Inkjet Printing Efficiency
Yield and the Customer Experience

Final Report Presentation: Groups 1&2

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Project Objective and Scope

Objective

- Compare Levels of Printing Efficiency in Different Inkjet Printing Systems
- Gain Insight into Effective Yield of Inkjet Cartridges in Typical Consumer Usage
  - *Consumer usage is Intermittent; testing is usually based upon Continuous usage*

Scope

- Determine Impact on Yield of Intermittent versus Continuous Usage
  - *Measure Continuous Inkjet Cartridge Yields for each black and color cartridge*
  - *Measure Maintenance Ink used during cartridge changes and other servicing*
  - *Determine Intermittent Inkjet Cartridge Yields*
    - Use *SpencerLab* Black/White and Color-only test documents in weighted ratio
    - Print as 2-page documents at a 70-page-per-month rate for 8-week test duration
    - Measure ink usage, adjust for maintenance ink usage, and extrapolate
  - *Calculate impact as Printing Efficiency percentages*

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Some Definitions

Consumer

- *A typical inkjet printer user normally printing mixed, general purpose documents*

Continuous Inkjet Cartridge Yield

- *The average number of prints-per-cartridge through the entire life of a cartridge when printing in 100-print increments, with minimum interventions such as for paper jams, replenishment, computer communication errors, etc. and overnight if necessary*

Intermittent Inkjet Cartridge Yield

- *The average number of prints-per-cartridge through the entire life of a cartridge when printing only one or a few pages at a time, with significant time periods between print jobs*

Effective Yield

- *The actual number of prints-per-cartridge available to the user in intermittent use – the Intermittent Inkjet Cartridge Yield*

Maintenance Ink

- *Ink used for other than page printing, to maintain printer functionality by keeping nozzles clear, removing air bubbles, etc.*

Printing Efficiency

- *The percentage of ink actually used for printing in intermittent use (total available ink minus Maintenance Ink); equal to the ratio of Intermittent to Continuous inkjet cartridge yield*

Intermittent Usage Model

Consumer Intermittent Usage

- Consumers print a wide variety of documents, often with no consistent pattern
  - *They may print photos, web pages with color graphics, and black-only documents one day, only black text a few days later, and some web pages the next day*
- Consumers do not print continuously, start to finish of an ink cartridge
  - *Although some high-end users may print very regularly, it would be highly unusual for any user to print non-stop until a cartridge is depleted*
- Typical consumer printing is intermittent, reflecting everyday starts and stops
  - *Intervals may be fairly short, or may last for days*

An Intermittent Usage Test Model

- We can propose a typical consumer usage profile by assuming
  - *The ratio of black/white to color pages*
  - *The average document length*
  - *The monthly page volume*
- We applied the following estimates
  - *Black/white to color ratio*† *= 2:1*
  - *Document length*† *= 2 pages*
  - *Prints per month* = 70*

†*SpencerLab* estimate; individual user experience may vary

*Estimate based upon analysis of Lyra research, *H1 2004 Bulk Ink Forecast,* including the installed bases of several vendors and involving the full range of home to office users

- Our test model is an estimate, but should allow insight into Effective Yield

Printers and Inkjet Cartridges Tested

GROUP 1 *Four-Color Inkjet Printers* *≤$99 Price Range**	GROUP 2 *Four-Color Inkjet Multi-Functional Printers* *$139-199 Price Range**
HP DeskJet 5740 **HP #96 Black, HP #97 TriColor**	**HP PSC 2355** **HP #94 Black, HP #97 TriColor**
Epson Stylus c86 **High Capacity Black (T043120), Cyan (T044220), Magenta (T044320), Yellow (T044420)**	**Epson Stylus CX6600** **High Capacity Black (T043120), Cyan (T044220), Magenta (T044320), Yellow (T044420)**
Canon PIXMA iP3000 **Black (BCI-3eBK), Cyan (BCI-6C), Magenta (BCI-6M), Yellow (BCI-6Y)**	**Canon MultiPASS MP390** **BCI-24 Black, BCI-24 Color**
Lexmark z816 **High Yield Black (#34), High Yield Color (#35)**	**Dell AIO 962** **High Capacity Black, High Capacity Color**

**At time of testing (June 2005)*

Summary Findings

Effective Yield varies with the Tested Usage Profile

- The consumer's usage profile and the efficiency of the printing system are significant factors in determining Effective Yield
- Intermittent Inkjet Cartridge Yield, more reflective of typical consumer usage, may be very different than Continuous Inkjet Cartridge Yield, the most common method of measurement
- Printing Efficiency varies considerably among vendors

HP printers had the highest average Printing Efficiency

- HP products had the smallest percentage change from Continuous to Intermittent Inkjet Cartridge Yield within both test groups

Summary Findings (continued)

