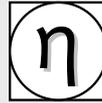


Introducing the Baseline Performance Reference

Anton Driesse

PV Performance Labs, Freiburg, Germany



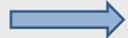
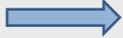
Aron Habte and Manajit Sengupta

NREL, Golden, Colorado, USA



PVPMC Workshop, Mendrisio, Switzerland, November 8, 2023

PV System

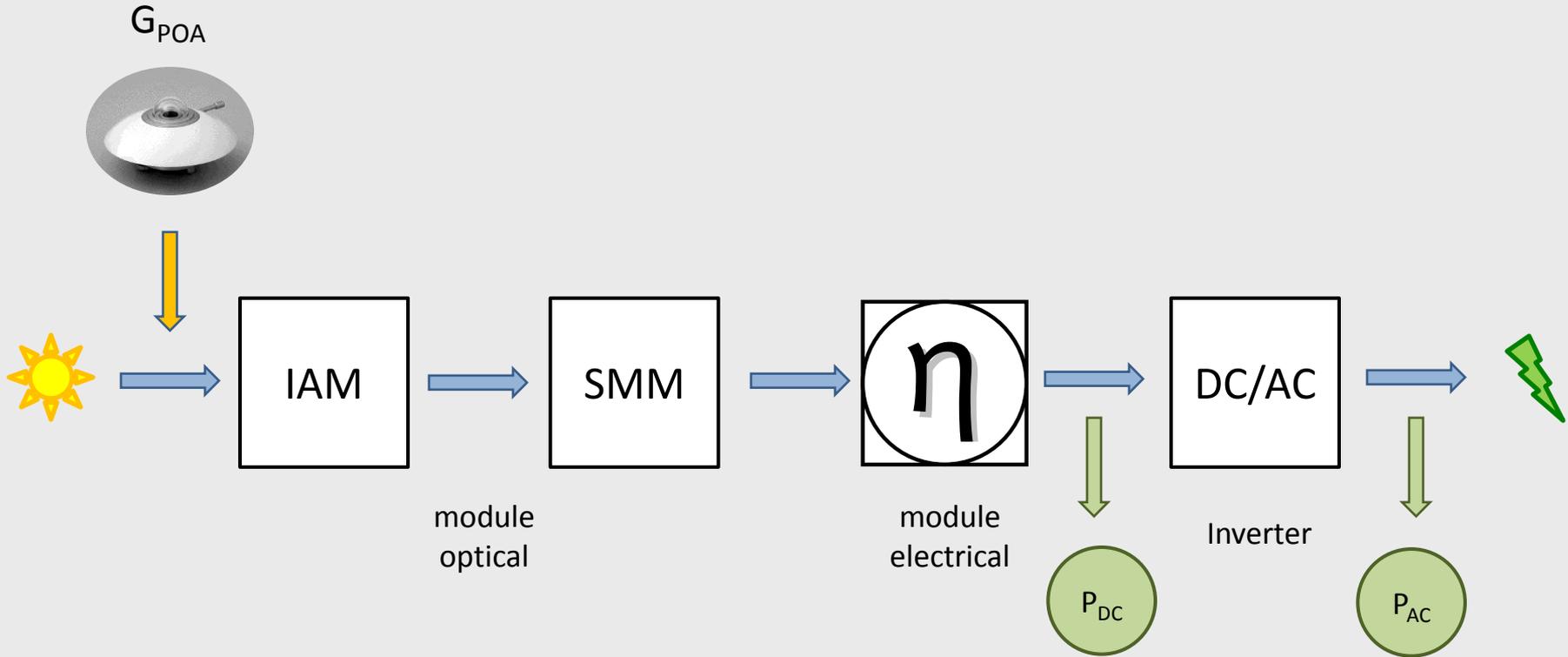


PV System Performance

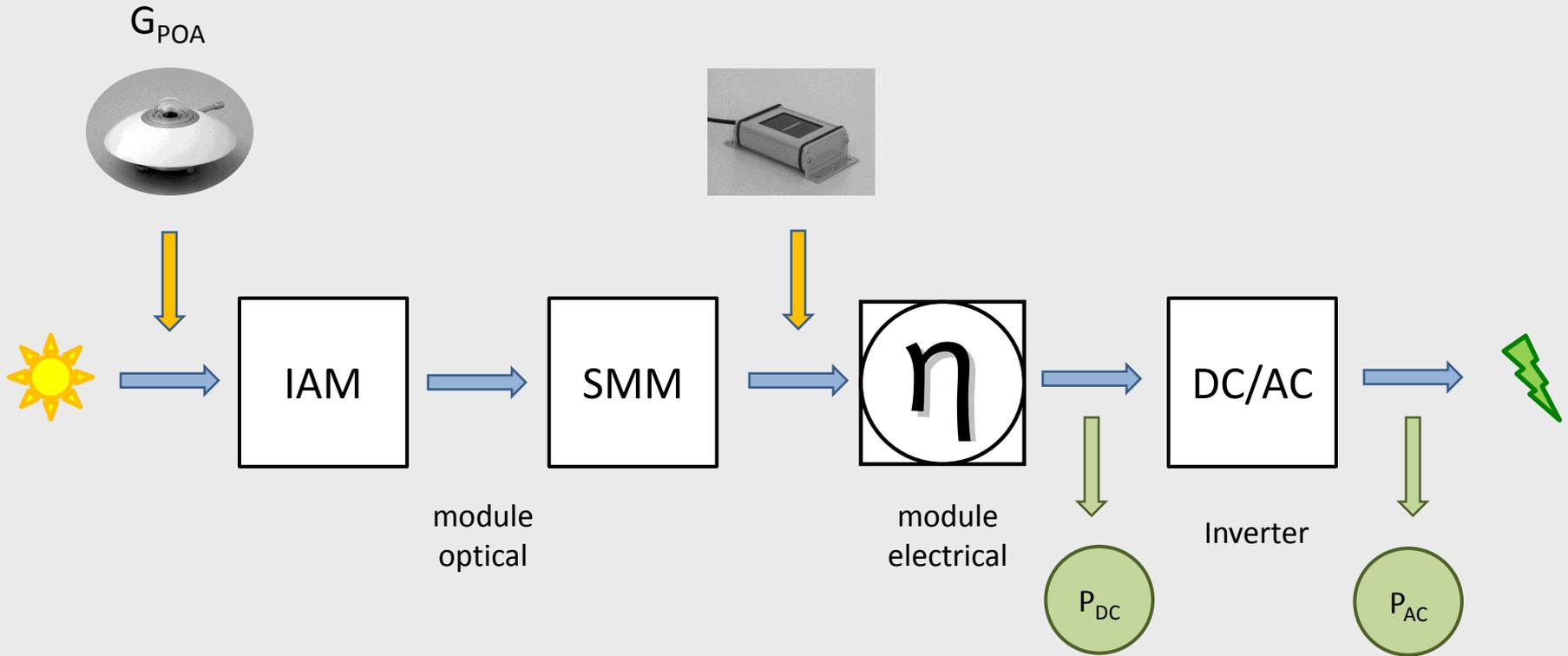


