CLSPARSE:
A VENDOR-OPTIMIZED OPEN-SOURCE SPARSE BLAS LIBRARY

JOSEPH L. GREATHOUSE, KENT KNOX, JAKUB POŁA*,
KIRAN VARAGANTI, MAYANK DAGA
*UNIV. OF WROCŁAW & VRATIS LTD.

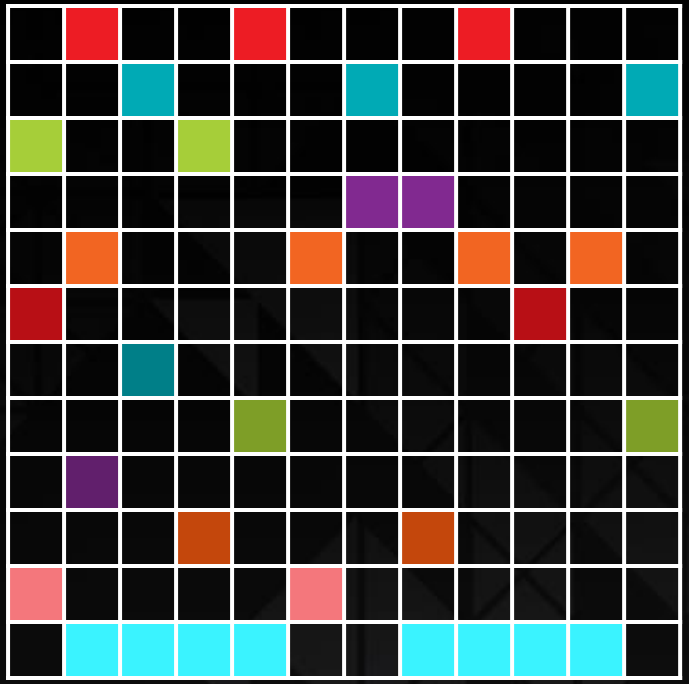
SPARSE LINEAR ALGEBRA

- Operate on matrices and vectors with many zero values

- Useful in numerous domains
  - Computational fluid dynamics, other engineering applications
  - Computational physics, other HPC applications (e.g. HPCG)
  - Graph algorithms

- Requires very different optimizations than dense BLAS
  - Kernels are often bandwidth-bound
  - Sometimes lack parallelism

- Needs different library support than traditional dense BLAS



EXAMPLES OF EXISTING LIBRARIES

- Proprietary, optimized libraries
  - Nvidia cuSPARSE
  - Intel MKL

- Open-source libraries
  - ViennaCL
  - MAGMA
  - Numerous one-off academic libraries (clSpMV, bhSPARSE, yaSpMV, etc.)

PROPRIETARY LIBRARIES

+ Often highly optimized (especially by hardware vendors) – performance matters!
  - Lots of engineers working to optimize libraries for customers

— Often work on (or optimized for) limited set of hardware
  - Nvidia cuSPARSE only works on Nvidia GPUs
  - Intel MKL optimized for Intel processors

— Can be slow to add new features from the research community
  - More than 50 GPU-based SpMV algorithms in the literature; few end up in proprietary libraries

— You can't see or modify the code!
  - e.g. Kernel fusion shown to be performance benefit – closed-source libraries don't allow this
  - Difficult for academic research to move forward the state of the art

OPEN-SOURCE LIBRARIES

- \+ You can see and modify the code!
  - Not only can you modify code to improve performance, you can advance the algorithms
- \+ Often closely integrated with research community
  - e.g. ViennaCL support for CSR-Adaptive and SELL-C-σ within months of their publication
- \+ Sometimes work across vendors (thanks to languages like OpenCL™!)
  - e.g. ViennaCL works on Nvidia GPUs, AMD CPUs & GPUs, Intel CPUs & GPUs, Intel Xeon Phi, etc.

- — Sometimes do not work across vendors
  - e.g. Caffe (DNN library) originally CUDA-only (ergo Nvidia hardware only)
- — Not always the best performance
  - Can trade off performance for portability and maintainability
  - Do not always include hardware-specific optimizations

AMD AND THE GPUOPEN INITIATIVE

AMD

- Vendor-optimized open-source support for important GPU software
  - http://gpuopen.com/
  - Most source code available on GitHub or Bitbucket!
- Open-source Gaming Libraries
  - e.g. TressFX – Hair physics
  - e.g. AOFX – optimized ambient occlusion
  - Many others!
- Open-source Compute Libraries
  - clBLAS
  - clFFT
  - clRNG

GPUOpen

AND CLSPARSE

- Open-source OpenCL™ Sparse BLAS Library for GPUs
  - Source code available, mostly Apache licensed (some MIT)
  - Compiles for Microsoft Windows®, Linux®, and Apple OS X
- Vendor optimizations. Developed as a collaboration between:
  - AMD (both product and research teams)
  - Vratis Ltd. (of SpeedIT fame)
- Available at https://github.com/clMathLibraries/clSPARSE

clSPARSE: An OpenCL™ Sparse BLAS Library

CLSPARSE DESIGN CHOICES

- C Library API
  - Make using library in C and FORTRAN programs easier
- Allow full control of OpenCL™ data structures, work with normal `cl_mem` buffers
- Abstract internal support structures from user
- Use compressed sparse row (CSR) as sparse matrix storage format
  - Much existing code already uses CSR – no GPU-specific storage format
  - Many complex algorithms (SpMSpM, SpTS) require CSR, so no structure swapping in clSPARSE

CLSPARSE API EXAMPLES – INITIALIZING A SPARSE MATRIX (1)

```
// CSR matrix structure
clsparseCsrMatrix A;
// Matrix size variables
clsparseIdx_t nnz, row, col;
```

CLSPARSE API EXAMPLES – INITIALIZING A SPARSE MATRIX (1)

```
// CSR matrix structure
clsparseCsrMatrix A;
// Matrix size variables
clsparseIdx_t nnz, row, col;

// read matrix market header to get the size of the matrix
clsparseStatus fileErr = clsparseHeaderfromFile( &nnz, &row, &col, mtx_path.c_str( ) );
A.num_nonzeros = nnz; A.num_rows = row; A.num_cols = col;
```

CLSPARSE API EXAMPLES – INITIALIZING A SPARSE MATRIX (1)

```
// CSR matrix structure
clsparseCsrMatrix A;
// Matrix size variables
clsparseIdx_t nnz, row, col;

// read matrix market header to get the size of the matrix
clsparseStatus fileErr = clsparseHeaderfromFile( &nnz, &row, &col, mtx_path.c_str( ) );
A.num_nonzeros = nnz; A.num_rows = row; A.num_cols = col;

// Allocate device memory for CSR matrix
A.values = clCreateBuffer( ctxt, CL_MEM_READ_ONLY, nnz * sizeof(float), NULL, &cl_status );
A.col_indices = clCreateBuffer( ctxt, CL_MEM_READ_ONLY, nnz * sizeof(clsparseIdx_t),
                      NULL, &cl_status );
A.row_pointer = clCreateBuffer( ctxt, CL_MEM_READ_ONLY, (num_rows + 1) *
                      sizeof(clsparseIdx_t), NULL, &cl_status );
```

CLSPARSE API EXAMPLES – INITIALIZING A SPARSE MATRIX (2)

```
// Reminder: clsparseCsrMatrix A;

// clSPARSE control object
// Control object wraps CL state (contains CL queue, events, and other library state)
clsparseCreateResult createResult = clsparseCreateControl( cmd_queue );
```

CLSPARSE API EXAMPLES – INITIALIZING A SPARSE MATRIX (2)

```
// Reminder: clsparseCsrMatrix A;

// clSPARSE control object
// Control object wraps CL state (contains CL queue, events, and other library state)
clsparseCreateResult createResult = clsparseCreateControl( cmd_queue );


// Read matrix market file with explicit zero values straight into device memory
// This initializes CSR format sparse data
err = clsparseSCsrMatrixfromFile( &A, mtx_path.c_str(), createResult.control, CL_TRUE );
```

CLSPARSE API EXAMPLES – INITIALIZING A SPARSE MATRIX (2)

AMD

```
// Reminder: clsparseCsrMatrix A;

// clSPARSE control object
// Control object wraps CL state (contains CL queue, events, and other library state)
clsparseCreateResult createResult = clsparseCreateControl( cmd_queue );

// Read matrix market file with explicit zero values straight into device memory
// This initializes CSR format sparse data
err = clsparseSCsrMatrixfromFile( &A, mtx_path.c_str(), createResult.control, CL_TRUE );

// OPTIONAL - This function allocates memory for rowBlocks structure.
// The presence of this meta data enables the use of the CSR-Adaptive algorithm
clsparseCsrMetaCreate( &A, createResult.control );
```

CLSPARSE API EXAMPLES – INITIALIZING VECTORS

```
// Allocate and set up vector
cldenseVector x;
clsparseInitVector(&x);
```

CLSPARSE API EXAMPLES – INITIALIZING VECTORS

```
// Allocate and set up vector
cldenseVector x;
clsparseInitVector(&x);

// Initialize vector in device memory
float one = 1.0f;
x.num_values = A.num_cols;

x.values = clCreateBuffer( ctxt, CL_MEM_READ_ONLY, x.num_values * sizeof(float),
                      NULL, &cl_status);
cl_status = clEnqueueFillBuffer( cmd_queue, x.values, &one, sizeof(float),
                      0, x.num_values * sizeof(float), 0, NULL, NULL);
```

CLSPARSE API EXAMPLES – INITIALIZING SCALARS

```
// Allocate scalar values in device memory
clsparseScalar alpha;
clsparseInitScalar(&alpha);
alpha.value = clCreateBuffer( ctxt, CL_MEM_READ_ONLY, sizeof(float), nullptr,
                &cl_status);
```

CLSPARSE API EXAMPLES – INITIALIZING SCALARS

```
// Allocate scalar values in device memory
clsparseScalar alpha;
clsparseInitScalar(&alpha);
alpha.value = clCreateBuffer( ctxt, CL_MEM_READ_ONLY, sizeof(float), nullptr,
              &cl_status);

// Set alpha = 1;
float* halpha = (float*) clEnqueueMapBuffer( cmd_queue, alpha.value, CL_TRUE,
                             CL_MAP_WRITE,  0, sizeof(float), 0, NULL, NULL, &cl_status);
*halpha = 1.0f;
cl_status = clEnqueueUnmapMemObject( cmd_queue, alpha.value, halpha, 0, NULL, NULL);
```

CLSPARSE API EXAMPLES – PERFORMING SPMV

```
// Reminder:
//      clsparseCsrMatrix A;
//      clsparseScalar alpha, beta;
//      cldenseVector x, y;
//      clsparseCreateResult createResult;

// Call the SpMV algorithm to calculate y=αAx+βy
// Pure C style interface, passing pointer to structs
cl_status = clsparseScsrmv(&alpha, &A, &x, &beta, &y, createResult.control );
```

CLSPARSE API EXAMPLES – CG SOLVE

```
// Create solver control object. It keeps info about the preconditioner,
// desired relative and absolute tolerances, max # of iterations to be performed
// We use: preconditioner:diagonal, rel tol:1e-2, abs tol:1e-5, max iters: 1000
clsparseCreateSolverResult solverResult =
                            clsparseCreateSolverControl( DIAGONAL, 1000, 1e-2, 1e-5 );
```

CLSPARSE API EXAMPLES – CG SOLVE

```
// Create solver control object. It keeps info about the preconditioner,
// desired relative and absolute tolerances, max # of iterations to be performed
// We use: preconditioner:diagonal, rel tol:1e-2, abs tol:1e-5, max iters: 1000
clsparseCreateSolverResult solverResult =
                            clsparseCreateSolverControl( DIAGONAL, 1000, 1e-2, 1e-5 );

// OPTIONAL - Different print modes of the solver status:
// QUIET:no messages (default), NORMAL:print summary, VERBOSE:per iteration status;
clsparseSolverPrintMode( solverResult.control, VERBOSE);
```