Group 1: HP DeskJet 5740

- Highest Printing Efficiency in its Group
  - *Both HP's Black and Tri-color cartridges had the Highest Printing Efficiency*
  - *Both HP's Black and Tri-color cartridges had the Smallest Yield Change*
    - Lexmark's Black cartridge had Printing Efficiency and Yield Changes comparable to HP's Black cartridge
  - *HP's Black and Tri-color cartridges had the Lowest Total Ink Usage*

Group 2: HP PSC 2355

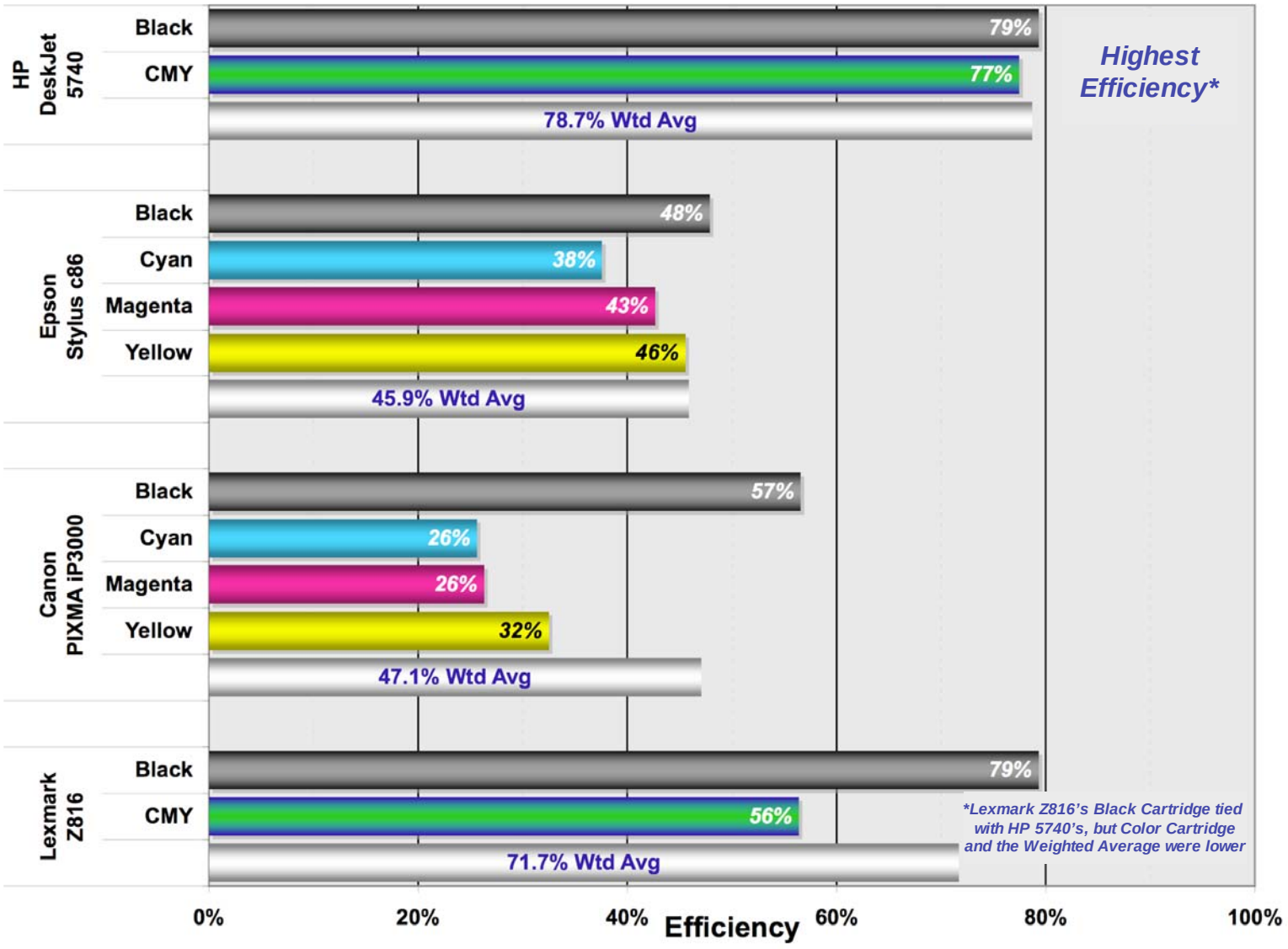
- Highest Printing Efficiency in its Group
  - *Both HP's Black and Tri-color cartridges had the Highest Printing Efficiency*
  - *Both HP's Black and Tri-color cartridges had the Smallest Yield Change*
  - *HP's Black and Tri-Color cartridges had the Lowest Total Ink Usage*