$$\frac{P}{G} \rightarrow \frac{\frac{P}{G}}{\frac{P_o}{G_o}} \rightarrow \frac{\frac{P(T)}{G}}{\frac{P_o}{G_o}} \rightarrow \frac{\text{measured}}{\text{simulated}}$$

PV System under the hood



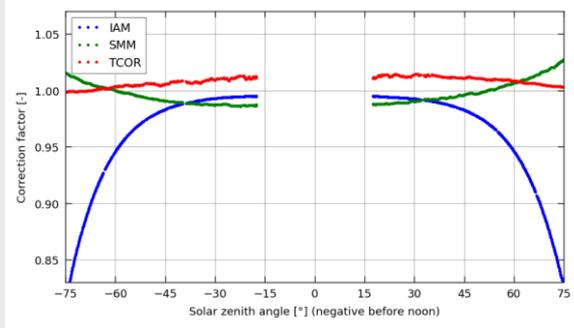
PV System under the hood



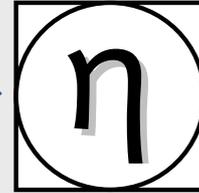
PV System under the hood



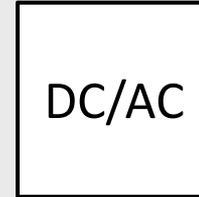
G_{POA}



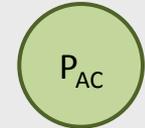
module
optical



module
electrical



Inverter



Pyranometer or reference cell?