CLSPARSE API EXAMPLES – CG SOLVE

```
// Create solver control object. It keeps info about the preconditioner,
// desired relative and absolute tolerances, max # of iterations to be performed
// We use: preconditioner:diagonal, rel tol:1e-2, abs tol:1e-5, max iters: 1000
clsparseCreateSolverResult solverResult =
                             clsparseCreateSolverControl( DIAGONAL, 1000, 1e-2, 1e-5 );

// OPTIONAL - Different print modes of the solver status:
// QUIET:no messages (default), NORMAL:print summary, VERBOSE:per iteration status;
clsparseSolverPrintMode( solverResult.control, VERBOSE);


// Call into CG solve
cl_status = clsparseScsrcg(&x, &A, &y, solverResult.control, createResult.control );
```

UNDERLYING ALGORITHMS FROM THE RESEARCH LITERATURE

AMD

- SpMV uses CSR-Adaptive algorithm
  – Described by AMD in research papers at SC'14 and HiPC'15
  – Requires once-per-matrix generation of some meta-data (`clsparseCsrMetaCreate()`)
  – Falls back to slower CSR-Vector style algorithm if meta-data does not exist

- Batched CSR-Adaptive for SpM-DM multiplication

- SpMSpM uses algorithm described in Liu and Vinter at IPDPS'14 and JPDC'15

clSPARSE Performance Comparisons

BENCHMARKING CLSPARSE

AMD Test Platform

- **AMD Radeon™ Fury X**
  - Intel Core i5-4690K
  - 16 GB Dual-channel DDR3-2133
  - Ubuntu 14.04.4 LTS
  - fglrx 15.302 driver
  - AMD APP SDK 3.0
- **clSPARSE v0.11**
- ViennaCL v1.7.1

BENCHMARKING CLSPARSE

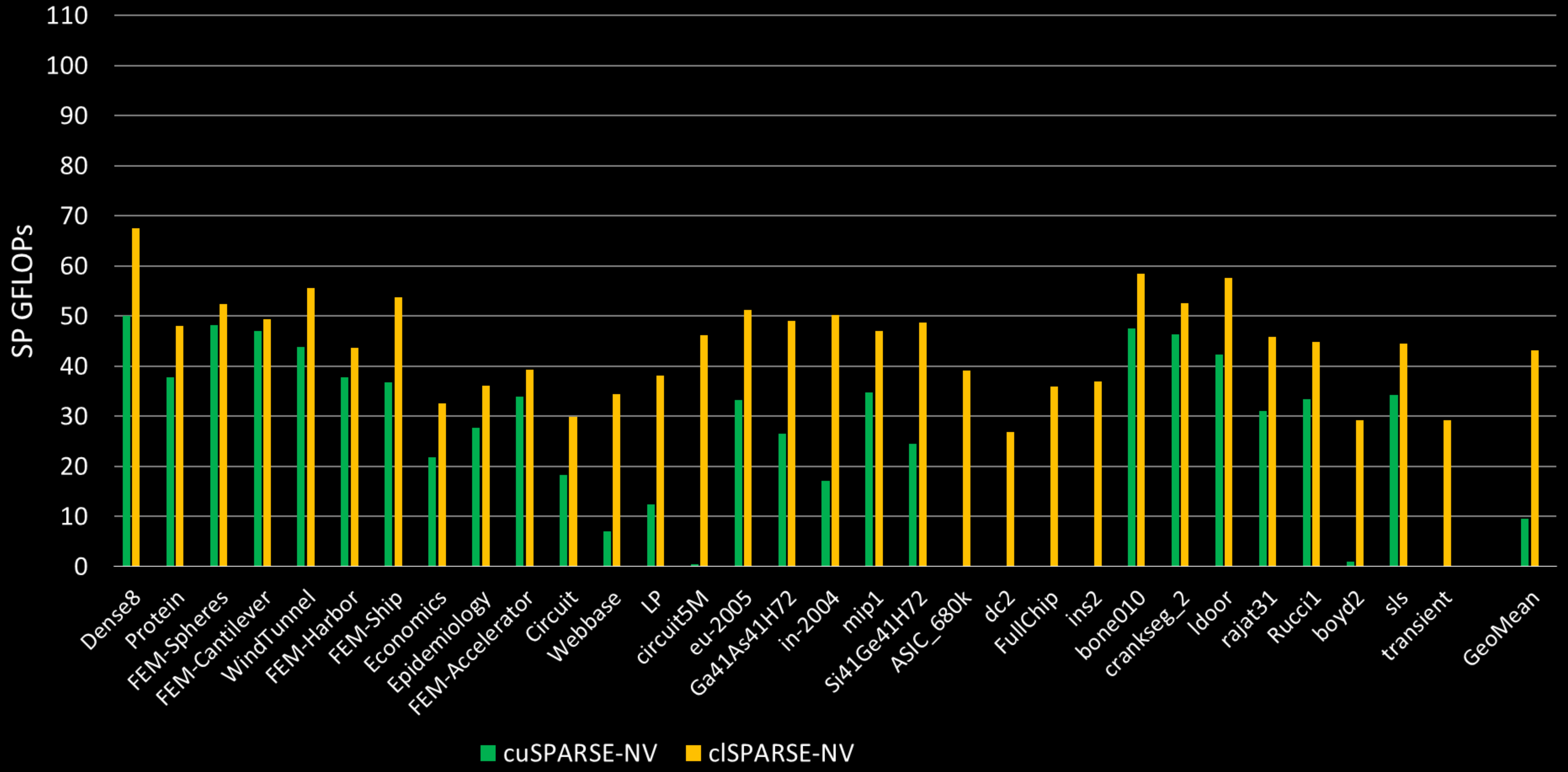
AMD Test Platform	Nvidia Test Platform
AMD Radeon™ Fury X	**Nvidia GeForce GTX TITAN X**
Intel Core i5-4690K	Intel Core i7-5960X
16 GB Dual-channel DDR3-2133	64GB Quad-channel DDR4-2133
Ubuntu 14.04.4 LTS	Ubuntu 14.04.4 LTS
fglrx 15.302 driver	Driver 352.63
AMD APP SDK 3.0	CUDA 7.5
clSPARSE v0.11	**clSPARSE v0.11**
ViennaCL v1.7.1	cuSPARSE v7.5

COMPARISON TO PROPRIETARY VENDOR-OPTIMIZED LIBRARY

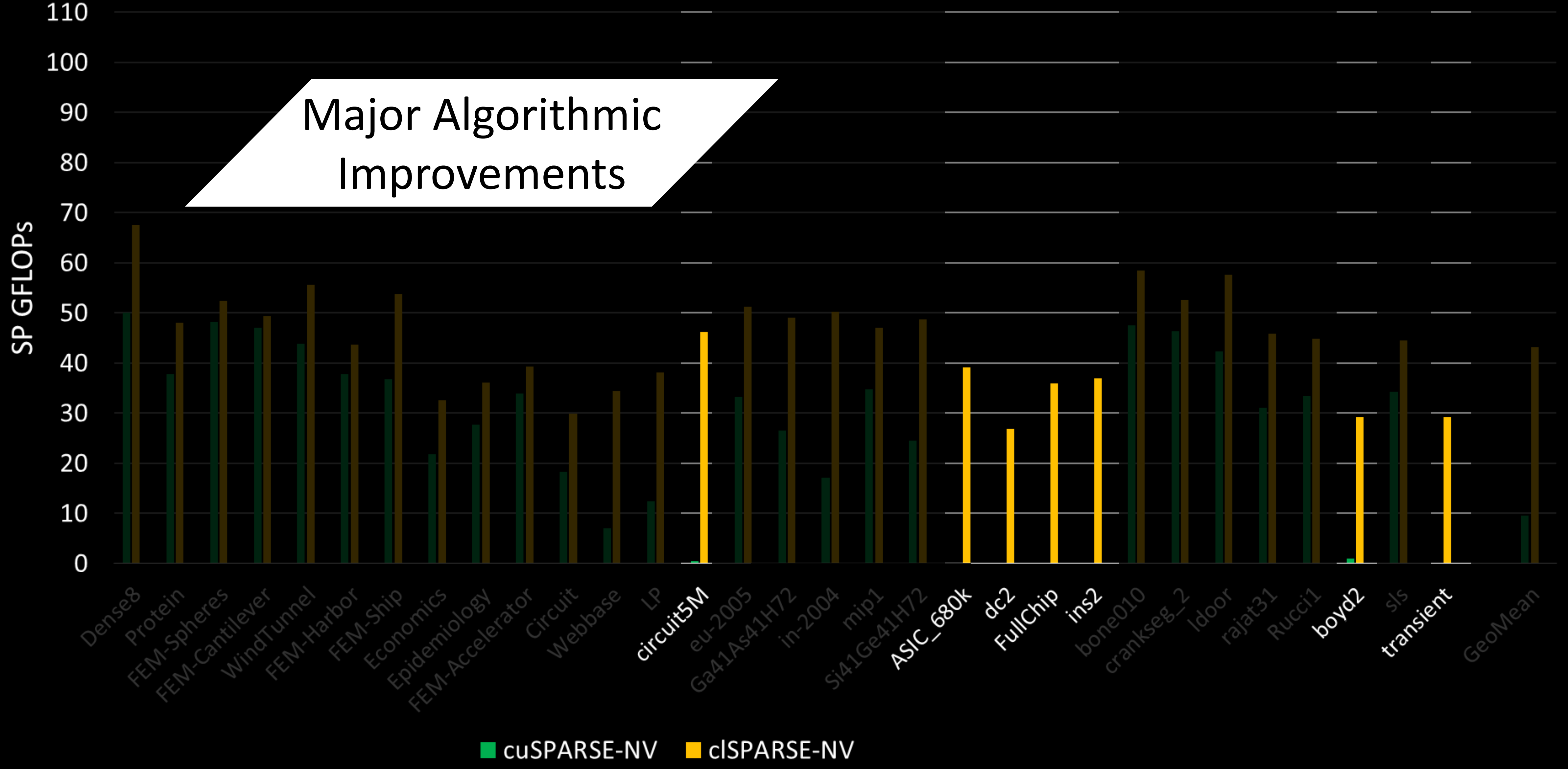
- Compare clSPARSE performance to Nvidia's cuSPARSE library

- clSPARSE works across vendors, directly compare on identical Nvidia hardware
  - Also compare AMD GPU to all of this