Summary Test Results

Results are summarized in the following graphs

- Printing Efficiency – GROUP 1
- Printing Efficiency – GROUP 2
  - *Each black and color cartridge is represented by a horizontal bar*
  - *Length of the bar represents the Printing Efficiency*
  - *Weighted Average reflects the 2:1 ratio of black to color pages*
- Intermittent *vs.* Continuous Yield Change – GROUP 1
- Intermittent *vs.* Continuous Yield Change – GROUP 2
  - *Each black and color cartridge is represented by a vertical bar*
  - *Total height represents Continuous Inkjet Cartridge Yield*
  - *Darker portion represents Effective Yield*
  - *Percentage difference represents Printing Efficiency*
- Ink Used in One Month of Intermittent Usage — GROUP 1
- Ink Used in One Month of Intermittent Usage — GROUP 2
  - *Usage rate of 70 pages-per-month, as tested*

Printing Efficiency – GROUP 1



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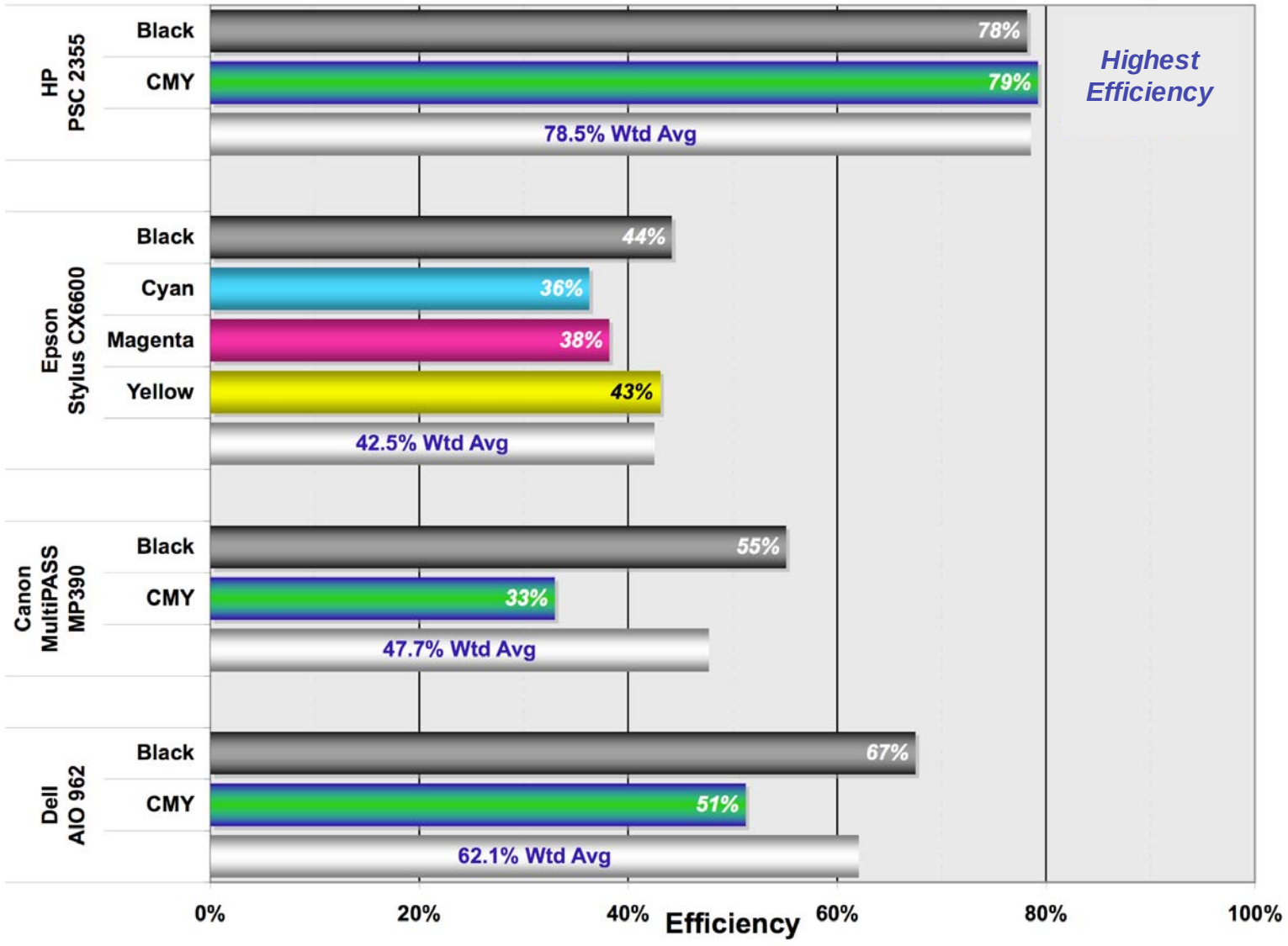
Printing Efficiency – GROUP 2