Modeling SMM and IAM introduces uncertainty

Measurements from a matched reference cell remove this modeling uncertainty

But what about the measurement uncertainty?

And can I even buy a “matched” reference cell ??

Evaluation of reference cells you can buy



PVPLabs (2014...): 4 manufacturers, 6 types, 20 cells, 2 locations

NREL (2019...): 6 manufacturers, 10 types, 40+ cells, 3 locations

single-axis tracker



2023-11-08

fixed-tilt



Anton Driesse, PV Performance Labs, Germany

dual-axis tracker



8

Evaluation of reference cells you can buy



Example: Comparison of annual POA energy

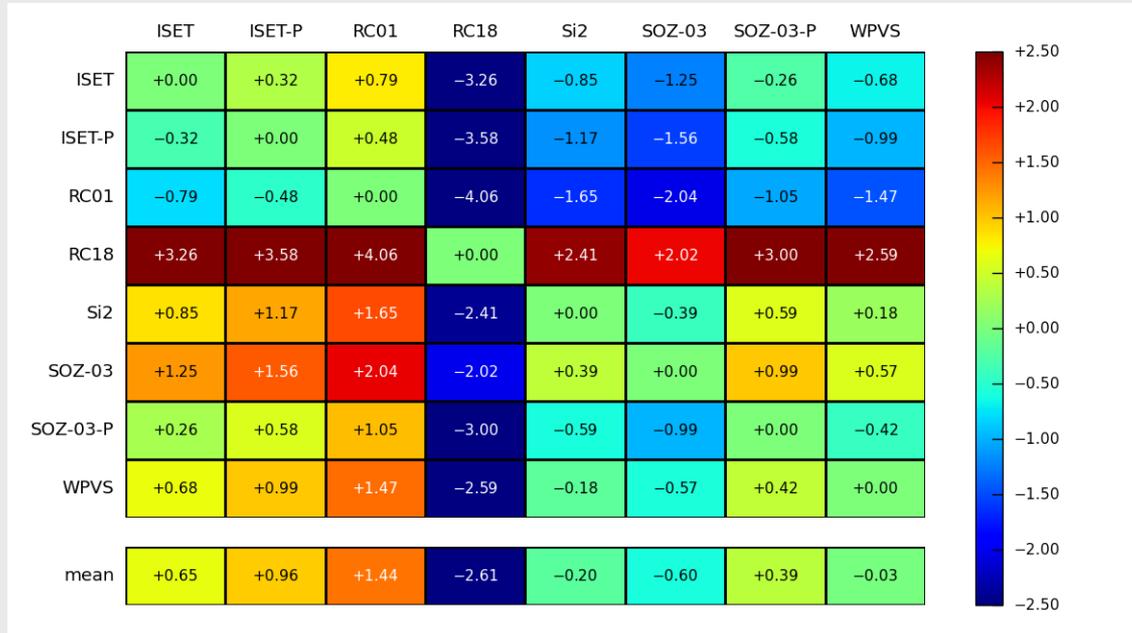
fixed-tilt



Comparison of annual POA energy at fixed tilt



using factory calibrations

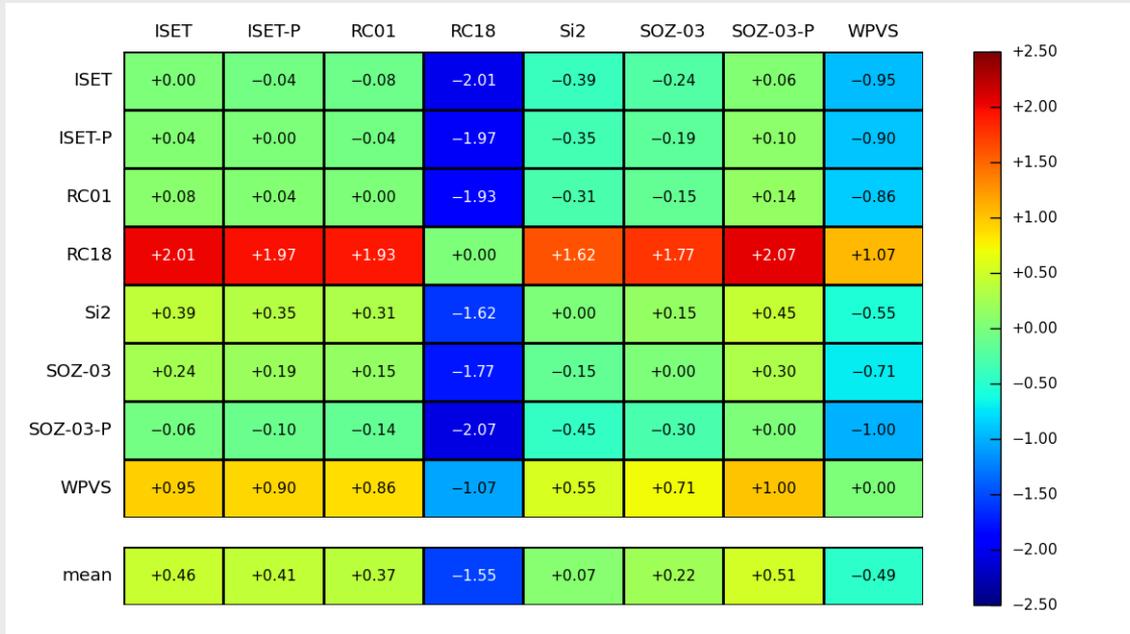


$$\frac{(max - min)}{mean} = 4.1\%$$

Comparison of annual POA energy at fixed tilt



using local field calibrations



$$\frac{(max - min)}{mean} = 2.0\%$$

