SunShot
U.S. Department of Energy

Gen3 CSP Workshop

High-Temperature Particle Technology Pathway: Identification of Gaps and Prioritization of Needs

Particle Technology Working Group

Presented by Cliff Ho, Sandia National Laboratories

energy.gov/sunshot

SAND2016-

Particle Working Group

(* indicates attendance during particle breakout session Aug. 18, 2016)

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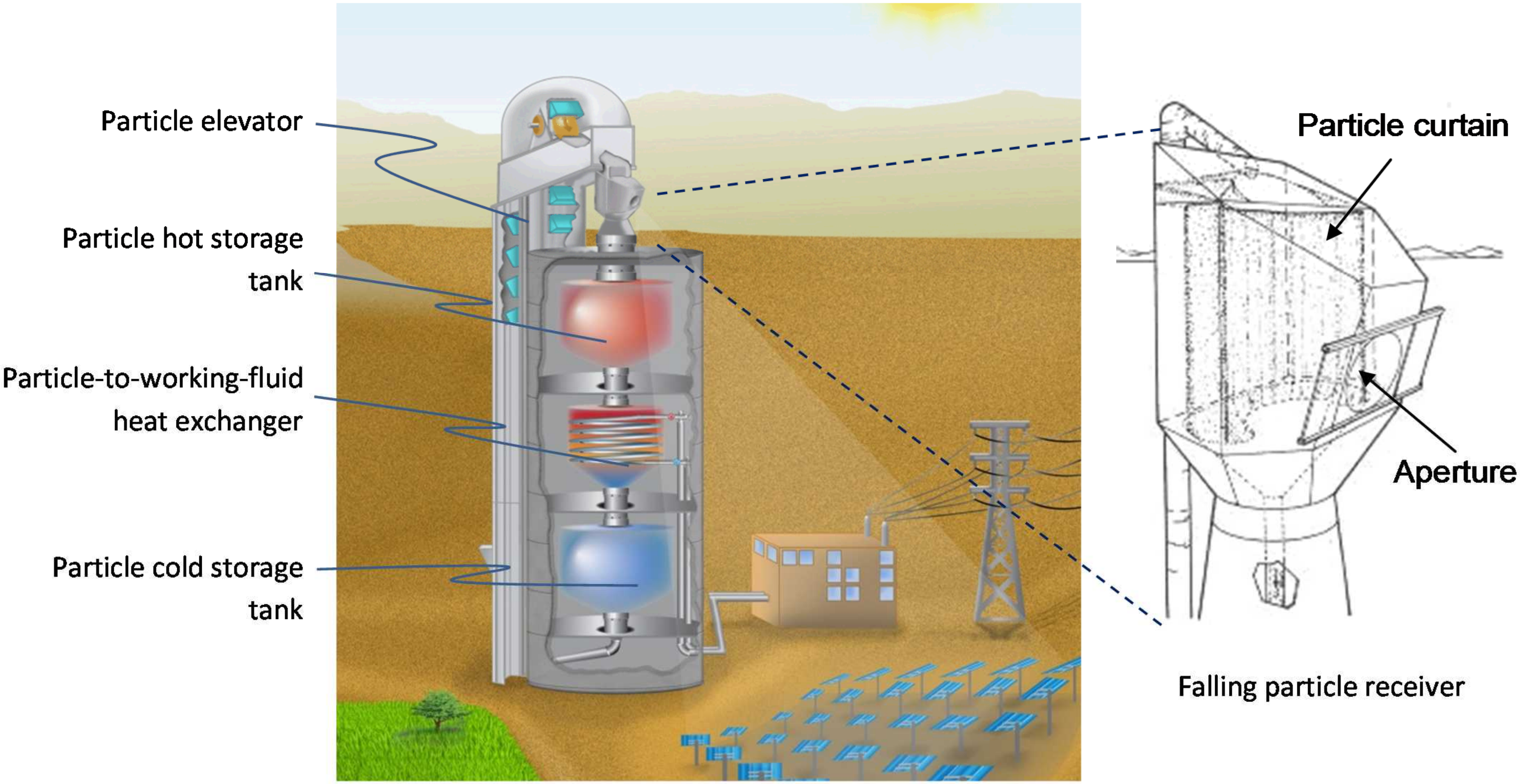
- DOE: Vijay Rajgopal,* Matt Bauer, Levi Irwin*
- DLR: Reiner Buck,* Birgit Gobereit, Lars Amsbeck
- King Saud University: Hany Al-Ansary*
- Georgia Tech: Sheldon Jeter
- Bucknell University: Nate Siegel*
- Colorado School of Mines: Ray Zhang
- Black & Veatch: Daniel Andrew,* Larry Stoddard
- Babcock & Wilcox: Tom Flynn,* Bartev Sakadjian*
- Solex Thermal Science: Ashley Byman, Rob McGillivray, Neville Jordison
- Carbo Ceramics: Claude Krauss, Chad Cannan
- Allied Mineral Products: Dana Goeski
- Jenike & Johanson: Greg Mehos
- Olds Elevator: Richard McIntosh,* Jack Gilchrist*
- Materials Handling Equipment: Steve Bednarz
- FLSmidth Mine Shaft Systems: Todd Kennedy

Review of Particle Receiver System

High Temperature Falling Particle Receiver
(DOE SunShot Award FY13 – FY16)