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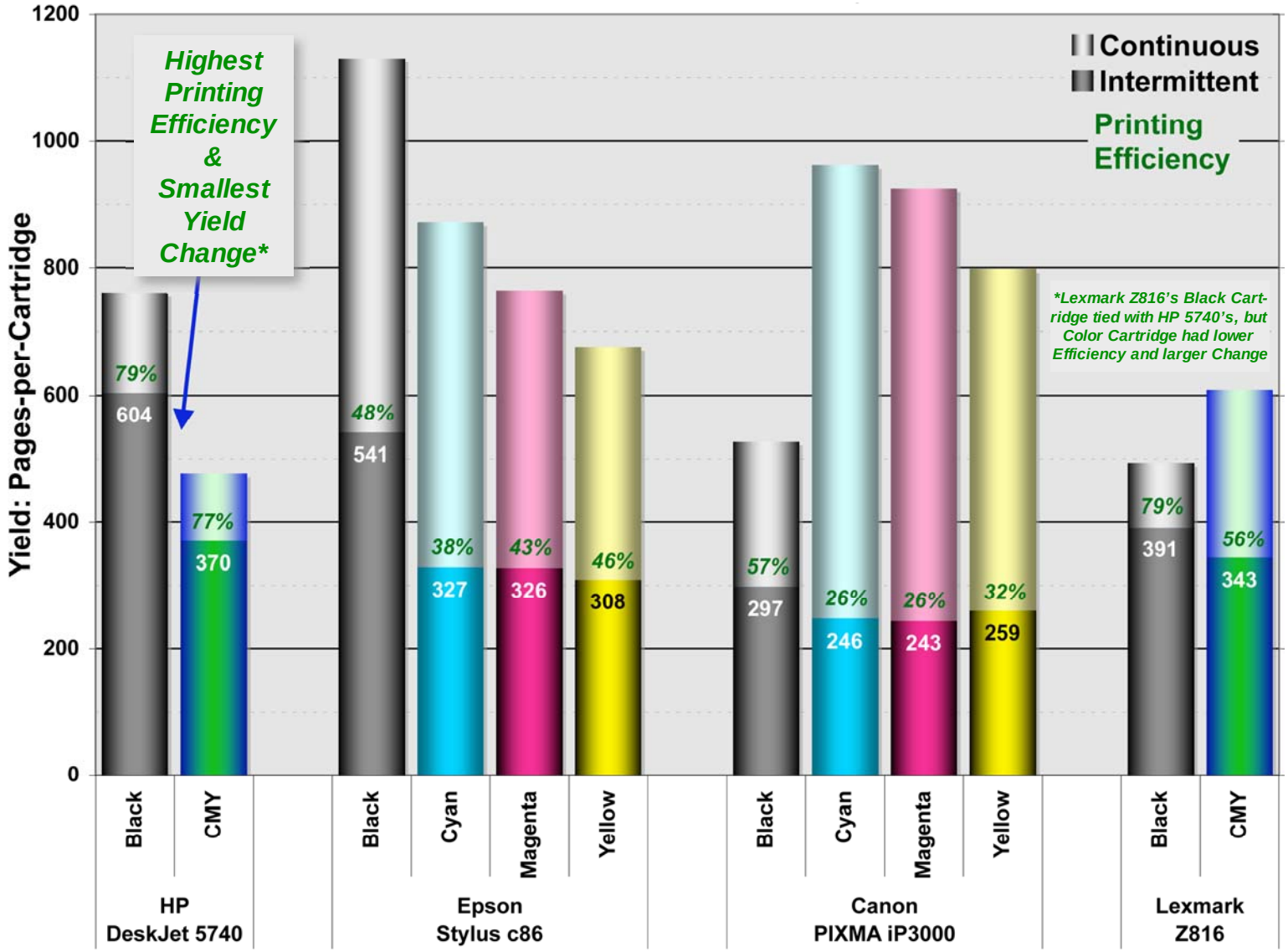
Intermittent *vs.* Continuous Yield Change – GROUP 1