Comparison of annual POA energy at fixed tilt



The cells we bought and tested have different IAM and SMM characteristics
(among other things)
and therefore “match” different PV modules—or perhaps none at all.

But there are no *right* or *wrong* IAM and SMM characteristics,
therefore, we can't quantify measurement *error*
and we can't quantify measurement *uncertainty*.



Introducing the Baseline Performance Reference



Proposal for standardized reference cell characteristics

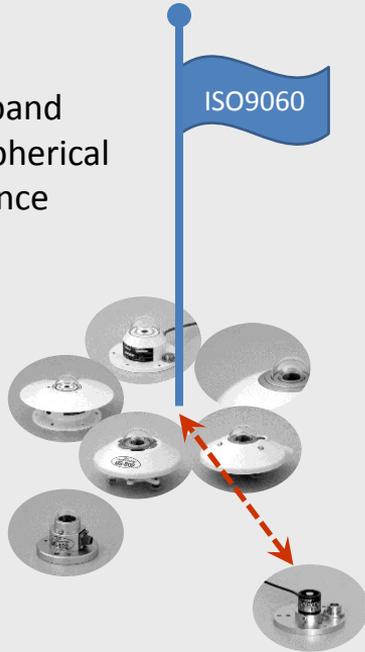
Definition of a “measurand”

Equivalent of ISO 9060 for reference cells

Introducing the Baseline Performance Reference

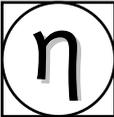


broadband
hemispherical
irradiance

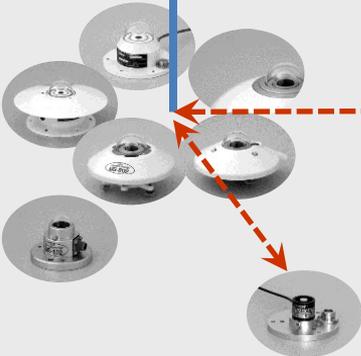


POA
effective
irradiance

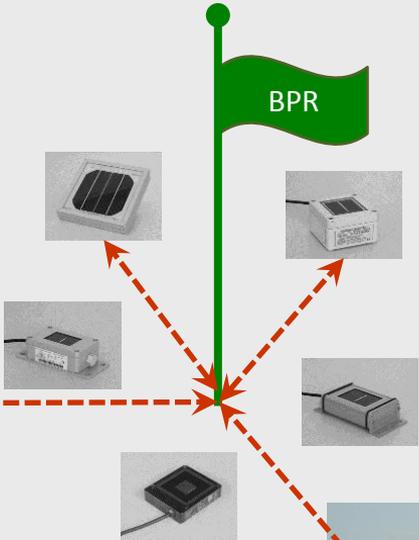
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broadband
hemispherical
irradiance