Goal: Achieve higher temperatures, higher efficiencies, and lower costs

Other Particle Receiver Demonstrations and R&D

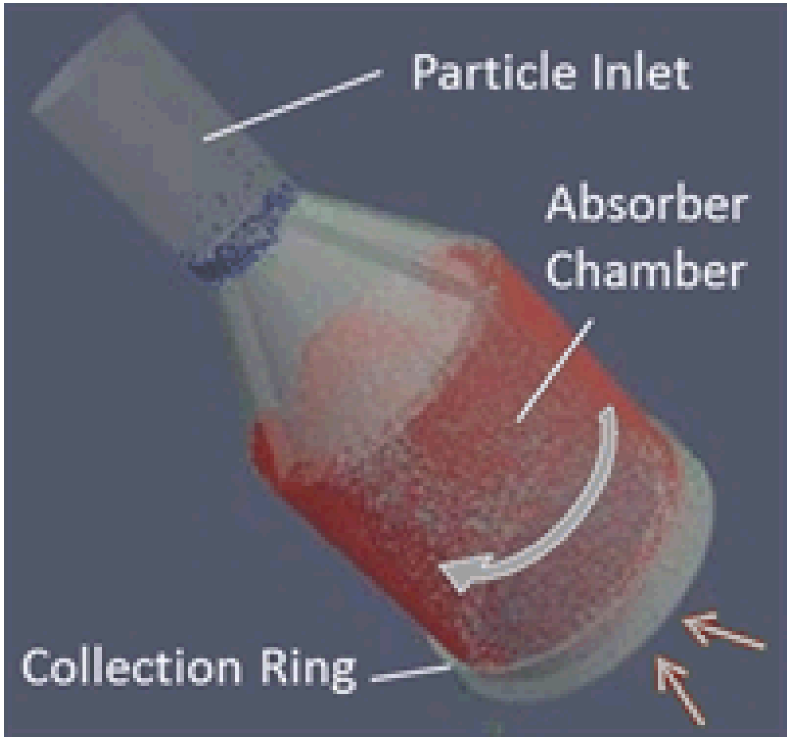
300 kW_t Particle Receiver System – King Saud Univ.

Professor Hany Al-Ansary

- 300 kW_t heliostat field
- Obstructed flow particle receiver
- Particle storage system
- Particle heat exchanger
- Olds elevator particle lift

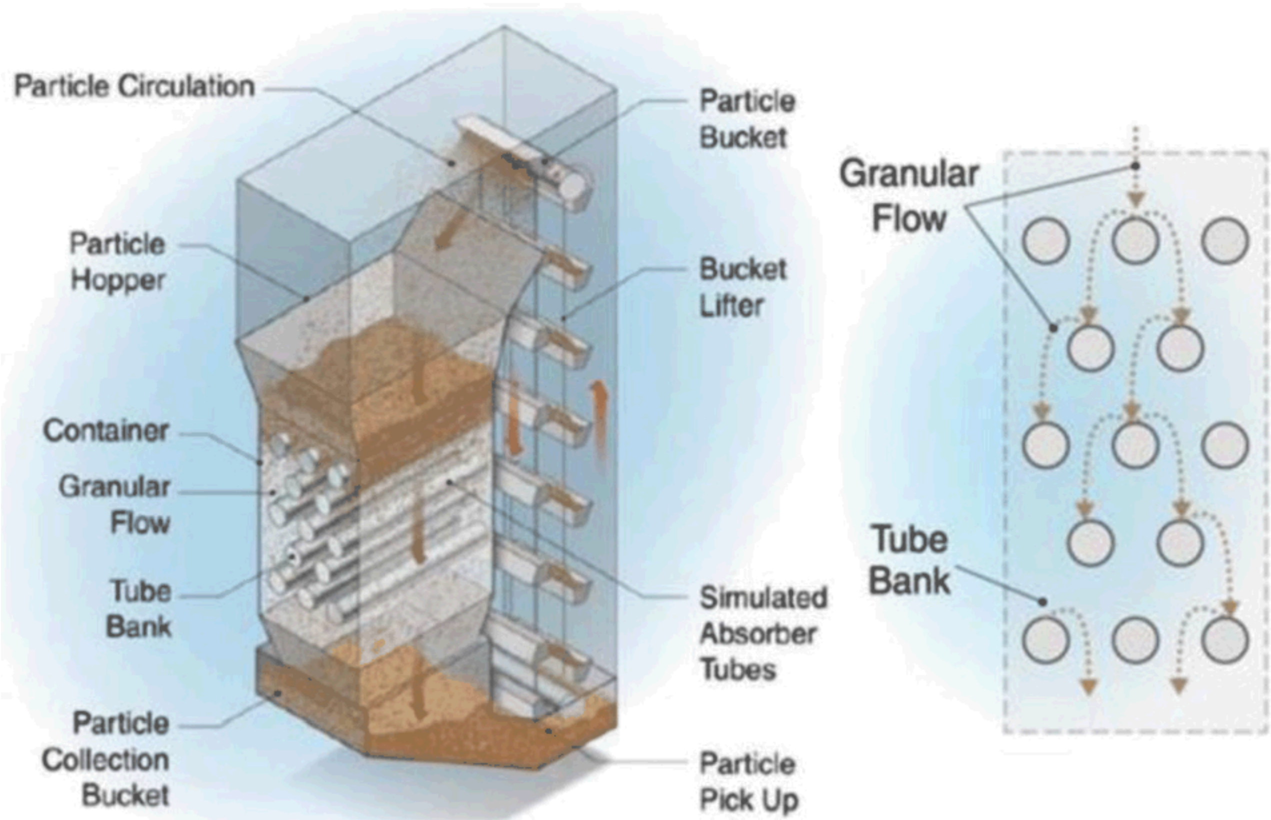
DLR – Centrifugal Particle Receiver

- 15 kW_{th} prototype tested
- 900 C particle temperature at 670 kW/m^2
  - 75% efficiency



NREL – Enclosed particle receiver with light trapping

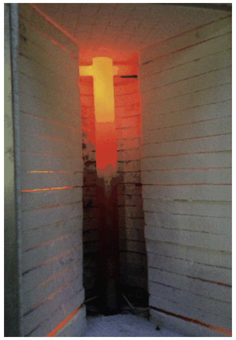
- Particles flow inside enclosure around tubes
- Light penetrates inside tubes



Martinek & Ma (2015)

Fluidized Tubular Particle Receiver

- Flamant et al. – 1980's – present
  - Fluidized particles in opaque tubes
  - 150 kW_{th} pilot tests (1 MW solar furnace)
  - Efficiency 50 – 90%, 585 – 720 C