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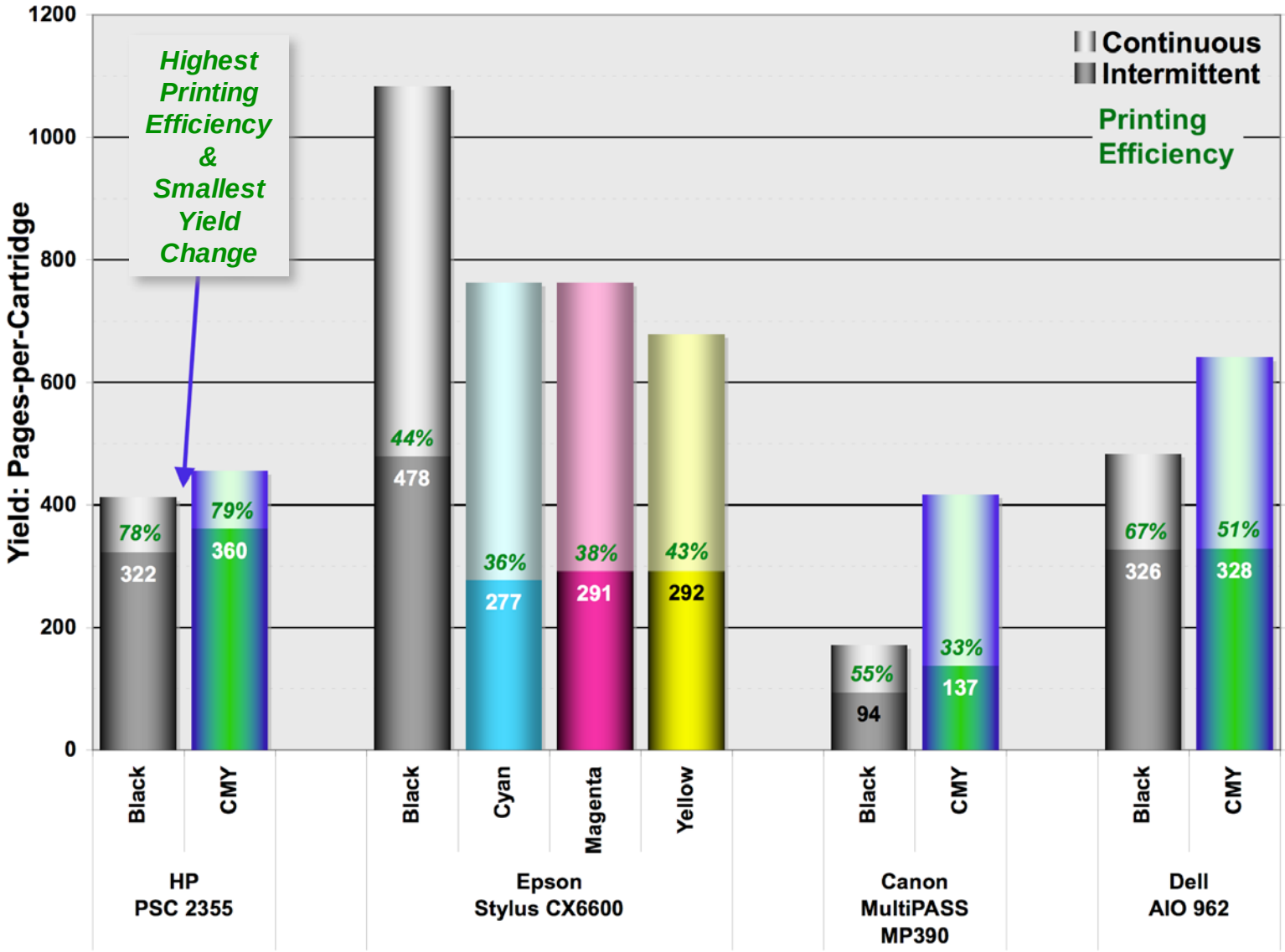
Intermittent *vs.* Continuous Yield Change – GROUP 2



