ON THE USE OF OPTICAL WAVEGUIDES IN HYBRID PHOTOVOLTAIC SOLAR THERMAL ENERGY CONVERTERS

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A Solar Energy Converter With Improved Photovoltaic Efficiency, Frequency Conversion and Thermal Management Permitting Super Highly Concentrated Collection

OVERVIEW

- Principles of Operation
- Demonstrated Improvement Factors
  - over concentrated PV
  - over full sky ambient PV
- Demonstrated Heat Transfer
  - and thermal distribution advantages
- Manufacturability

PRINCIPLES OF OPERATION

Phase One = filtering

efficiency improvement and thermal distribution

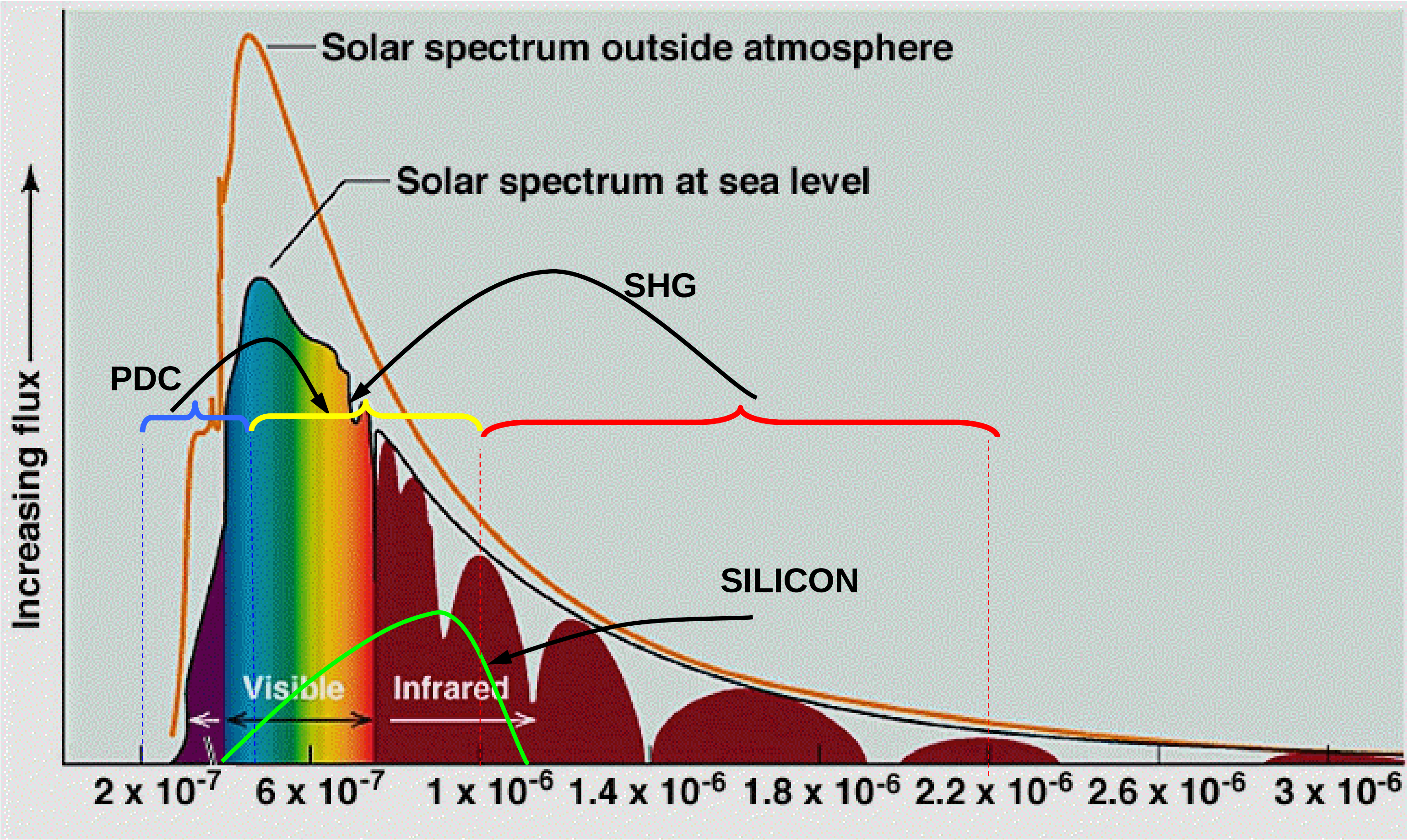
ready for deployment