BPR



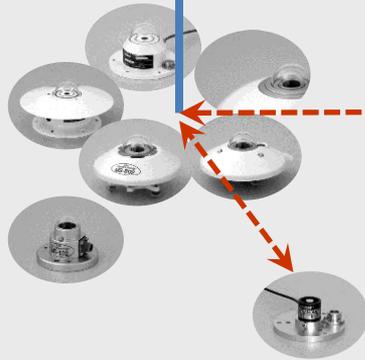
POA
effective
irradiance



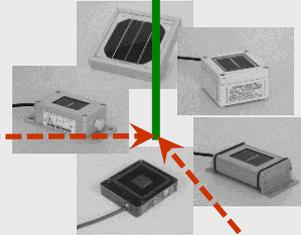
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broadband
hemispherical
irradiance



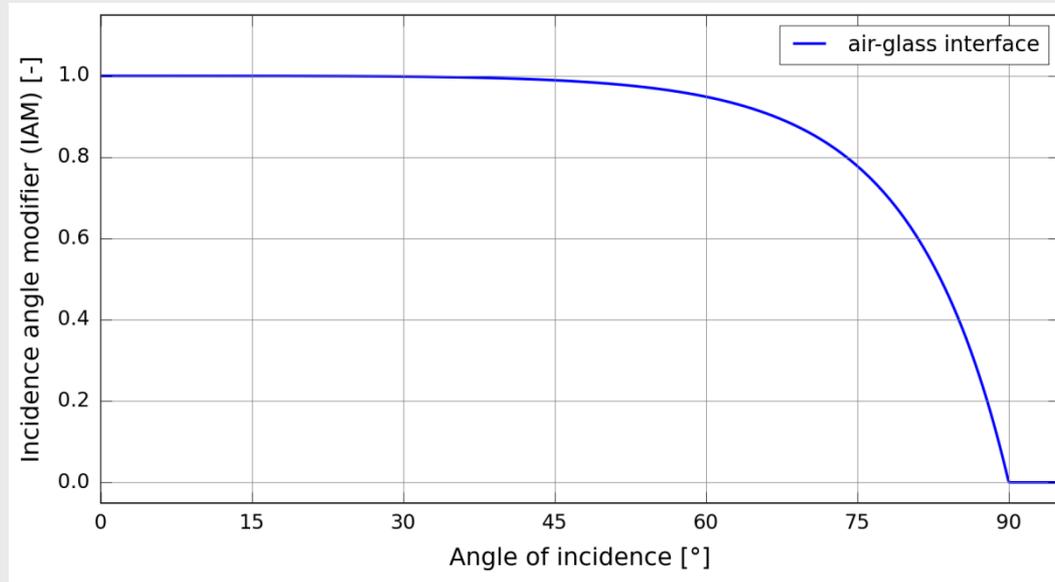
BPR



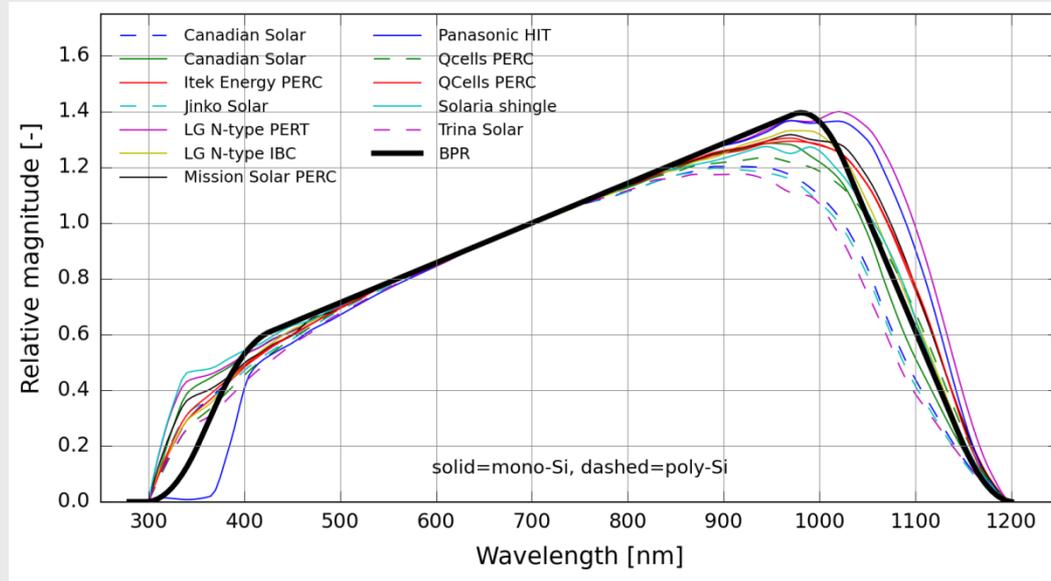
POA
effective
irradiance



BPR directional response



BPR spectral response



Summary of key differences



	ISO 9060	IEC 60904-2	ASTM E1040	WPVS	BPR
Directional response	Lambertian	Incompletely specified by physical package constraints			One air-glass interface