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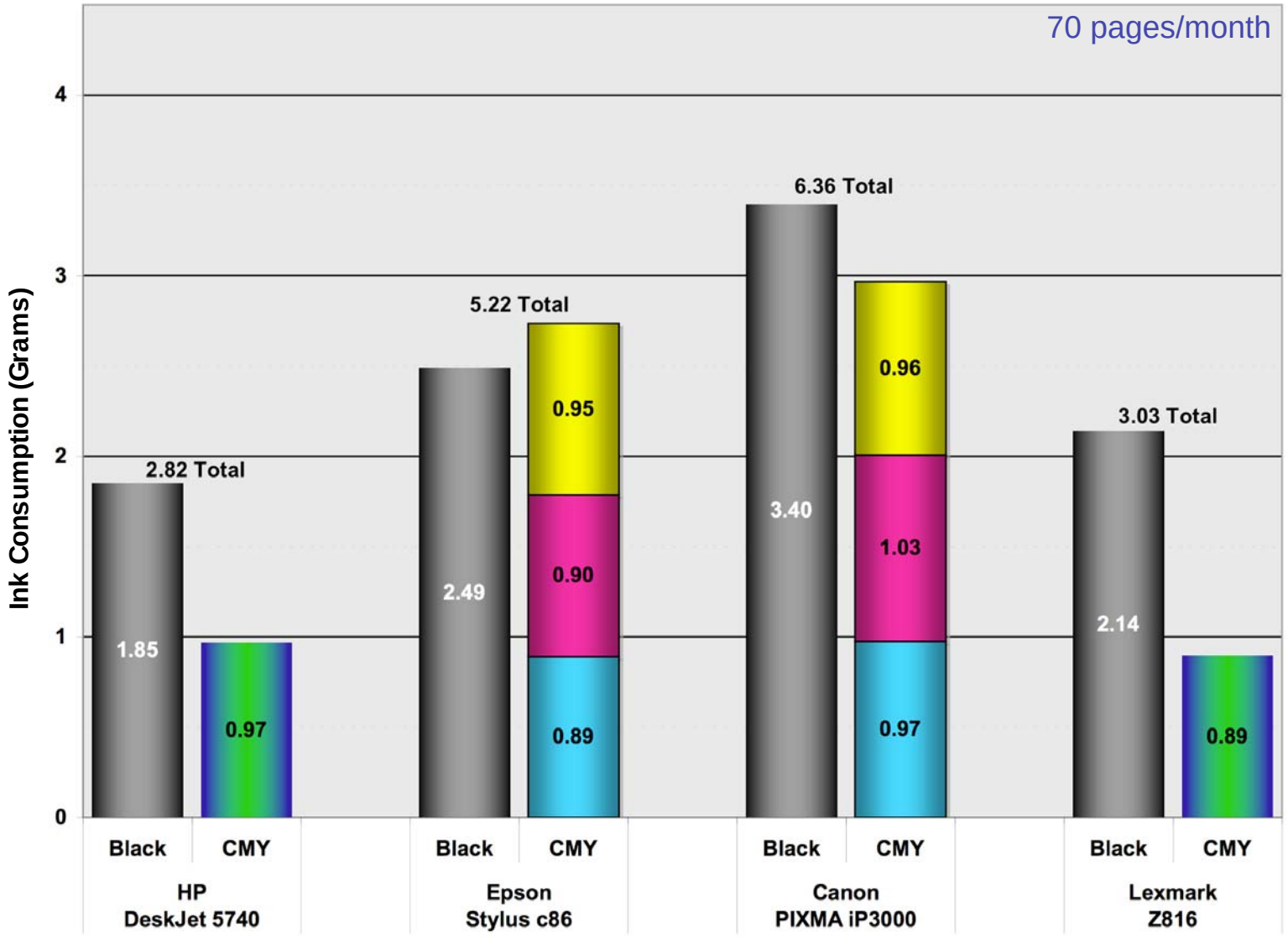
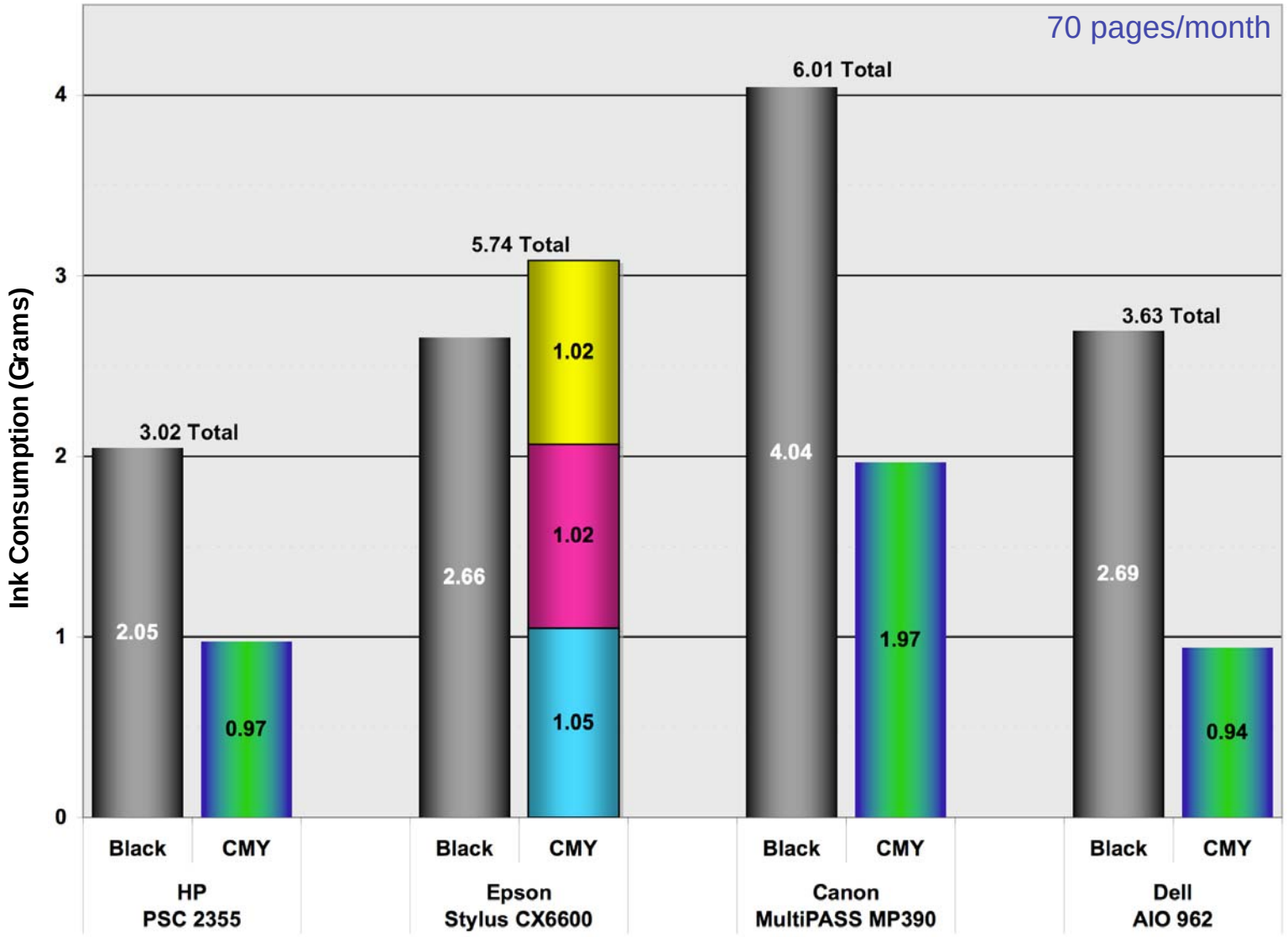
Ink Used in One Month of Intermittent Usage — GROUP 1