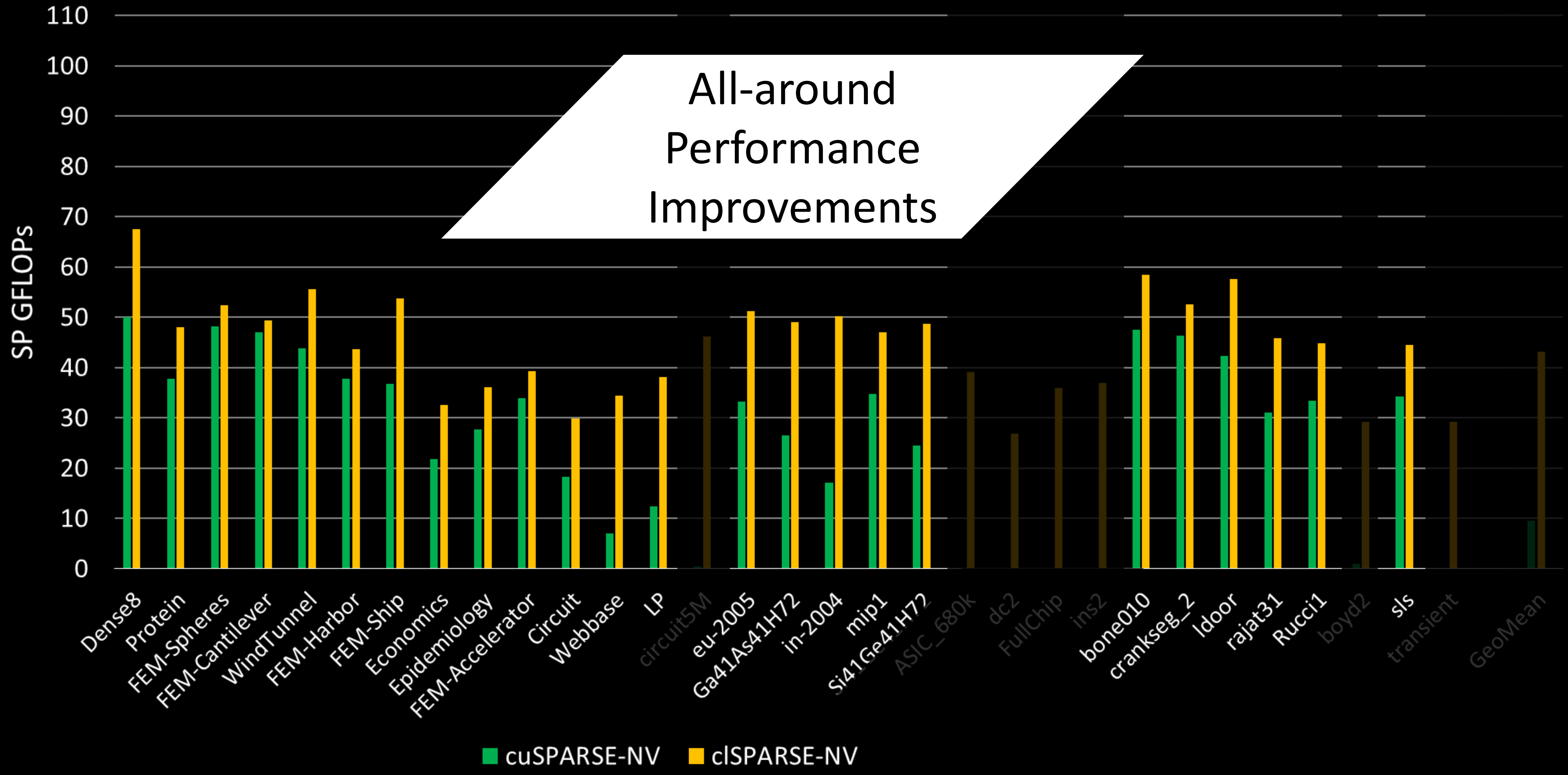
SINGLE PRECISION SPMV – VENDOR OPTIMIZED



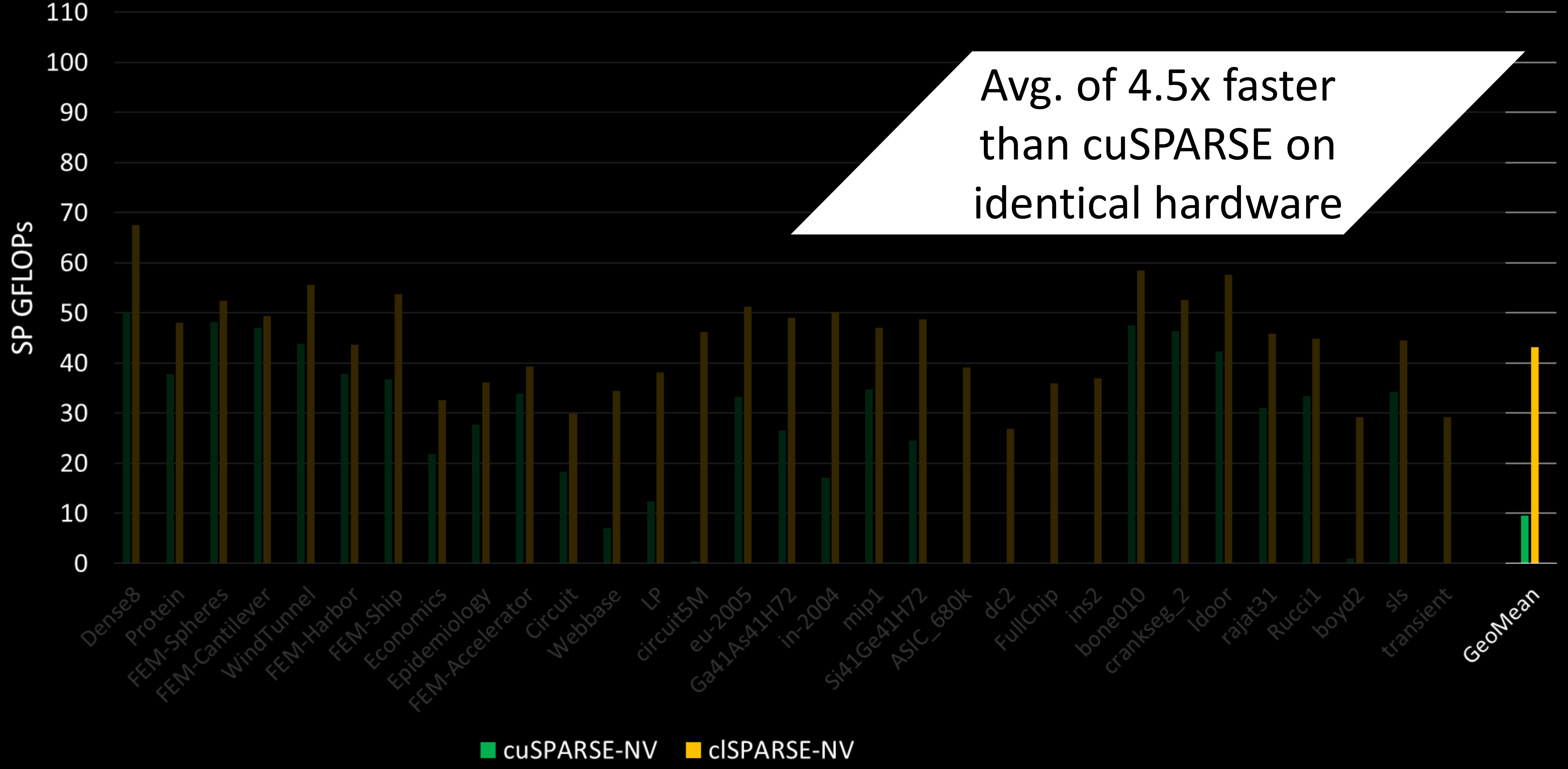
SINGLE PRECISION SPMV – VENDOR OPTIMIZED



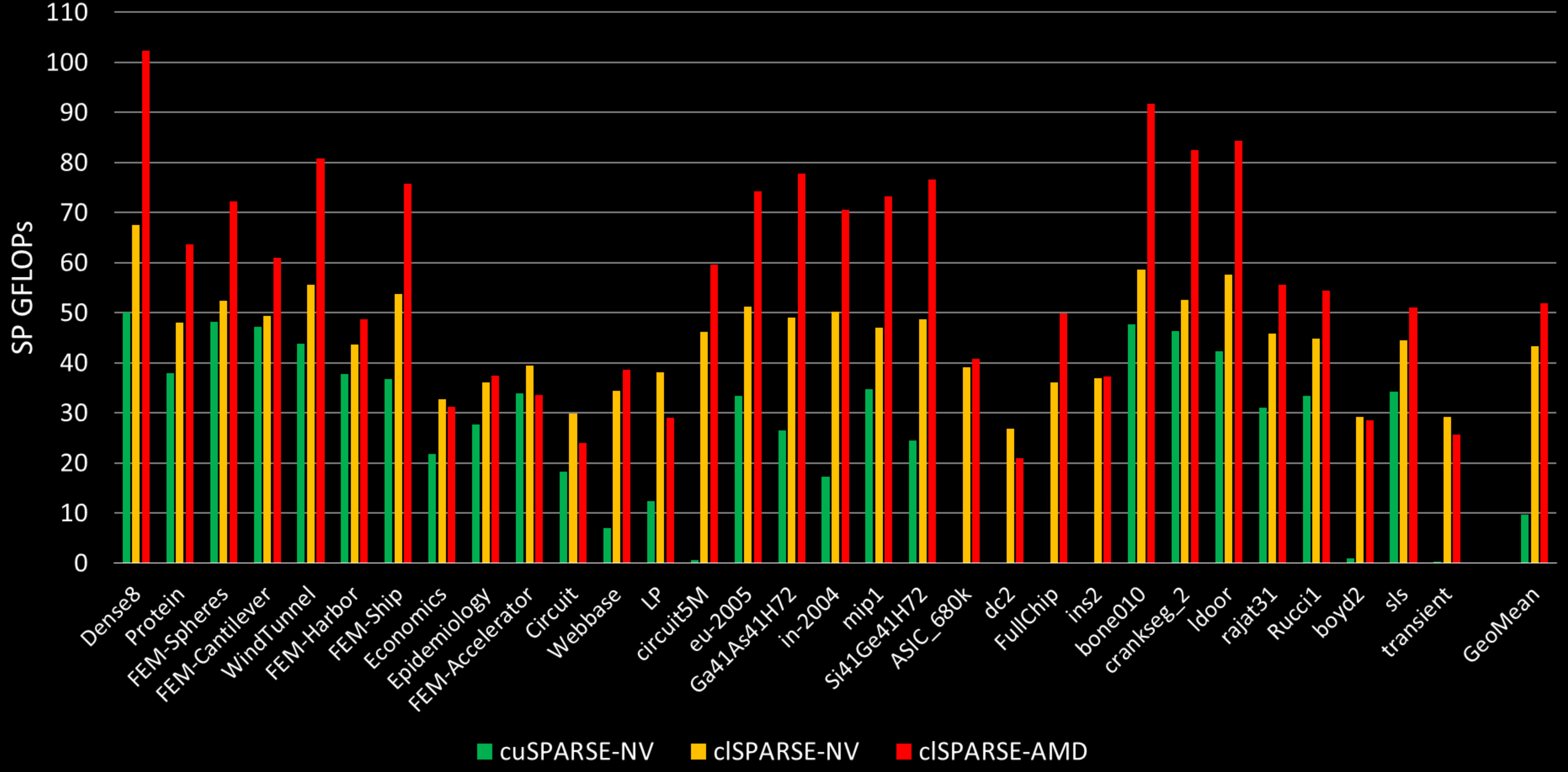
SINGLE PRECISION SPMV – VENDOR OPTIMIZED