- Bai et al. (2014) and Matsubara et al. (2015)
  - Fluidized particles in quartz tubes to heat air

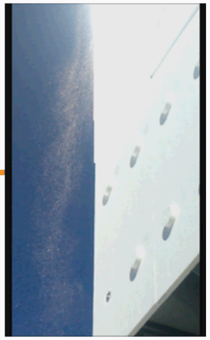
- 2 MW beam-down fluidized sand/steam power plant in Sicily, Italy
  - http://helioscsp.com/concentrated-solar-power-plant-begins-operation-in-italys-sicily/

Identification of Gaps and Needs

Particles

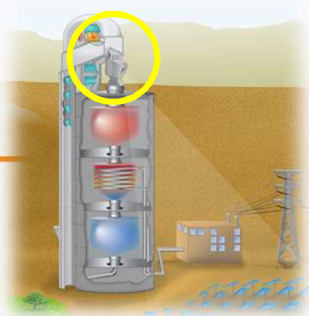
- Need for more flowable media rather than absorptive media
- Improved durability/ less attrition
- Maintaining high solar absorptivity (say, >.95) at high temperatures (≥ 750 ° C)
- Particle cost reduction
  - Calcium flint is about $0.15/kg vs $1-2/kg for CARBO proppants)
  - Spent catalysts are essentially free – KSU is considering this in Saudia Arabia with a company (particles are larger in size ~ 1 mm)

Particle Loss



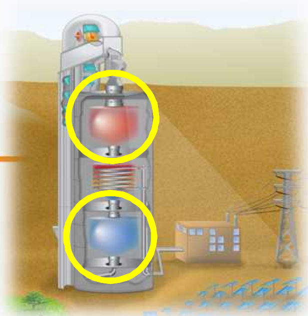
- Need for better particle containment and characterization of loss mechanisms
  - Enclosed indirect particle receiver
  - Aperture covering using quartz glass
- Larger cavities at scale may reduce particle loss
- Use of air curtain to mitigate particle and heat loss
- Use of wind diverters to reduce particle loss
- Particle release location (move toward back)
- Negative pressure zone in cavity

Receiver and Feed Bin



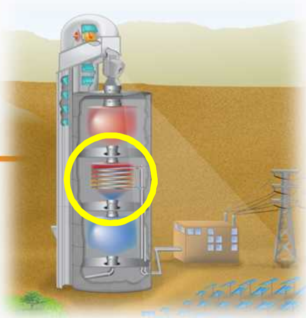
- Demonstration of particle mass flow control and distribution into receiver
- Demonstration of operation, materials and high thermal efficiency at scale
- Evaluate alternative geometries, nod angle, and configurations for increased efficiency
- Demonstration of higher solar flux at larger scale to increase efficiency
- Need a vendor partner to validate receiver design at scale
- Demonstration of increased mass flow to 10-20 kg/s/m
- Particle recirculation demonstration

Particle Storage



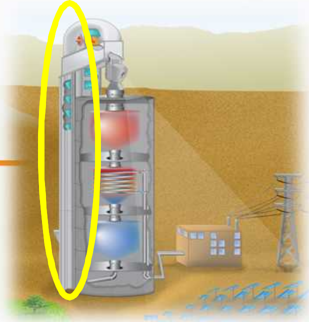
- Evaluate abrasion on interior of storage bin at temperature
- Refined cost analysis
- Demonstration of charging and discharging at scale and at temperature while minimizing heat loss
- Seismic load and foundation considerations for relevant geologic conditions at scale
- Need demonstration of particle flow control from hot storage to heat exchanger
- Can storage be inside tower (e.g., stacked design), or do they need to be placed outside?
  - Need vendor approved design for large scales
- Demo getting particles from cold storage to lift

Particle Heat Exchanger



- Vendor approval of heat exchanger placement (inside tower?)
- Need to reduce costs of heat exchanger to meet SunShot metrics
- Materials degradation from particle abrasion
- Materials for sCO_2 tubes or plates
- Demo of particle to sCO_2 heat transfer at scale to achieve $T_{sCO2} \geq 700$ °C
- Low-cycle fatigue
- Particle-side mass flow control and uniformity (“mass flow”)
- Addressing plugging, bridging, and uncontrolled flow for moving packed bed heat exchanger designs
- Trace heating for temperature control
- Need for multi-material joining (high grade alloys to low grade alloys)
- Need to characterize erosion/corrosion for maintenance/replacement scheduling
- Design for easy replacement and inspection