Ink Used in One Month of Intermittent Usage — GROUP 2



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Methodology

Three Test Types Performed and Analyzed

- Continuous Inkjet Cartridge Yield
  - *Count good pages printed and measure ink used during continuous printing*
- New Cartridge Installation Ink Usage
  - *Measure amount of ink used by all cartridges when any cartridge is replaced*
- Intermittent Inkjet Cartridge Yield
  - *Measure amount of ink used over 8 weeks during intermittent printing*

Methodology (continued)

Controls

- Test printers and cartridges sourced from various retailers, where possible
  - *HP printers and tri-color (#97) cartridges supplied by HP*
  - *High capacity OEM cartridges were used where available*
  - *Paper and cartridges were acclimatized for at least 8 hours prior to testing*
- Print Modes: Default on Plain paper
  - *Office Depot Premium white copy paper, 20lb, 84 brightness*
- Ink weight measured with 1-milligram precision
- One of each printer model in a Group was tested simultaneously with a single computer to eliminate possible bias
  - *Printers connected via USB 2.0 to Intel Pentium 4 class, Windows XP platforms*
- Continuous testing included 9 cartridges of each type
  - *Three cartridges were tested on each of three printers of each model*
- Intermittent testing included 10 cartridges of each type
  - *Spares were added to assure at least 9 cartridges of each type survived the long test; all 10 did*
  - *10 printers of each model were used to minimize test duration*
- New Cartridge Installation testing included 3 cartridges of each type
  - *One cartridge was tested on each of three printers of each model*
  - *Individual color cartridges where each tested on one printer, per error analysis*

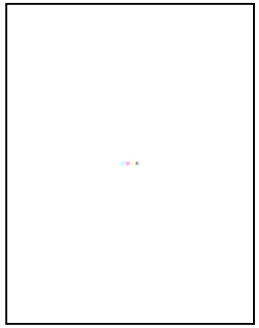
Methodology (continued)

SpencerLab Test Files

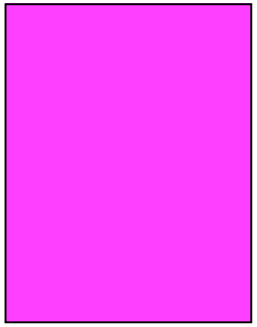
- Black Text
  - *Modeled after a black-and-white business letter*
  - *Included a small graph without grayscale*
  - *Digital coverage was below 5%*
    - Allowed for nominal dot gain of about 20%

- Color Slide
  - *Modeled after a simple presentation slide*
  - *Included simple graphics and bullet text*
  - *Created in RGB with only primary and secondary colors*
  - *Digital coverage was below 5% per color, nominally equal*
    - Allowed for nominal dot gain of about 20%

- "Nominal" CMYK Page
  - *Designed to use minimum amounts of all inks*
  - *Coverage is less than 1/1000th of Black Text or Color Slide test page coverage*



- Full Coverage page
  - *Designed to use maximum amounts of one ink*
  - *May be Black, Cyan, Magenta, or Yellow*



Continuous Inkjet Cartridge Yield

Test Methodology

- Measure ink used by each cartridge through test duration
  - *Black Text and Color Slide files tested individually*
  - *Print continuously, pausing for paper replenishment, jam clearance, and overnight*
- Test files printed until *End-of-Life*, the earlier of *Ink Out* or *Visible Fade*
  - End-of-Life *by* Ink Out *signal on control panel or in driver:*
    - Canon PIXMA iP3000, Epson Stylus c86, and Epson Stylus CX6600
  - End-of-Life *by* Visible Fade *attributed to ink supply:*
    - HP DeskJet 5740, HP PSC 2355, Lexmark z816, Canon MultiPASS MP390, and Dell AIO 962
- Each cartridge weighed immediately before test start and at *End-of-Life*
  - *Difference between weights is* Total Ink Available
    - Accounts for any residual ink in the cartridge, not available for printing