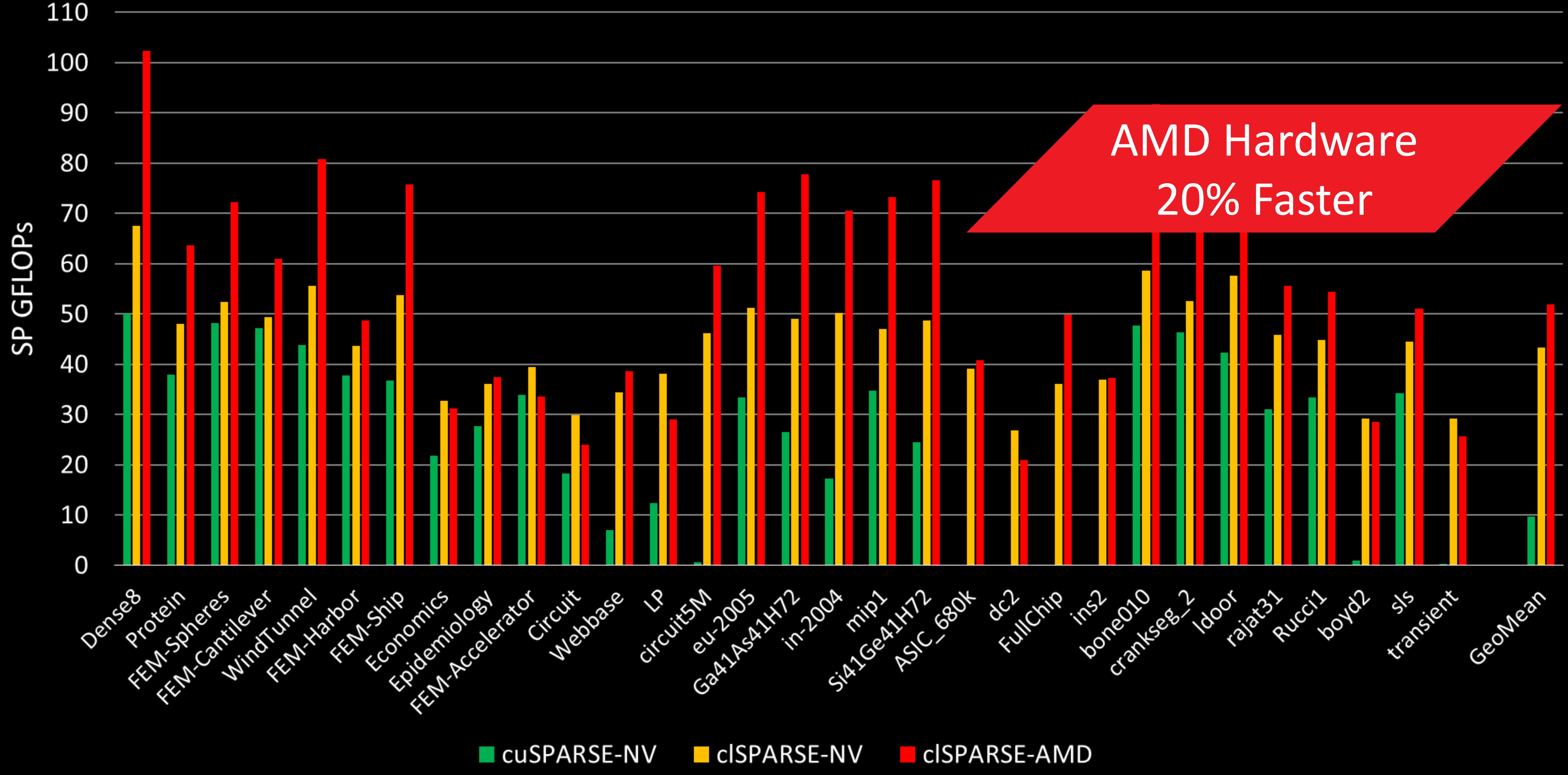
SINGLE PRECISION SPMV – VENDOR OPTIMIZED