Particle Lift

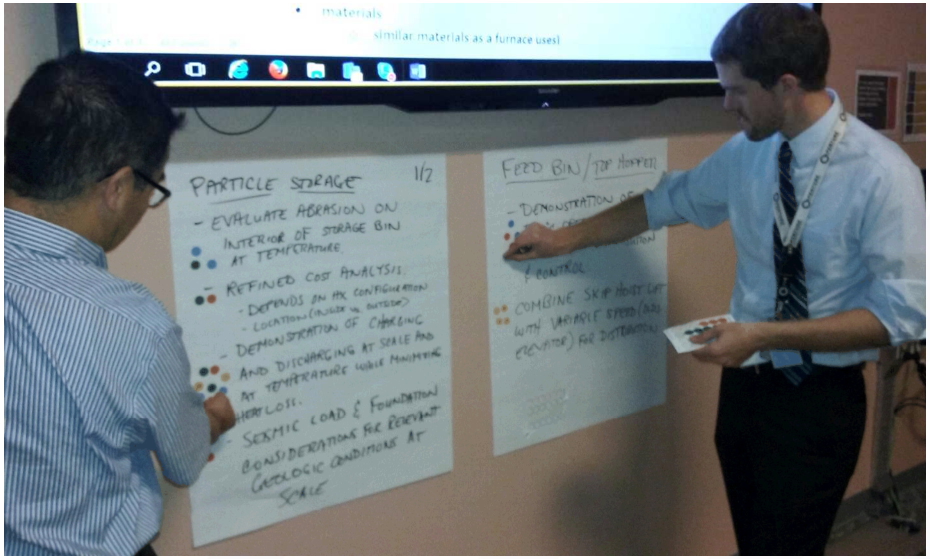


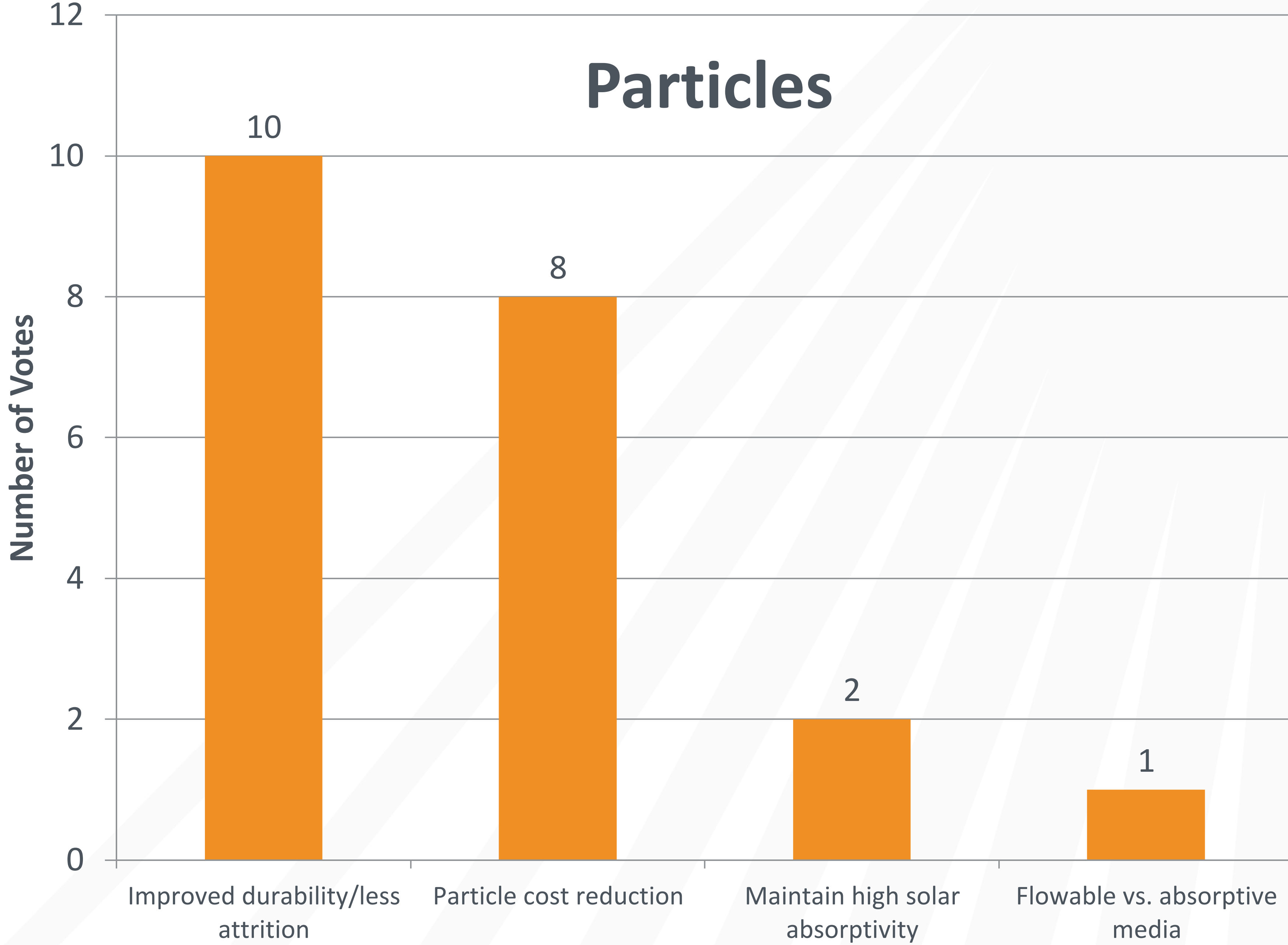
- Demo of high lift rates and capacity
  - 400 tons/hr with lift height of 60 – 70 m
- Insulation at high temperatures (T ≥ 550 °C and reduction of heat loss)
- Low abrasion/high efficiency
- Low footprint/low power requirement
- Demo of charging and discharging of high temperature product at scale
- Control system for mass flow