Phase Two = frequency conversion

ready for deployment in 2 years

can retrofit into phase one modules

Phase Two – Frequency Conversion



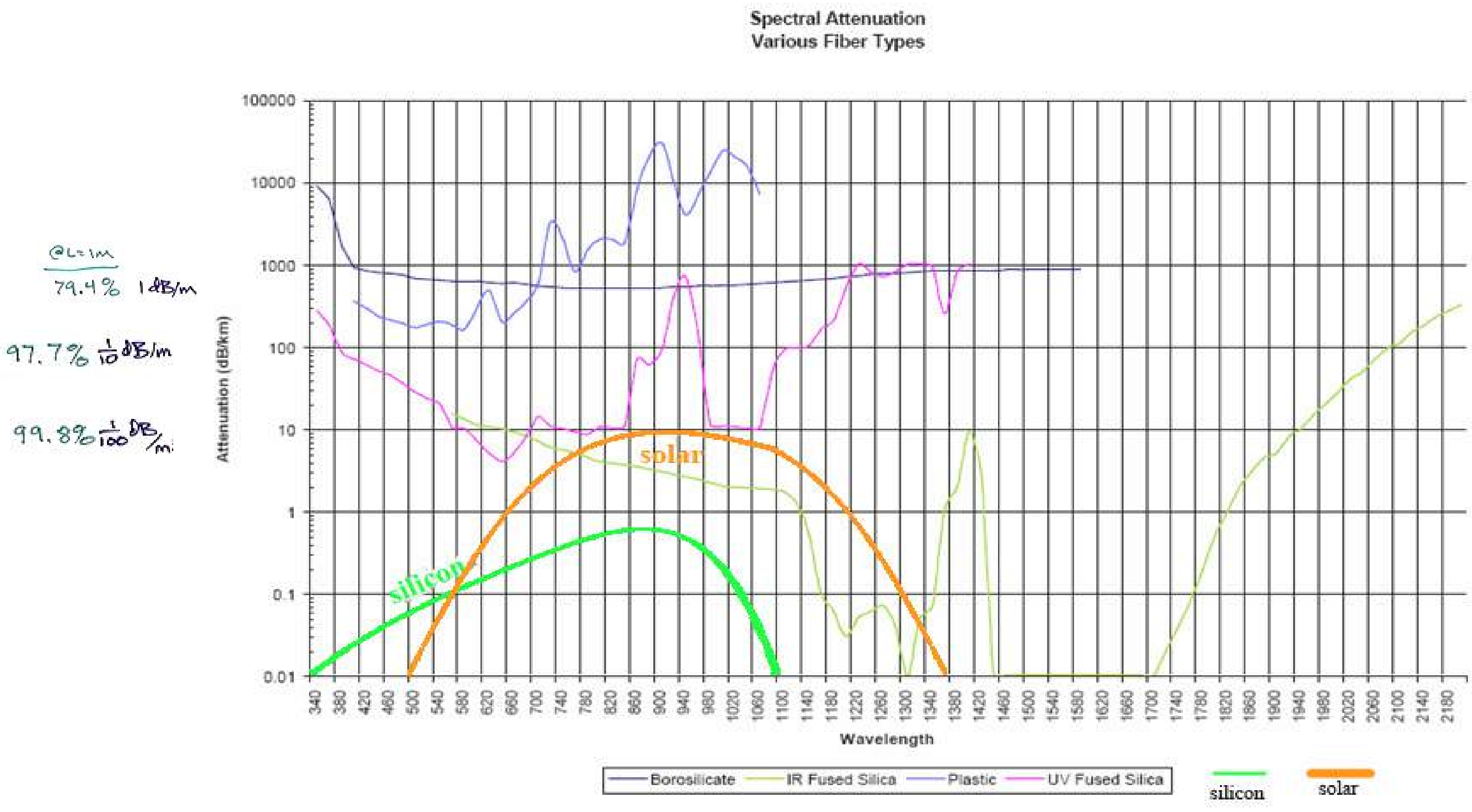
for silicon 25% → 40%

for InGaAs 20% → 60%

Phase One – Filtering and Thermal Distribution

- Plastic is cheaper than silicon, so why not…
  - problem is you're also concentrating the UV and IR sources of heat
- A variety of filtering technologies have been analyzed
  - the use of chromatic aberration (in a lens, prism, etc.)
  - multilayer dielectric filters
  - optical fiber; and optical rod waveguides
- Optical waveguides/fiber are useful filters with thermal distribution advantages