SINGLE PRECISION SPMV – VENDOR OPTIMIZED

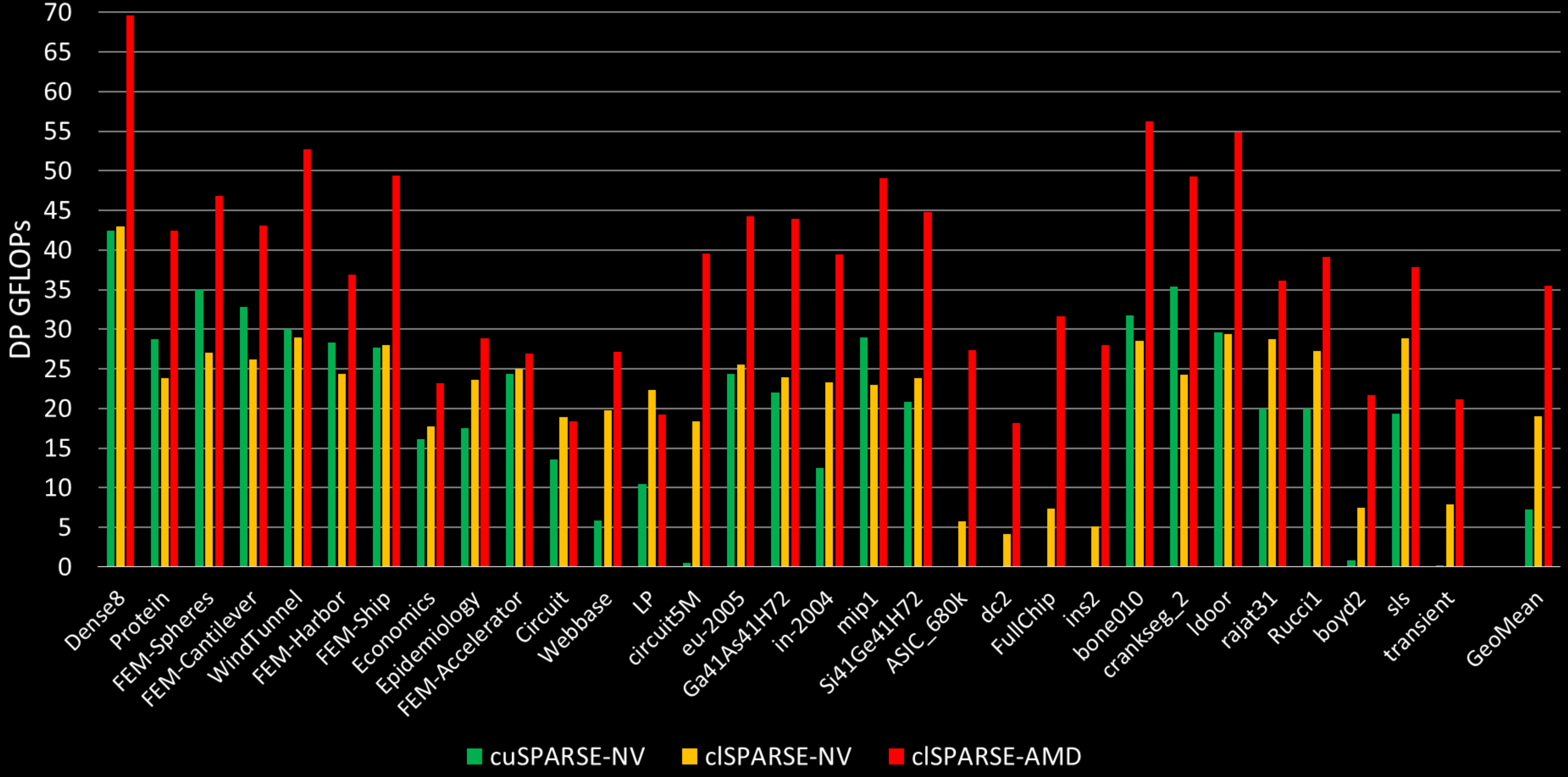


SINGLE PRECISION SPMV – VENDOR OPTIMIZED

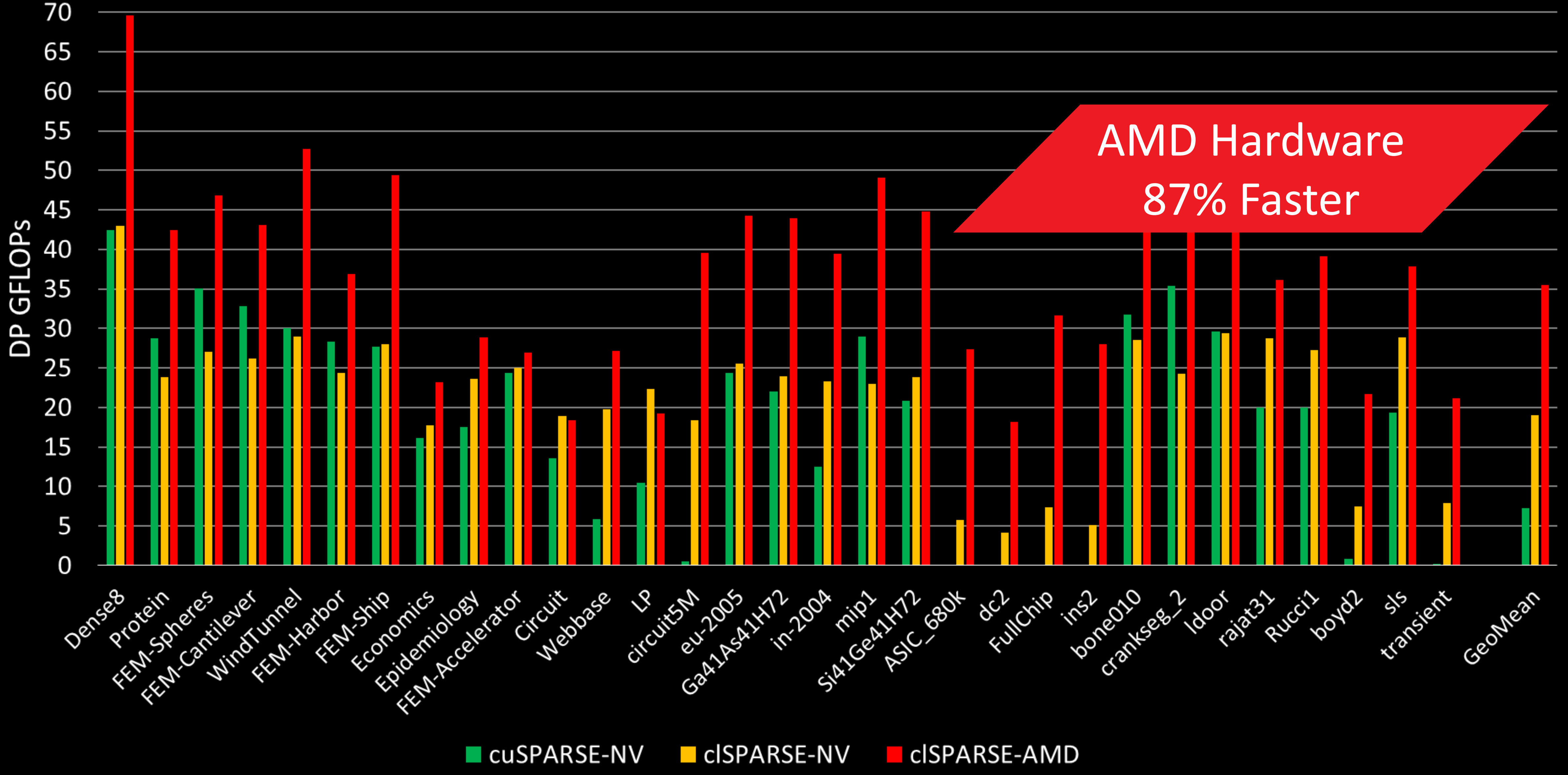


DOUBLE PRECISION SPMV – VENDOR OPTIMIZED

AMD

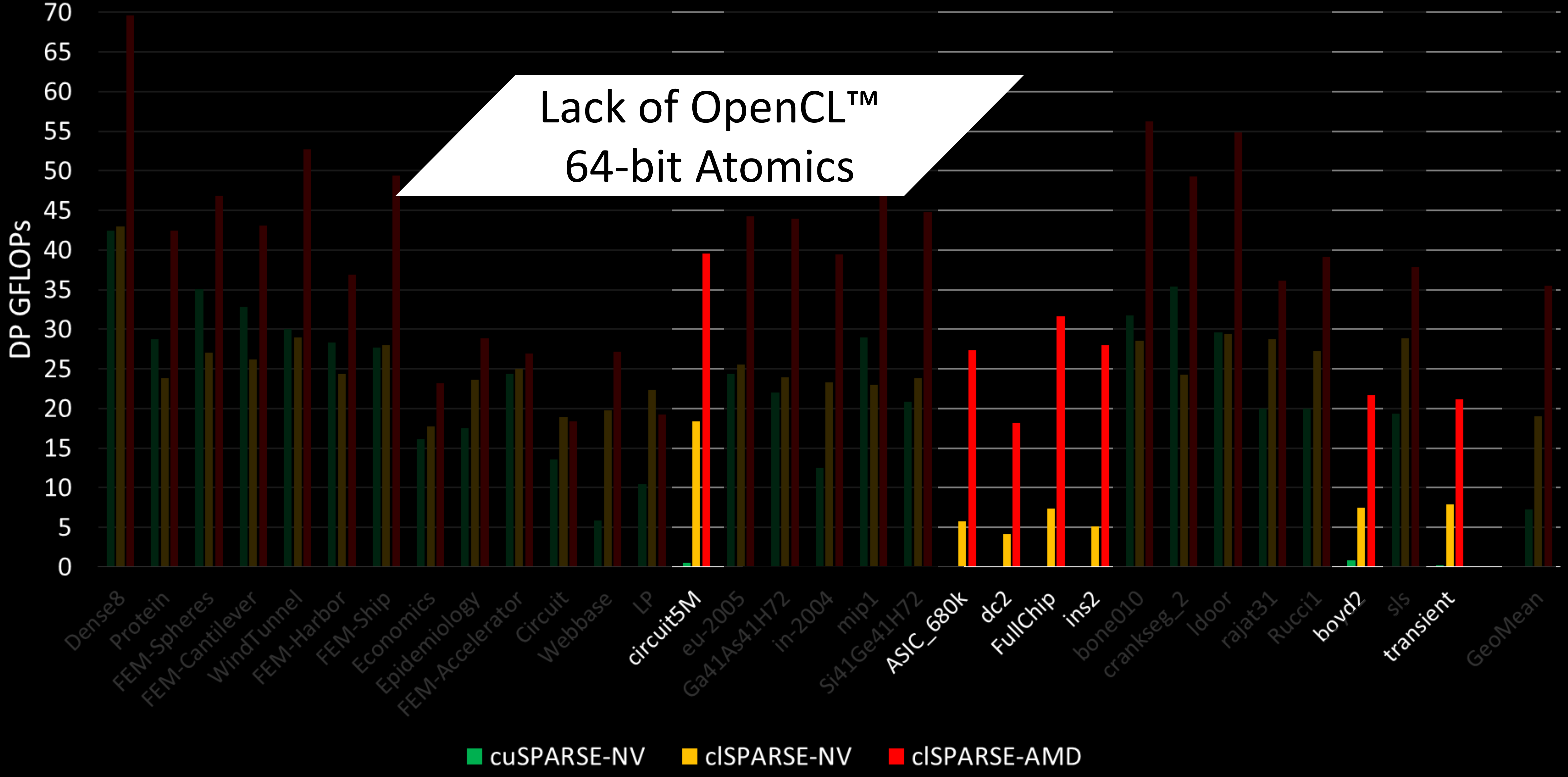


DOUBLE PRECISION SPMV – VENDOR OPTIMIZED

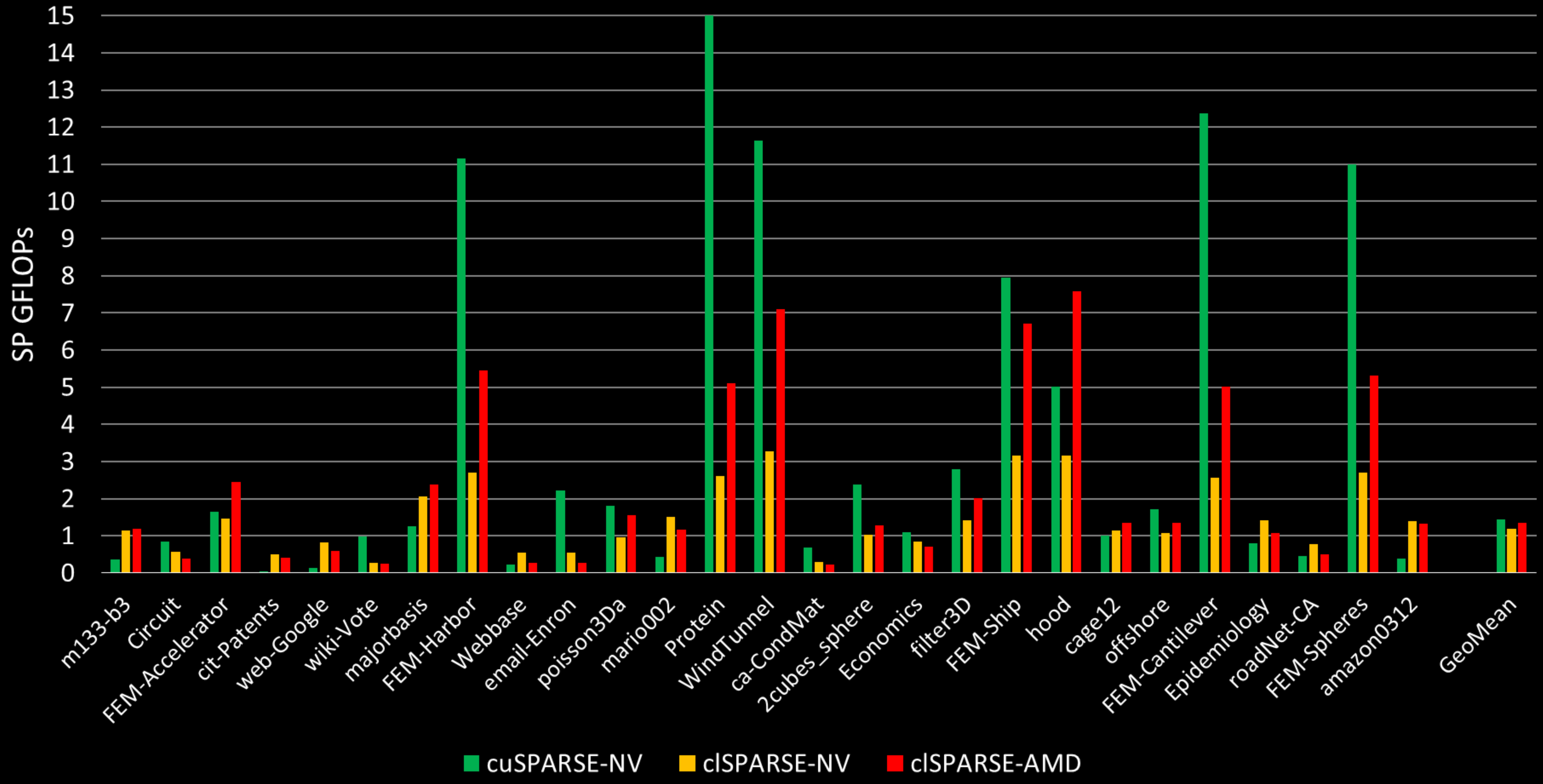


DOUBLE PRECISION SPMV – VENDOR OPTIMIZED

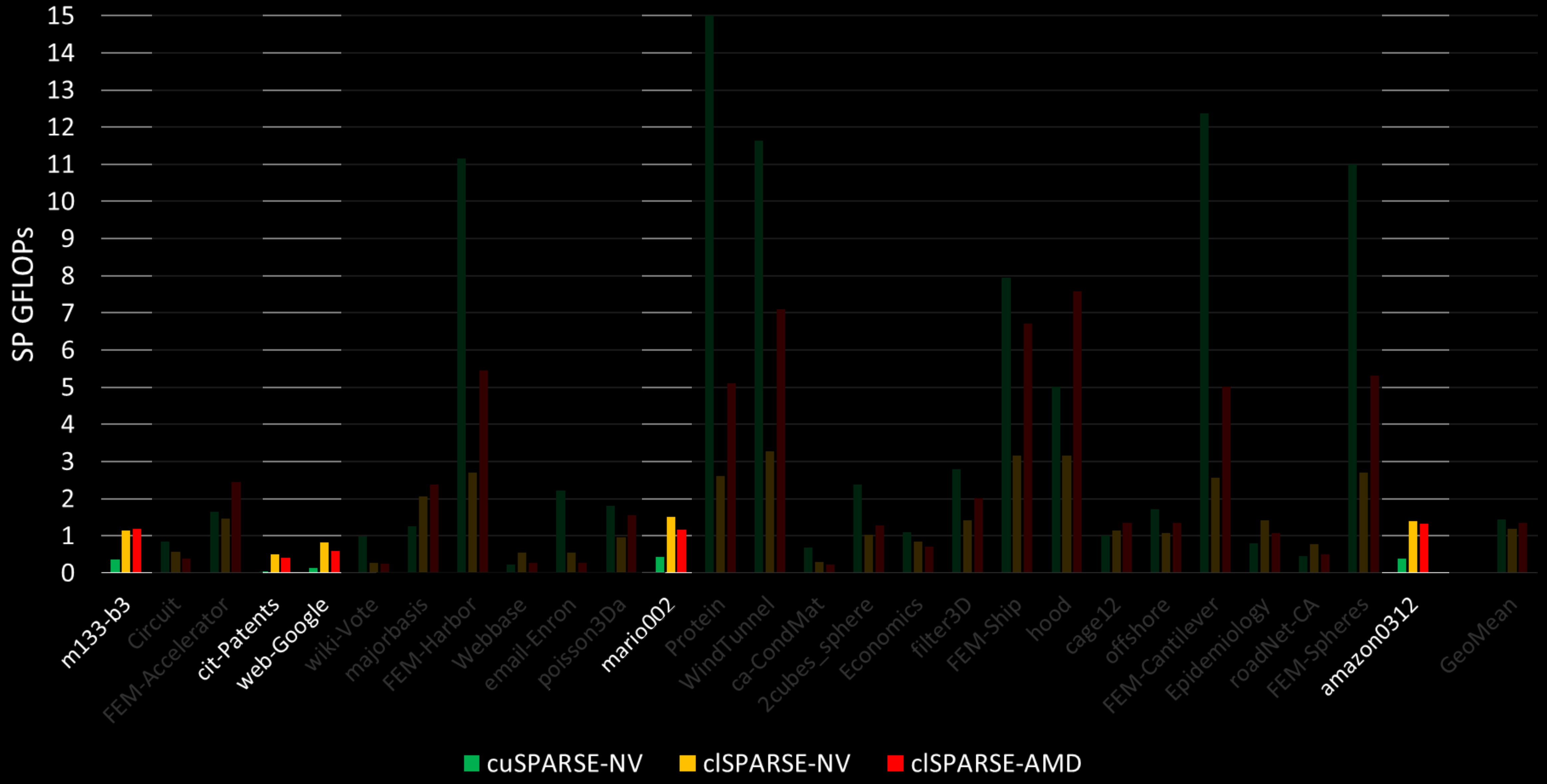
AMD



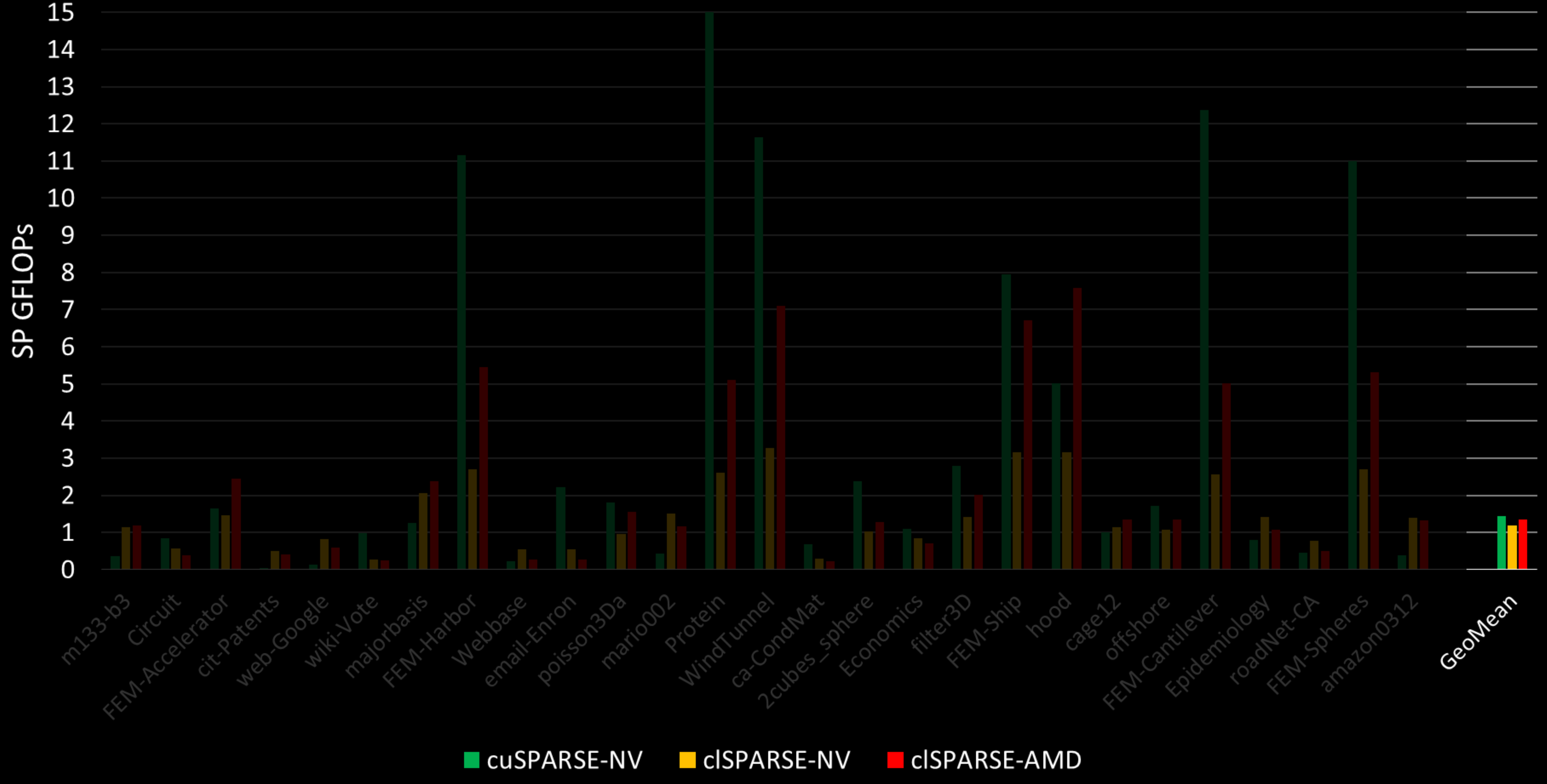