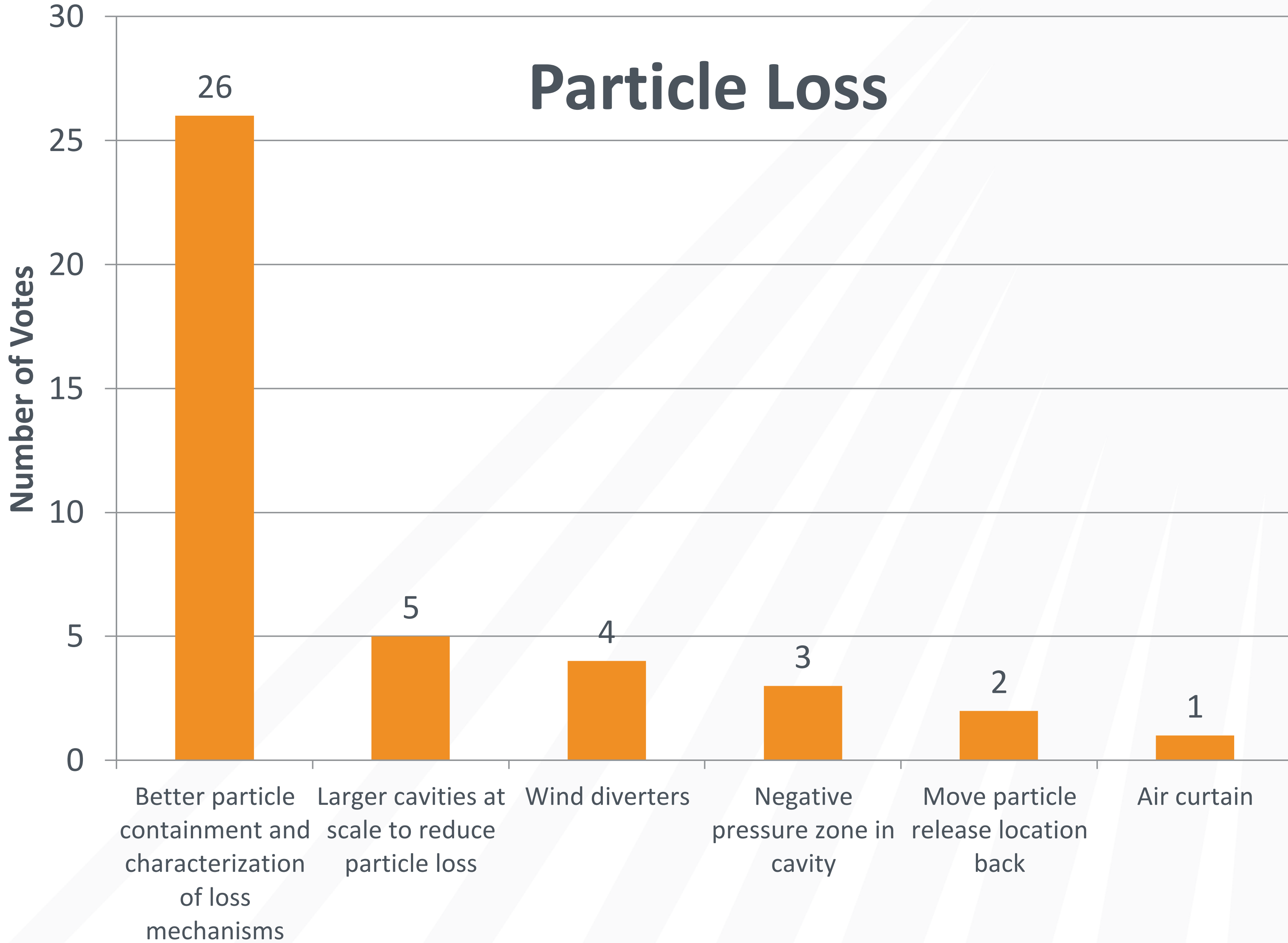
Prioritization of Gaps and Needs

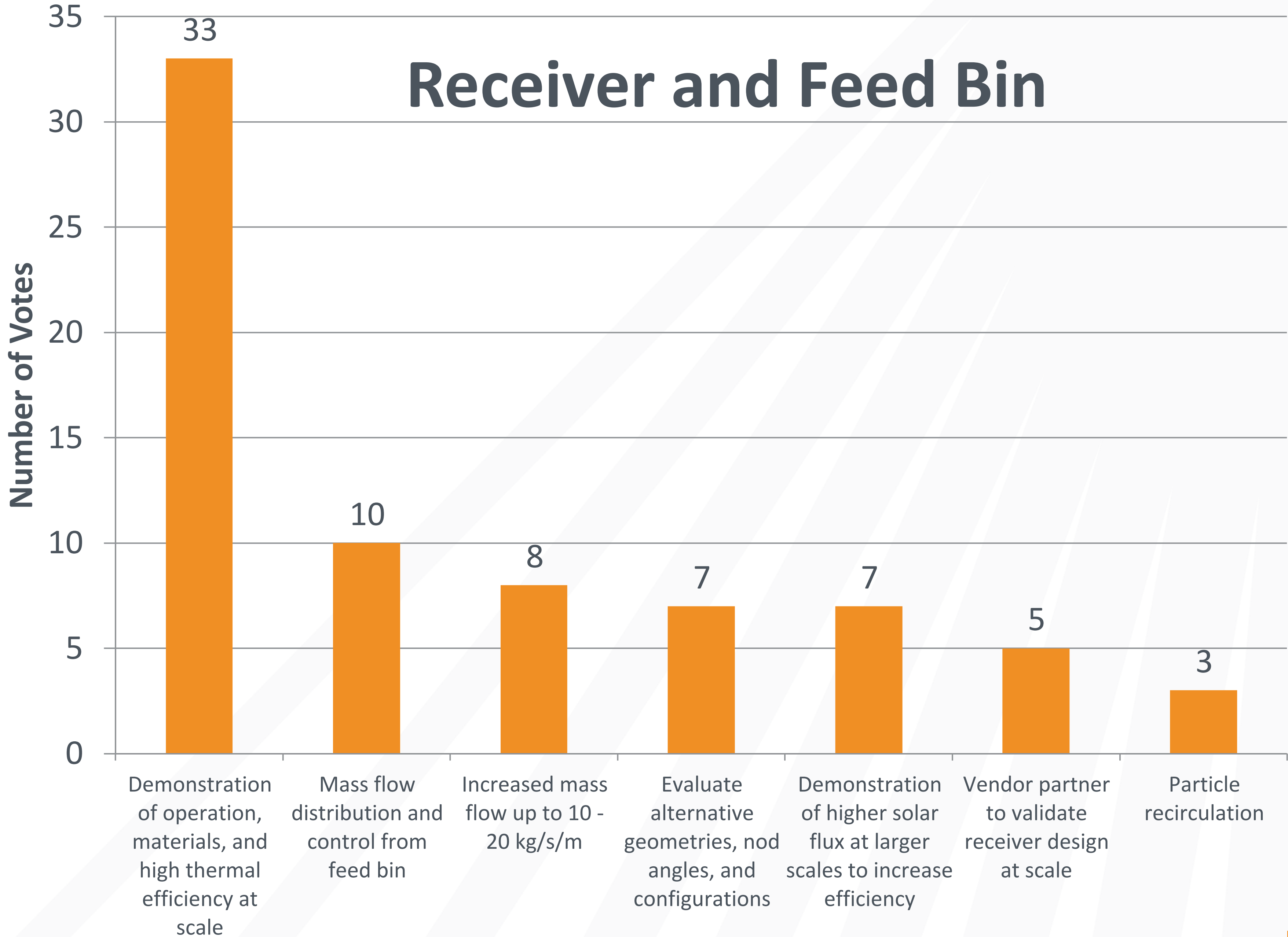
Prioritization Methodology