Analysis

- Count *Pages-per-Cartridge,* averaged for each cartridge type
- Note *Total Ink Available,* averaged for each cartridge type
  - Assumed to be the same when printing intermittent as when printing continuous

New Cartridge Installation Ink Usage

Test Methodology

Measure ink change of each cartridge due to insertion priming, and maintenance when replacing other cartridges

- *Insert a set of cartridges*
- *Print full coverage pages until Control Panel/Printer Driver indicates* Ink Low, preparing printer for a new cartridge
  - Full Black pages printed when measuring impact on color cartridges
  - Full Cyan, Magenta, or Yellow pages printed when measuring impact on black cartridges
- *Print one copy of CMYK page*
  - All colors will be printed, but in negligible quantities
- *Wait five minutes to allow for any automatic post-printing maintenance cycles*
- *Remove and weigh each cartridge*
- *Weigh and install a new cartridge for the one color that showed* Ink Low*; re-install all other cartridges*
- *Wait five minutes; print CMYK page; wait five minutes*
- *Remove and weigh each cartridge*

New Cartridge Installation Ink Usage (continued)

Analysis

- Difference between weights of each cartridge is *New Cartridge Installation Ink*
  - *When black cartridge is replaced*
    - *Maintenance Ink* used on each black and color cartridge due to black cartridge change
  - *When color cartridge is replaced*
    - *Maintenance Ink* used on each black and color cartridge due to color cartridge change

Intermittent Inkjet Cartridge Yield

Test Methodology

Measure ink used by each cartridge over Intermittent test duration

- *Insert a new priming set of cartridges, such as provided with the printer*
- *Print full coverage pages until* Control Panel/Printer Driver *indicates* Ink Low*, preparing printer for new cartridge*
  - Full Black pages printed on all ten printers; then
  - Full Cyan, Magenta, or Yellow pages printed on three, three, and four printers, respectively
- *Weigh and install all new test cartridges*
- *Print Black Text file as a 2-page print job; wait one-half day*
- *Print Black Text file as a 2-page print job; wait one-half day*
- *Print Color Slide file as a 2-page print job; wait one-half day*
- *Repeat 4 days each week for 8 weeks – a rate of 70 pages-per-month*
  - The four-day business week takes holidays into account
  - 84 Black Text Pages and 42 Color Slide pages printed
- *Maintenance cycles performed as required*
  - If print quality was unacceptable, head cleanings and nozzle checks were performed as necessary; pages were re-printed
  - Power Save Mode was left at factory defaults; printers not powered off during test
- *Remove and weigh each cartridge*
  - Difference between weights, averaged for each cartridge type, is *Test Intermittent Ink*

Intermittent Inkjet Cartridge Yield (continued)

Analysis: Calculate *Intermittent Inkjet Cartridge Yield* for each cartridge

Total Ink Available is the sum of its *New Cartridge Installation Ink*, *Intermittent Printing Ink,* and the probable impact of other color *New Cartridge Installation Inks*

- *The first two terms have been measured (p18-20)*
- Intermittent Printing Ink *is the* Test Intermittent Ink *(p21) less its* New Cartridge Installation Ink*, together normalized by the ratio of its* Intermittent Inkjet Cartridge Yield *to its number of* Test Pages Printed
- New Cartridge Installation Ink *(p20) for any other cartridges that may be changed during its life must be multiplied by that probability, the ratio of* Cartridge Yields *divided by the ratio of the number of* Test Pages Printed

Express this as equations for each color cartridge; *e.g.* for black:

$$\text{Total Ink Available}_{K} = \text{New Cartridge Installation Ink}_{K} + \text{Intermittent Printing Ink} + \text{Prob}(\text{New Cartridge Installation Ink}_{K/Color})$$

$$\textit{where } \text{Intermittent Printing Ink} = \left(\text{Test Intermittent Ink}_{K} - \text{New Cartridge Installation Ink}_{K}\right) \times \frac{\text{Yield}_{K}}{\text{Test Pages Printed}_{K}}$$

$$\textit{and } \text{Prob}(\text{New Cartridge Installation Ink}_{K/Color}) = \left(\frac{\text{Yield}_{K}}{\text{Yield}_{Color}} \times \frac{\text{N}_{Color}}{\text{N}_{K}}\right) \times \text{New Cartridge Installation Ink}_{K/Color.}$$

Calculate Yields from these *n* simultaneous equations with *n* Yield unknowns

Calculate Printing Efficiency and Yield Change

Printing Efficiency: the Ratio of Intermittent to Continuous Inkjet Cartridge Yield as a Percent

Yield Change: the Difference between Printing Efficiency and 100%

Thank You — The SpencerLab Project Team

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