SINGLE PRECISION SPM-SPM – VENDOR OPTIMIZED



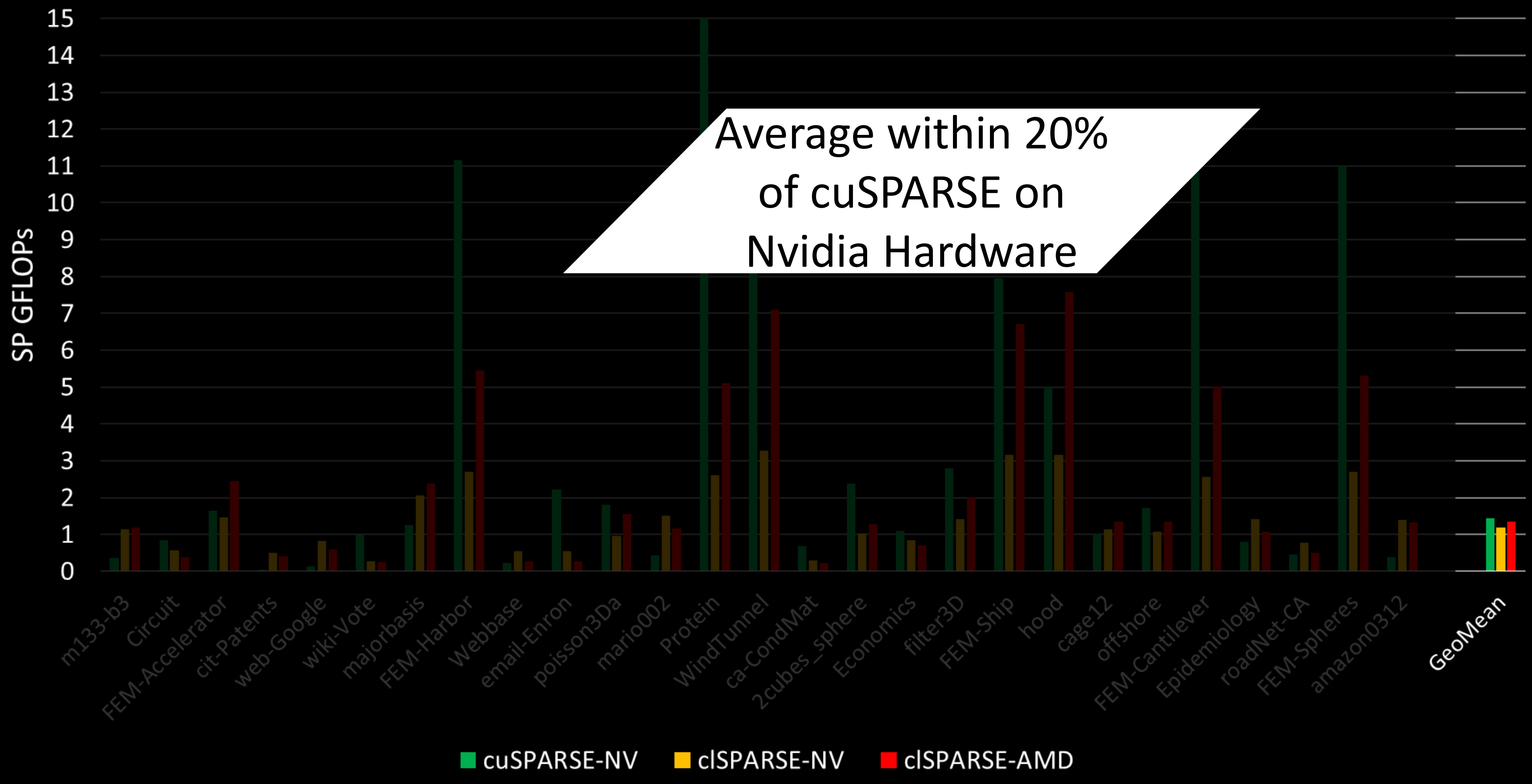
SINGLE PRECISION SPM-SPM – VENDOR OPTIMIZED



SINGLE PRECISION SPM-SPM – VENDOR OPTIMIZED

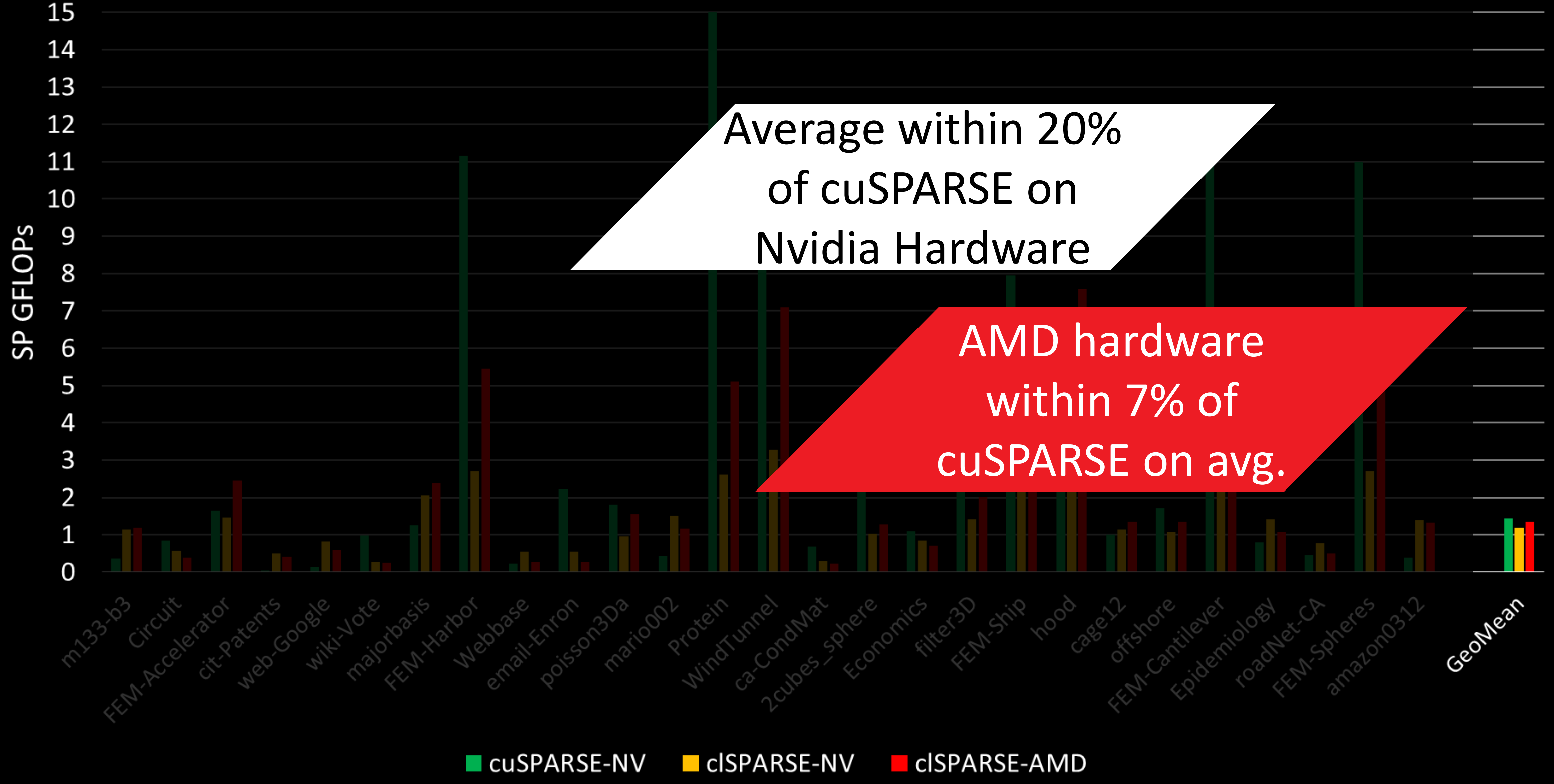


SINGLE PRECISION SPM-SPM – VENDOR OPTIMIZED



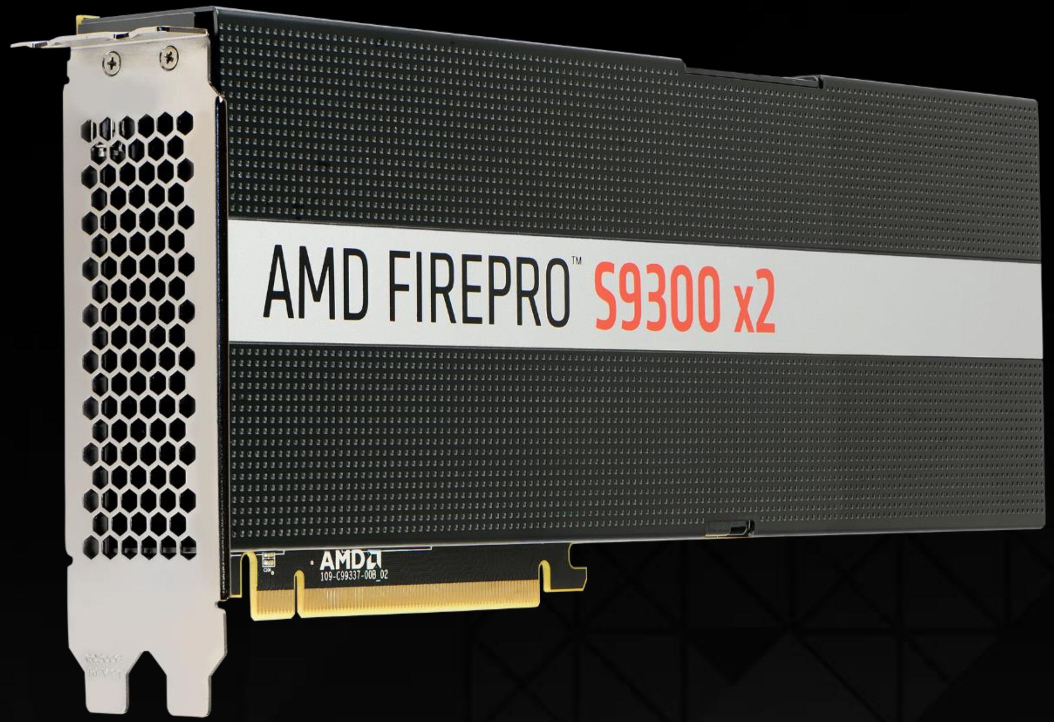
SINGLE PRECISION SPM-SPM – VENDOR OPTIMIZED

AMD



CLSPARSE IS PORTABLE ACROSS VENDORS

OPENCL™ GIVES YOU THE FREEDOM TO CHOOSE YOUR HARDWARE