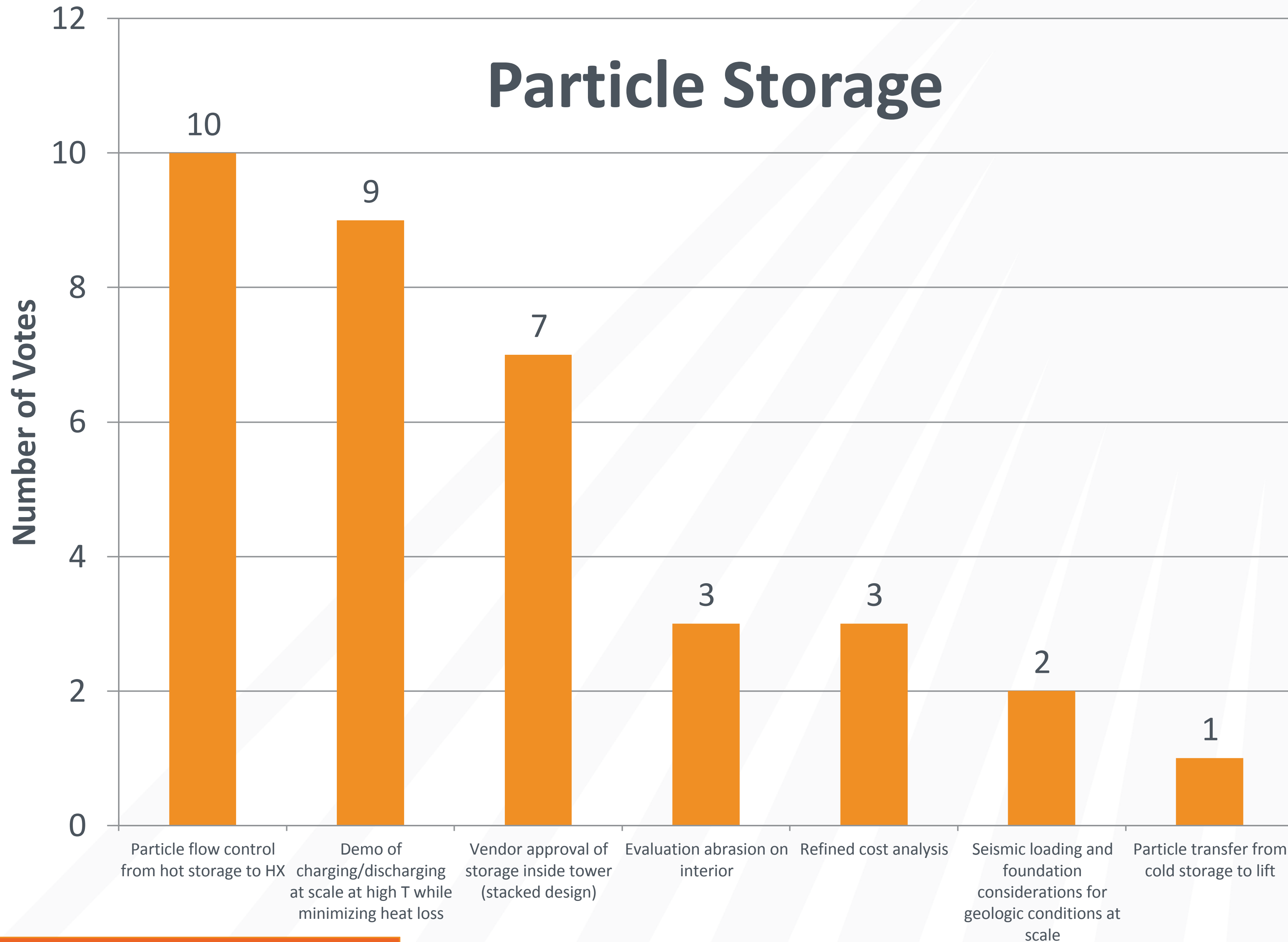
- "Sticky Dot" Voting
  - Each participant had 24 sticky dots to vote for any of the identified gaps and needs