- As a filter, the response evolves as a function of the length of the guide
  - this shape can be optimized for the application
- The thermal advantages are several
  - efficiently couple heat to almost any solar thermal technology – great flexibility
  - potential for heat transfer efficiencies that could approach 100% simply by making them longer (as low loss, low cost, options exist).

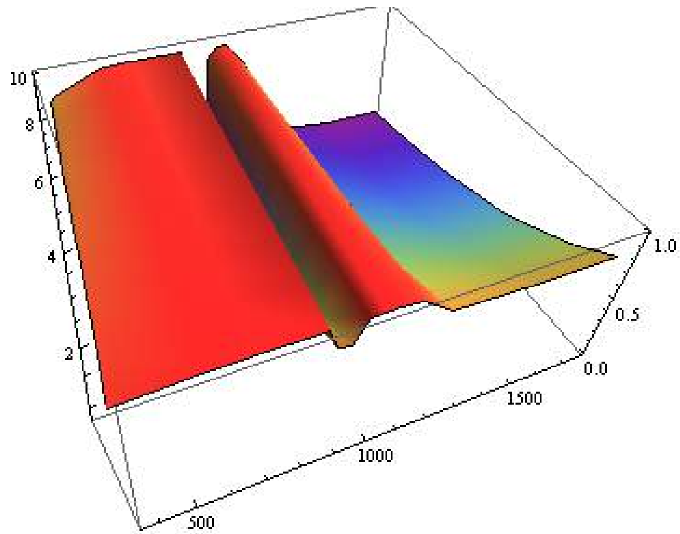
Phase One – Filtering and Thermal Distribution



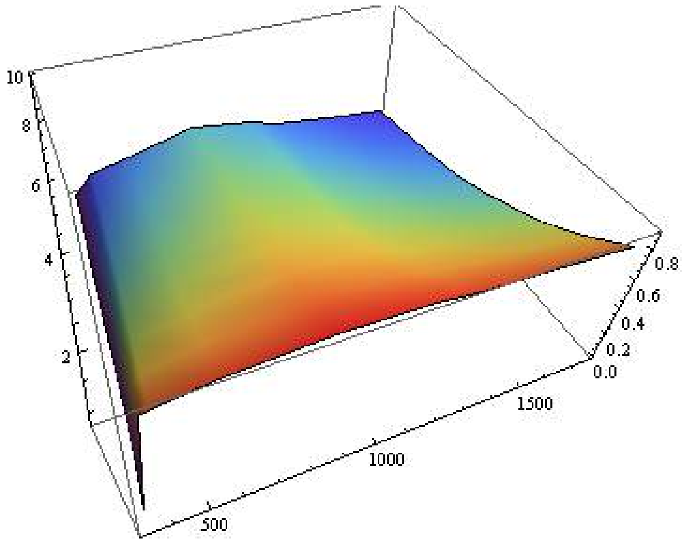
We remove the heat from the light BEFORE it hits the PV thus we can go to higher levels of concentration (w/o the costs of cooling PV etc.)