AMD Radeon™ Fury X

512 GB/s Memory BW

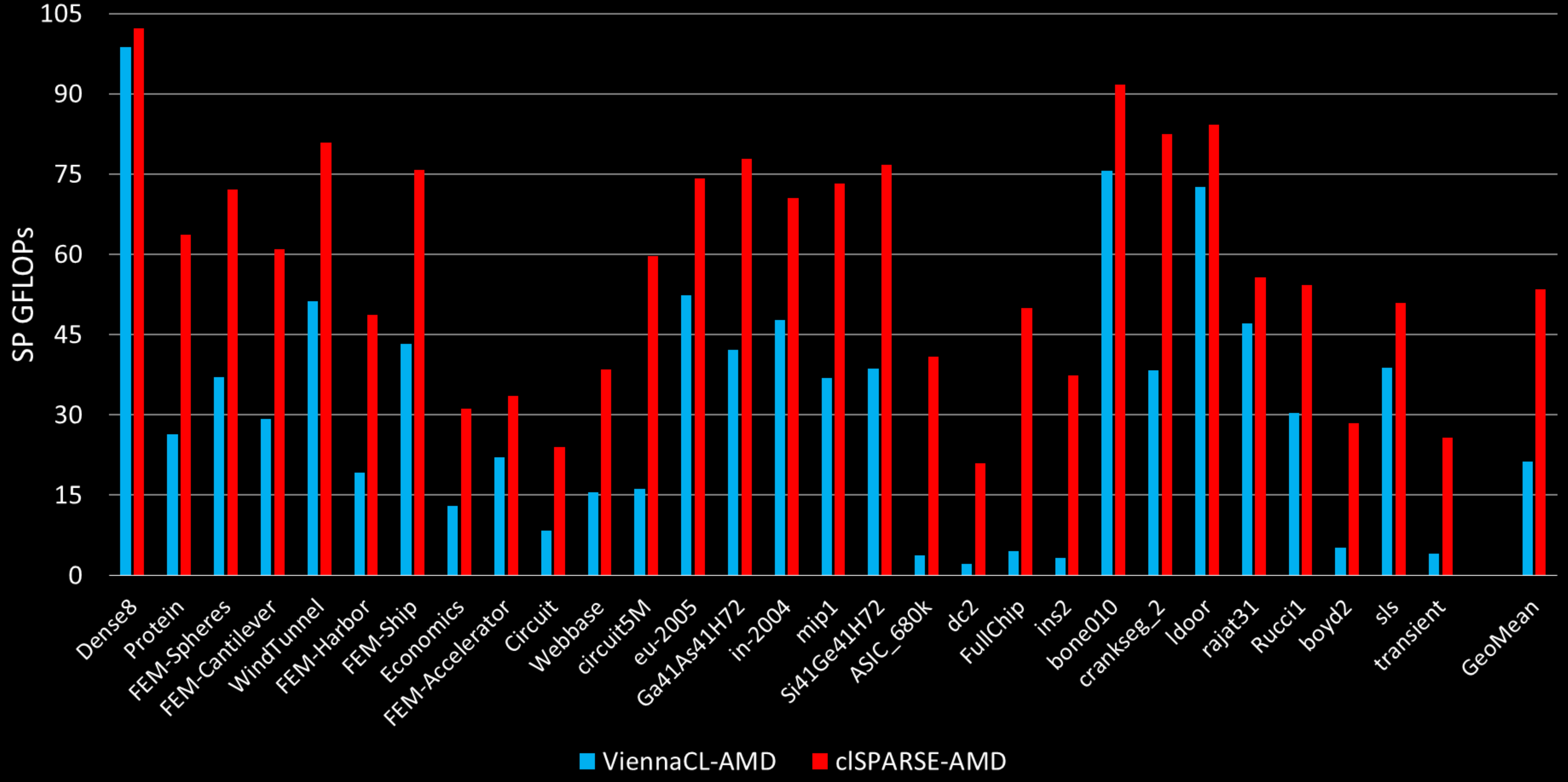
AMD FirePro™ S9300 x2

1024 GB/s Aggregate Memory BW

COMPARISON TO OPEN-SOURCE LIBRARY

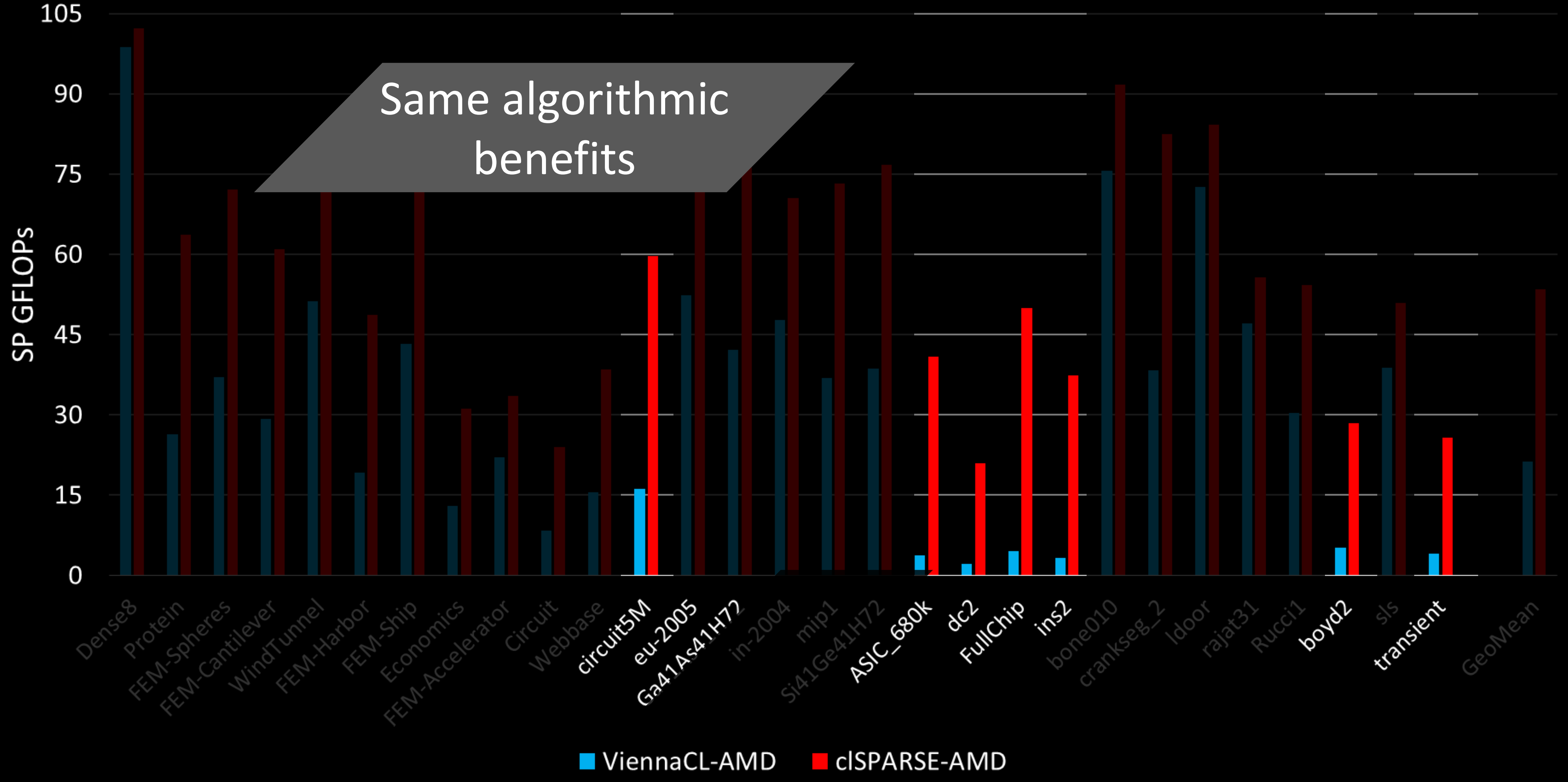
- Comparison against ViennaCL, the popular open-source linear algebra library
- Only used AMD hardware for this to ease readability
  - Both libraries work across vendors
- ViennaCL implements an older version of AMD's CSR-Adaptive algorithm for SpMV