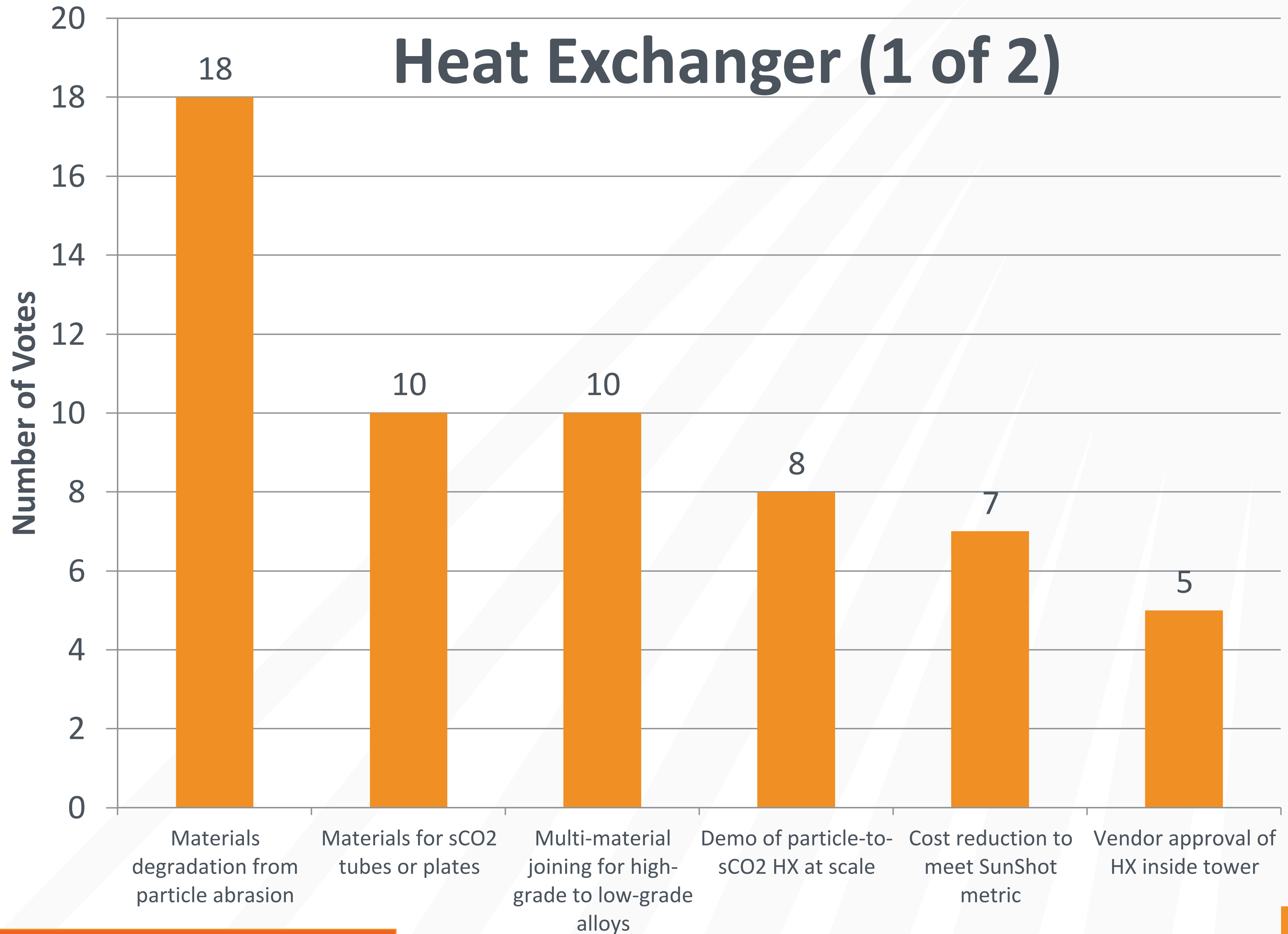

Particles
Number of Votes
12
10
8
6
4
2
0
10
8
2
1
Improved durability/less attrition
Particle cost reduction
Maintain high solar absorptivity
Flowable vs. absorptive media


Particle Loss
Number of Votes
30
25
20
15
10
5
0
26
5
4
3
2
1
Better particle containment and characterization of loss mechanisms
Larger cavities at scale to reduce particle loss
Wind diverters
Negative pressure zone in cavity
Move particle release location back
Air curtain