Temperature response	Flat	Linear correction	Linear correction	Operation at 25°C	Flat
Spectral response	Flat	Matched to the device under test			Simple idealization



The Baseline Performance Reference for Irradiance in PV System Applications

Anton Driesse,¹ Aron Habte,² and Manajit Sengupta³

1 PV Performance Labs

2 National Renewable Energy Laboratory

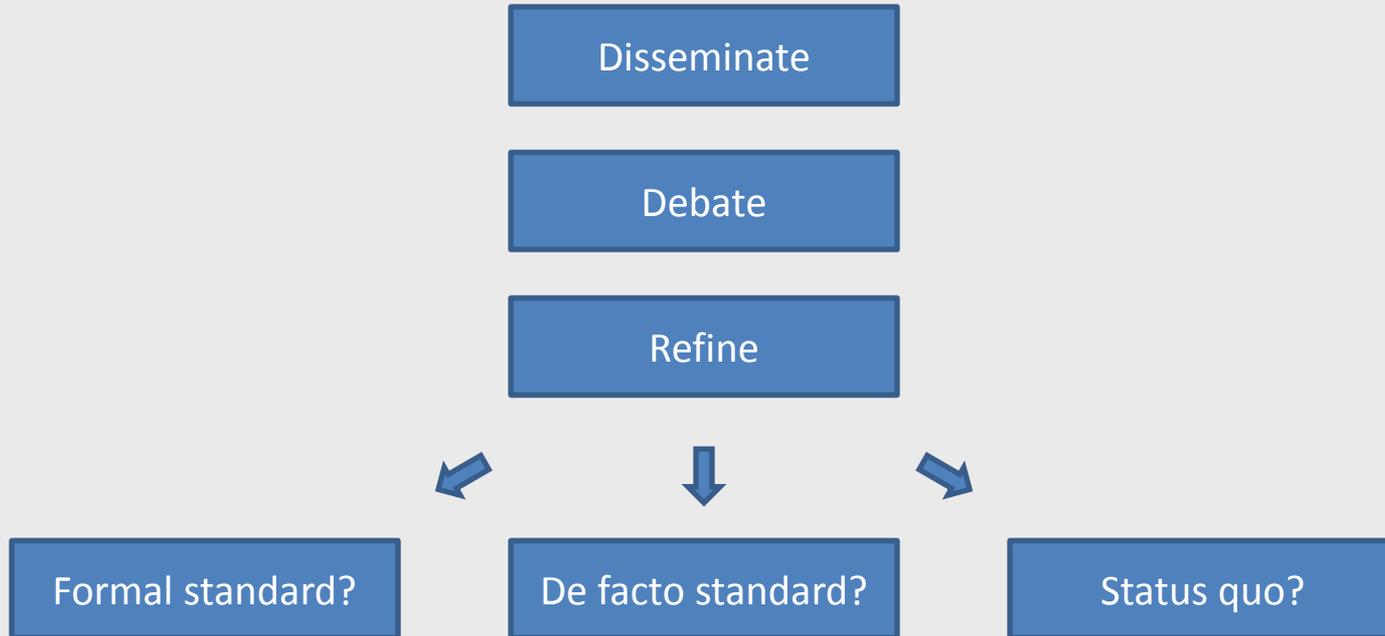
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Office of Energy Efficiency & Renewable Energy
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NREL/TP-5D00-86847
September 2023

What's next?





Thank you!