SINGLE PRECISION SPMV – OPEN SOURCE

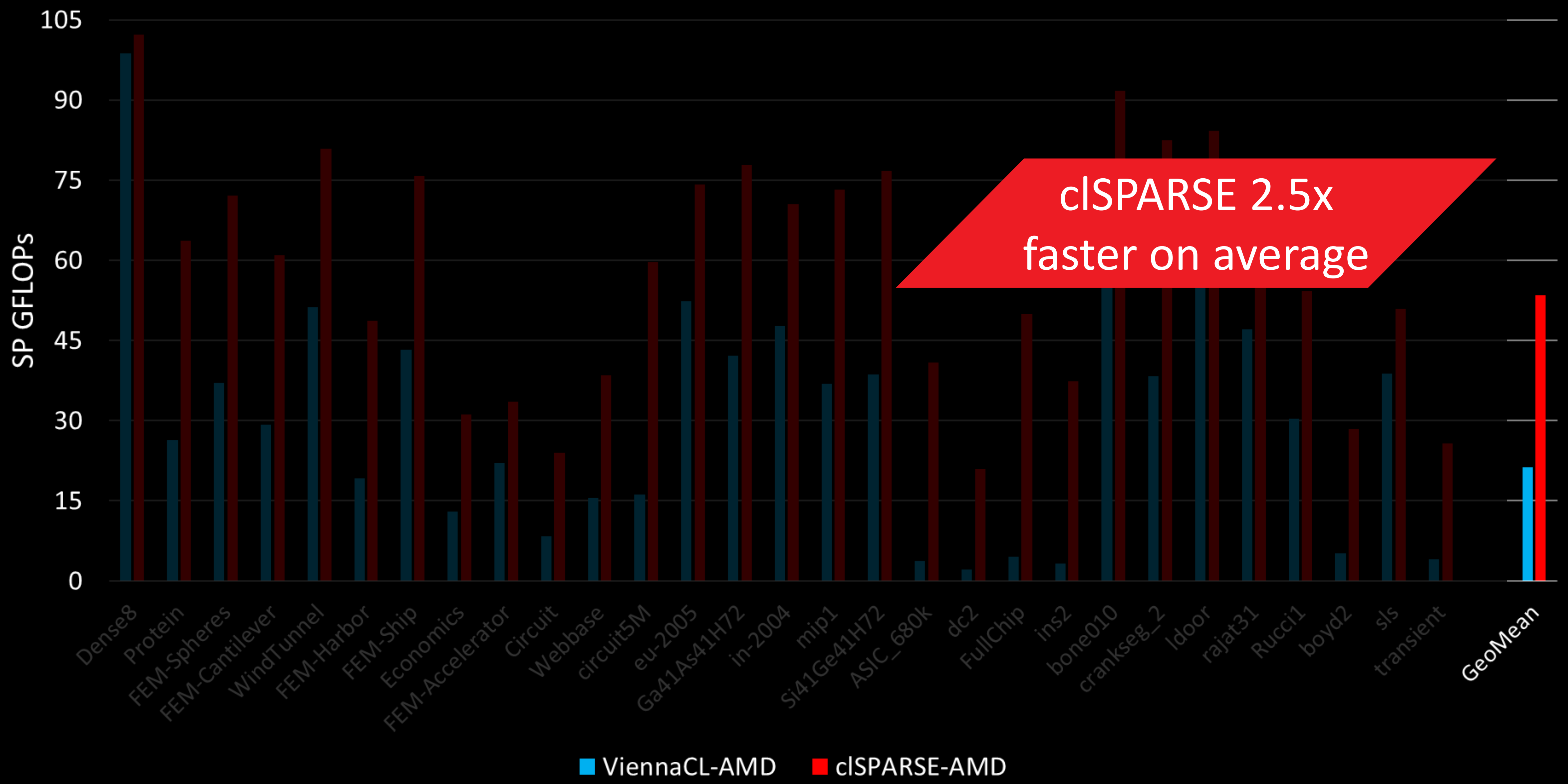


SINGLE PRECISION SPMV – OPEN SOURCE

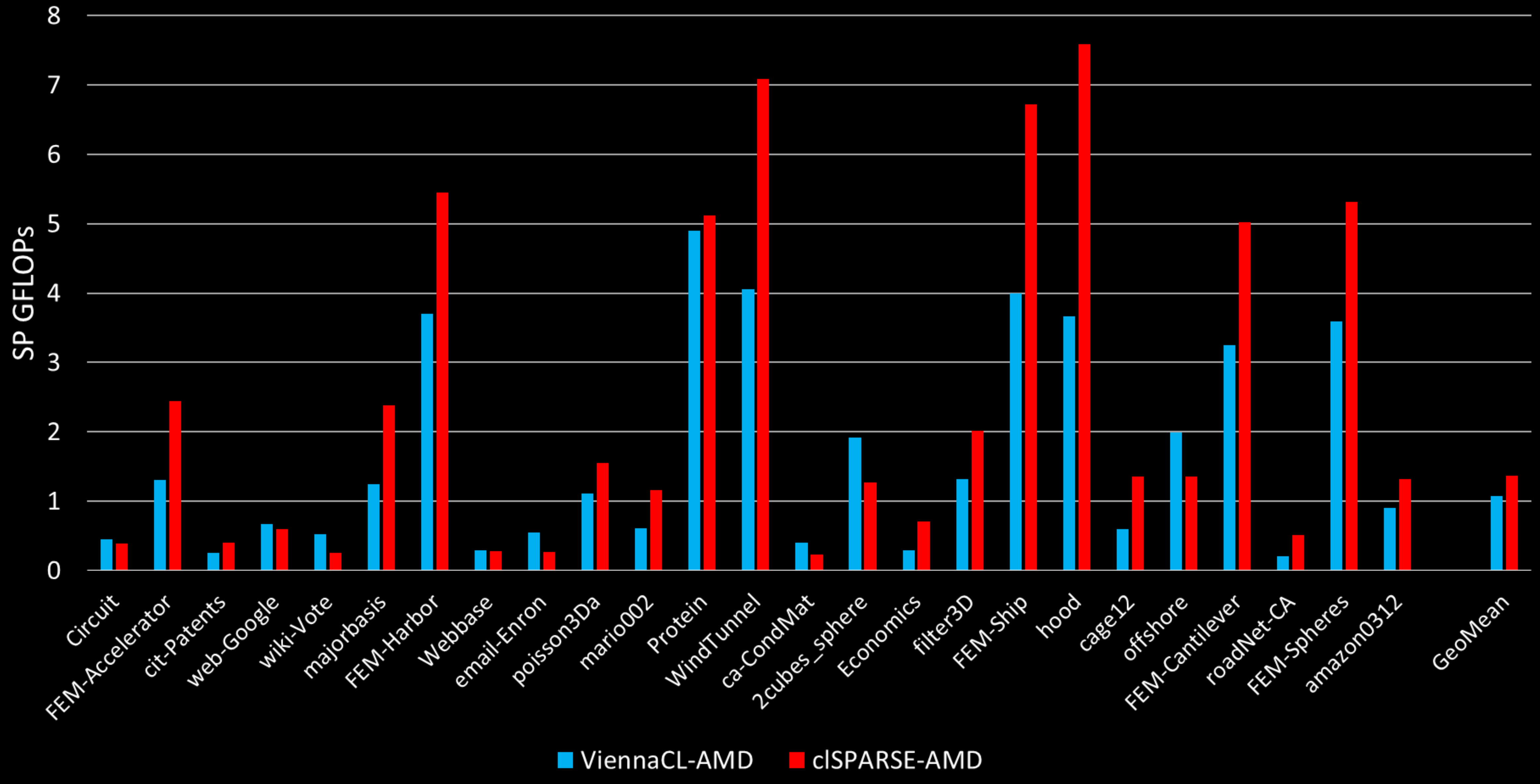
AMD



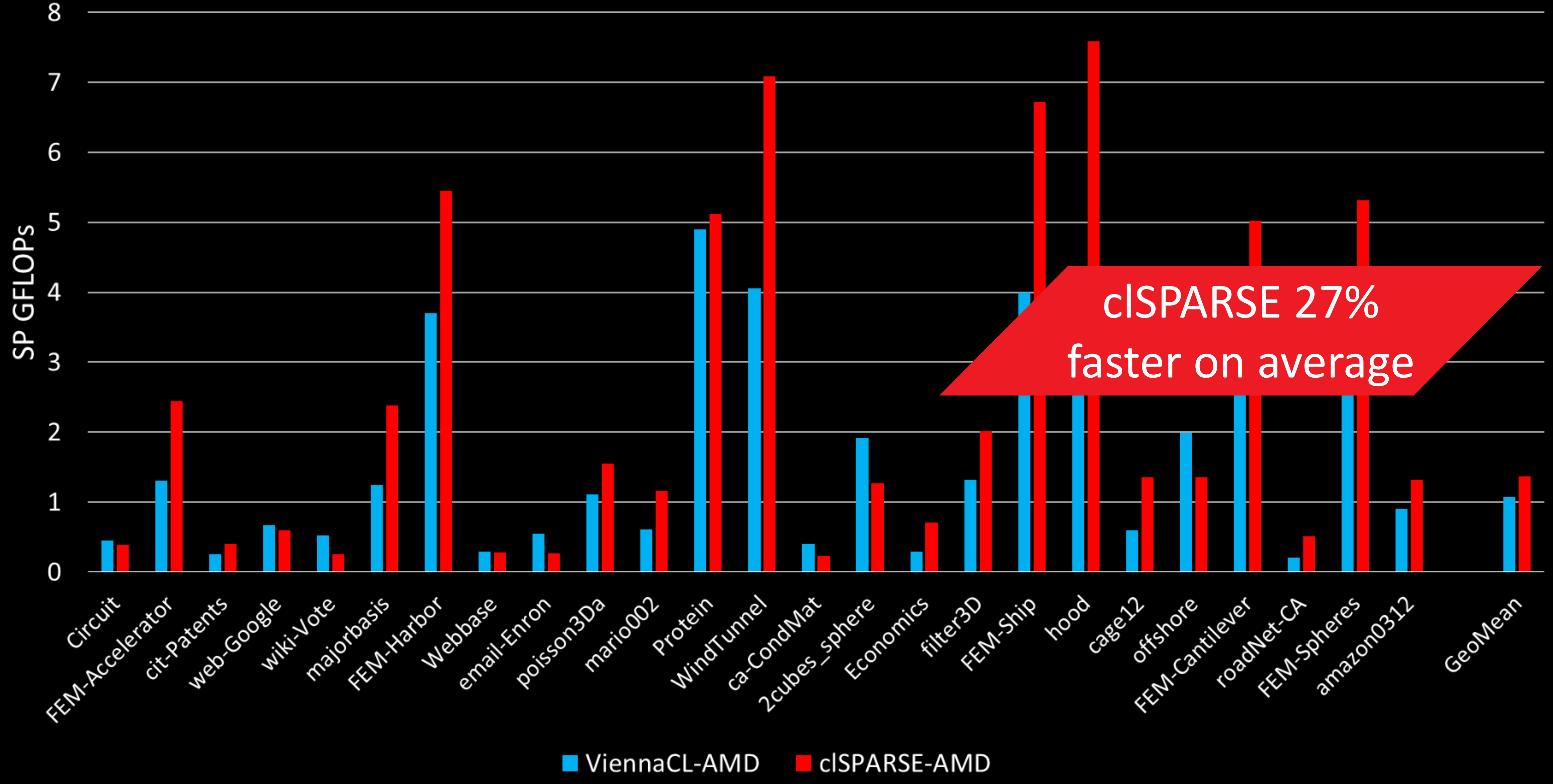
SINGLE PRECISION SPMV – OPEN SOURCE



SINGLE PRECISION SPM-SPM – OPEN SOURCE



SINGLE PRECISION SPM-SPM – OPEN SOURCE



Available at:

https://github.com/clMathLibraries/clSPARSE

Contributions welcome!

For more information on the range of AMD FirePro™ S-series graphics accelerators, contact:

Christian Seithe
Sr. Business Development Manager EMEA –
AMD Professional Graphics
AMD GMBH, Einsteinring 24, D-85609 Dornach b. München, GERMANY
Email: christian.seithe@amd.com
Mobile Office: +49 (0) 89 45053 255
Mobile Phone: +49 (0) 172 999 77 41

Donal Harford
Business Development Manager, UK/Ireland/Nordics –
AMD Professional Graphics Division
Email: donal.harford@amd.com
Mobile: +353 87 442 62 62

Joshue "Josh" Saenz
Sales, AMD Professional Graphics
7171 Southwest Parkway, Austin, TX 78735 USA
Email: Joshue.Saenz@amd.com
Office: +(1) 512-602-0256
Mobile: +(1) 512-201-3065

DISCLAIMER & ATTRIBUTION

AMD

DOUBLE PRECISION SPMV – OPEN SOURCE