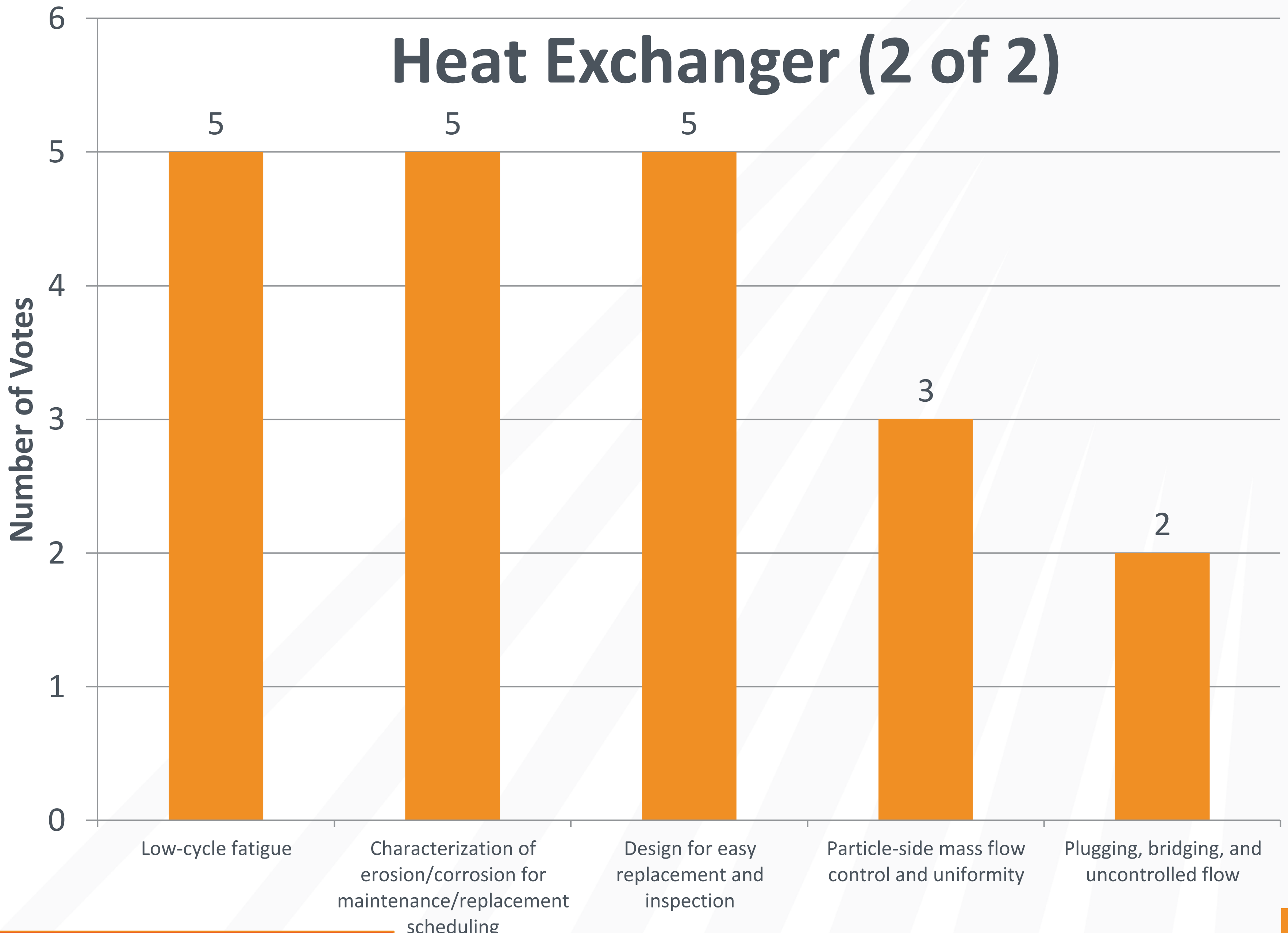

Receiver and Feed Bin
Number of Votes
35
30
25
20
15
10
5
0
33
10
8
7
7
5
3
Demonstration of operation, materials, and high thermal efficiency at scale
Mass flow distribution and control from feed bin
Increased mass flow up to 10 - 20 kg/s/m
Evaluate alternative geometries, nod angles, and configurations
Demonstration of higher solar flux at larger scales to increase efficiency
Vendor partner to validate receiver design at scale
Particle recirculation

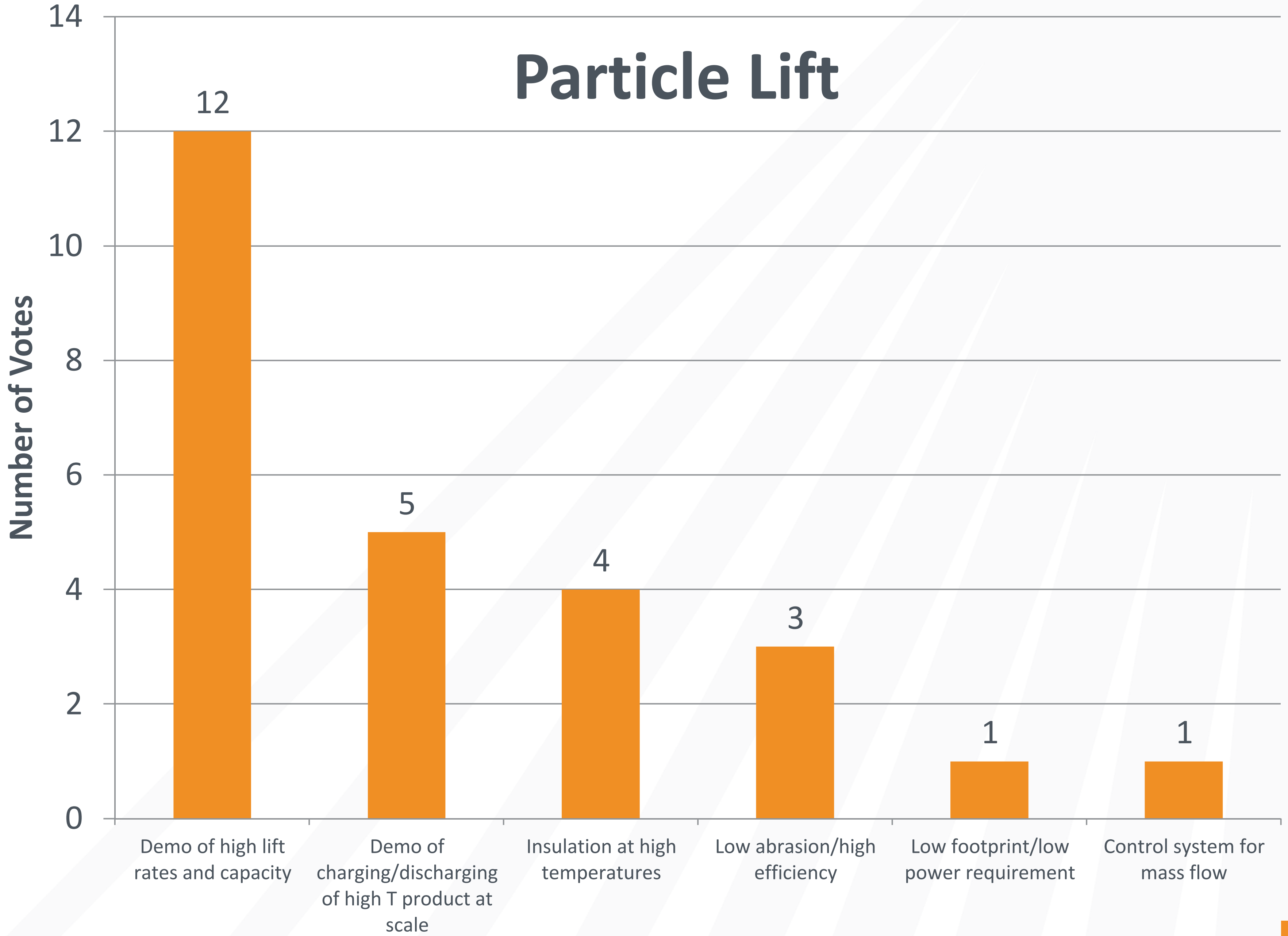

Particle Storage
Number of Votes
12
10
8
6
4
2
0
10
9
7
3
3
2
1
Particle flow control from hot storage to HX
Demo of charging/discharging at scale at high T while minimizing heat loss
Vendor approval of storage inside tower (stacked design)
Evaluation abrasion on interior
Refined cost analysis
Seismic loading and foundation considerations for geologic conditions at scale
Particle transfer from cold storage to lift

Heat Exchanger (1 of 2)



Heat Exchanger (2 of 2)




Particle Lift
Number of Votes
14
12
10
8
6
4
2
0
12
5
4
3
1
1
Demo of high lift rates and capacity
Demo of charging/discharging of high T product at scale
Insulation at high temperatures
Low abrasion/high efficiency
Low footprint/low power requirement
Control system for mass flow

Summary

Summary

- Gaps and needs were identified for particle technology components
  - Particles / particle loss
  - Receiver / feed bin
  - Particle storage
  - Particle heat exchanger
  - Particle Lift
- Gaps and needs were prioritized using "sticky dot" voting