Phase One – Theory

UV FUSED SILICA

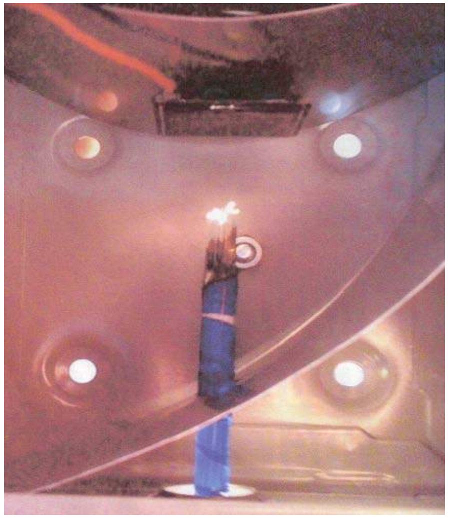


BOROSILICATE



Either one can yield a (lower bound) photovolatic improvement factor, "PVI", of more than 2.

Improvement Over Concentration



Spot Diameter	w/ TDE	w/o TDE
8cm	.8	.15
25cm	.3	.18
36cm	.14	.194

~4x via TDE & CONC.

Seeing Temp ≈ counter effect of concentration

But w/o conc. only see TDE loss

Hand made bundle

~ same incident area (actually TDE area LESS than hole)

same illumination area

So: 1W □ vs □ 4W

Fixed cost (neglecting TDE)

More power

OR

1 2
3 4 vs 1

Fixed power Less cost

NOTE: can't count both at same time

NOTE ALSO: it doesn't matter what size "□" is
scale it as big as you want – we get 4x that in cost/kW (if TDE cost negligible)

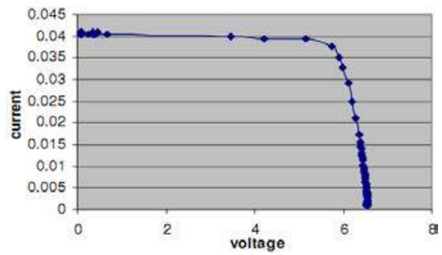
Improvement Over Full Sky Ambient PV

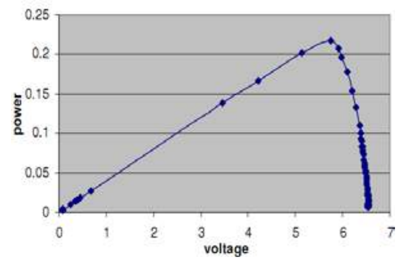
Production bundle, 6 ft. long!

