | [229] | 71 | [243] | AACCACTACGATTAAACGGGTAAAATATACACT |
| 65 | [148] | 54 | [128] | TCATTTGCCAGTTACAAAATAAATACACT |
| 66 | [146] | 67 | [159] | ACCCATCGATAGCAGCACC |
| 66 | [178] | 67 | [191] | TTAGAATCAAGAGCCGGAA |
| 66 | [249] | 65 | [228] | TACACTGGACAGATGAACGGTGTACAGAACGT |
| 66 | [167] | 71 | [167] | AAAATCACAATTATCAGCCGCCACTTGACAGG |
| 66 | [199] | 71 | [199] | CTTCATCATGACAAGAGGCAAAAGGACTAAAG |
| 67 | [192] | 69 | [199] | CGAGGCGCCTGCTCCATGACCCCC |
| 67 | [160] | 69 | [167] | GTAATCAGGACTGTAGAACCAGAG |
| 67 | [141] | 66 | [123] | AACATTAGCAAGGCCGGAATACACT |
| 67 | [123] | 68 | [118] | TACACTACGTCACCCATAGCCCCCTTATACACT |
| 67 | [216] | 68 | [227] | AGGGAACCGAACTGACTCGCC |
| 68 | [207] | 66 | [200] | TCCGCGACAGACGGTCTGGCTGAC |
| 68 | [226] | 69 | [243] | TGAAAAGTACAACGGAGATTACACT |
| 68 | [151] | 67 | [140] | CATCGGCATTTTCGGTAATGA |
| 68 | [175] | 66 | [168] | TAGCGTCATAGCGACAGAGCCAGC |
| 68 | [243] | 67 | [249] | TACACTTTGTATCACAACTTTGAAAGATACACT |
| 69 | [188] | 68 | [176] | TCTTTGTTACTTTTTGCCTT |
| 69 | [221] | 68 | [208] | AACTAAATTGTGTCGAAA |
| 69 | [168] | 55 | [170] | CCACCACCCCCTCAGACCGTCACCAGCGCCAAGAT |
| 69 | [118] | 70 | [140] | TACACTTTAGCGTTTGCCATCTTTTCACTCA |
| 69 | [200] | 55 | [202] | AGCGATTAACGAAAGAACCGGATAACGAGTAGAGG |
| 70 | [183] | 66 | [179] | AAACGCCTGGAACACAGGGAA |
| 70 | [215] | 67 | [215] | ACCTAAATACCAAGCATAGGCAATCATA |
| 70 | [151] | 66 | [147] | CCGCCACCTAATCAAACCATT |
| 70 | [243] | 65 | [249] | TACACTCGTAATGCAAAGCTGCTCATTTACACT |
| 70 | [139] | 64 | [123] | GAGCGACGGAAAATTGAGGGAGGGAAGGTACACT |
| 71 | [189] | 70 | [184] | GAGAATACACT |
| 71 | [118] | 72 | [118] | TACACTGCCGCCACCAGAACCACCACCCCTCATTAAAGCCAGAATGGATACACT |
| 71 | [168] | 64 | [179] | AGGTTGAGGCAGGGAGGGTTT |
| 71 | [200] | 57 | [202] | ACTTTTTCATCGGAACTCAACTTTTCTACGTTGTC |
| 72 | [151] | 65 | [147] | AAATAAATAGAGCCGCTTCAACCGTTAT |
| 72 | [243] | 63 | [249] | TACACTGGGATCGTGATTTTAAGAACTTACACT |
| 72 | [215] | 65 | [211] | AGACAGCATGAGGACACCAGATTC |
| 72 | [183] | 57 | [170] | ACATCAGACGATTGGCACAATCAAGTATGTTAACC |
| 73 | [118] | 74 | [118] | TACACTAAGCGCAGTCTCTGAATTTACCCTTGAGTAACAGTGCCCGTATACACT |

| | | | | |
|---|---|---|---|---|
| 73 | [200] | 61 | [204] | GGTCGCTGCGCCGACATATTA |
| 73 | [168] | 63 | [179] | CTTTTGATGATACACGATTACGCATAGA |
| 74 | [183] | 61 | [172] | CCCAGGAGTGTACTGGACTGG |
| 74 | [151] | 63 | [147] | GGTCAGTGCGTTCCAGCATACATAACCA |
| 74 | [215] | 63 | [211] | ATAGTTGAGGCTTGAGAAAAAAAT |
| 74 | [243] | 61 | [249] | TACACTAATTTCTTTTTAGGAATACCATACACT |
| 75 | [232] | 79 | [247] | TCGAGGTGGAAAGGAAAGCCCTCATAGTTTACACT |
| 75 | [118] | 79 | [140] | TACACTTAAACAGTTAATGCCCCCTGCAGCGGGGTATTTT |
| 75 | [168] | 78 | [168] | AACATGAAGGCTGAGAATGTACCGCCGCCACC |
| 75 | [200] | 78 | [202] | CCTTTAATAATTTTTTCAAACTACGTTAGT |
| 75 | [220] | 74 | [216] | ATCATGATACCG |
| 76 | [151] | 61 | [147] | TTAGGATTCTATTTCGATAGCCGAAATA |
| 76 | [186] | 61 | [179] | TCCAAATAAGAAGTATAAATTACCGAAGATT |
| 76 | [215] | 61 | [211] | GAATAATTGTATCGAAAGGAAGTA |
| 77 | [149] | 79 | [151] | TGATCAGAACCGGATAGCA |
| 77 | [208] | 75 | [219] | AACTTTCTCCAGACAACGCCTGTAGCATTTAACGCCAGTTT |
| 77 | [176] | 76 | [187] | TATCACCGTACTCGTAAAATC |
| 77 | [118] | 77 | [148] | TACACTAGGCGGATAAGTGCCGTCGAGAGGGT |
| 78 | [247] | 78 | [224] | TACACTAGCGTAACGATCTAAAGTTTT |
| 78 | [201] | 79 | [183] | AAATGAATTTTCTAGGAGGTTTAGTATAACACTG |
| 78 | [223] | 76 | [216] | GTCGTCTTAACAGTTTGGAATTGC |
| 78 | [167] | 76 | [152] | CTCAGAACCGCCACCCTATAAGTAGAGAAGGA |
| 79 | [152] | 74 | [152] | AGCCCAATGTAAGCAGGAACCTATTTTAACGG |
| 79 | [141] | 78 | [125] | CAGGCCACCCTCAGAGCCATACACT |
| 79 | [228] | 77 | [239] | AGACCAACTAAACAGCGGAGTGAGAATA |
| 79 | [125] | 76 | [118] | TACACTCCACCCTCTTTGCTCAGTACCTACACT |
| 79 | [196] | 77 | [207] | AGTACACGTTGATGGGATTTTGCTAAAC |
| 79 | [184] | 74 | [184] | AGTTTCGTGAGCAACAAAGGCTCCAACCATCG |

## 7- References


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