Very cheap, but lots of loss

$ .02/m 1 dB/m

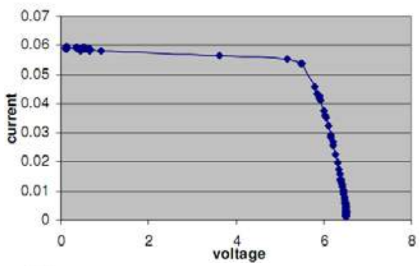
d=21

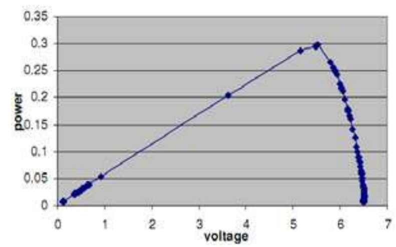




3.61 X ambient

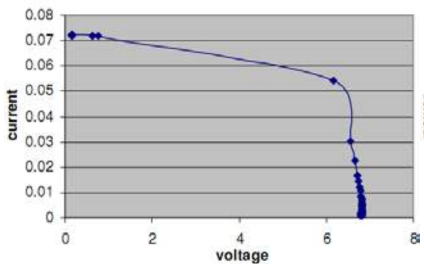
d=22

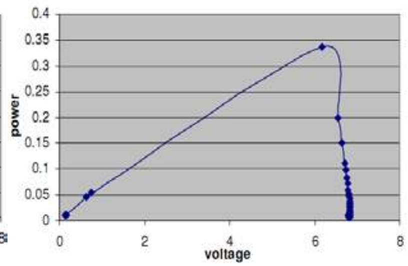




4.96 X ambient

d=23



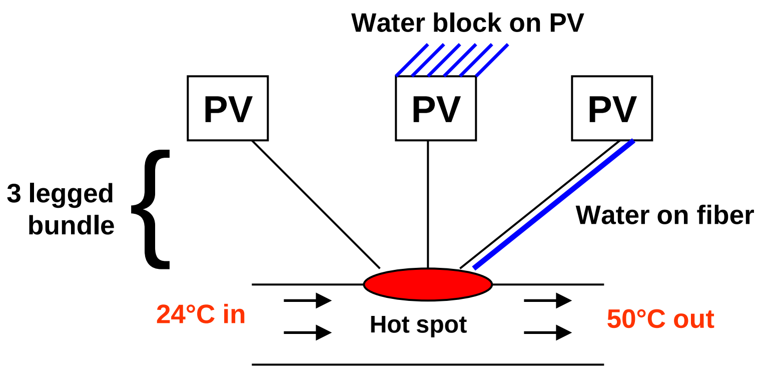


5.6(plus) X ambient
(missed peak)

Demonstration of Heat Transfer and Thermal Distribution Advantages

Water cooling hot spot @ fiber bundle input:

24°C in ⟶ 50°C out



d	Peak power	Peak power	Peak power
23	.27	.24	.81
22	.21	.21	.51
21	.18	.15	.27

Cooling PV after fiber not much effect

Cooling fiber definite effect

Thus, fiber IS conducting heat into water

MANUFACTURABILITY

- losses

@ 5% reflected | lens | fiber | PV efficiency @ temp. T | # of legs

$$P_{each} = \left[0.95\,(1-L)\,(1-l)\,f_1\,f_2\,f_3\right]\frac{1kW}{m^2}\,\eta_T\,A_{lens}\,\frac{1}{N}$$

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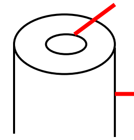

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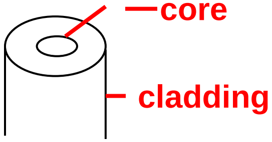

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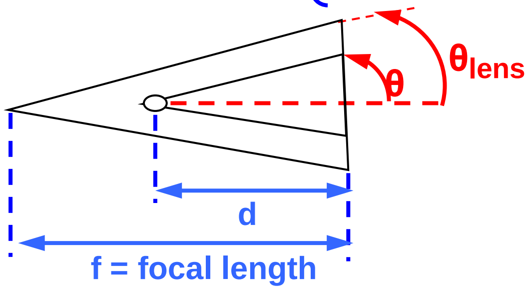

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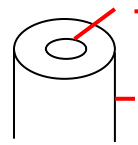

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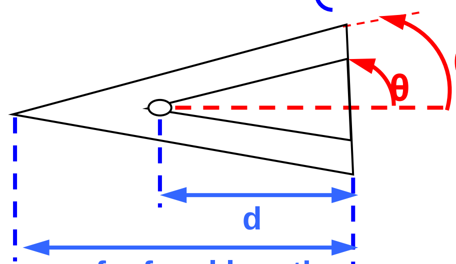
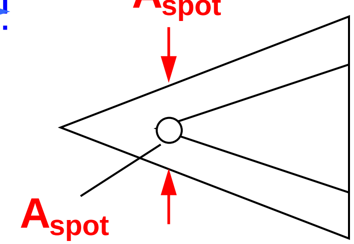


$$and \quad f_3 \quad is \quad \frac{A_{spot}}{A_{spot}^{lens}} = \frac{A_{spot}}{A_{lens}}C$$

where



and C= concentration of lens

Note: $f_3 \rightarrow 1$ via: high temp epoxy; smaller lens; or bigger bundle
else: C can compensate for other losses

Note:

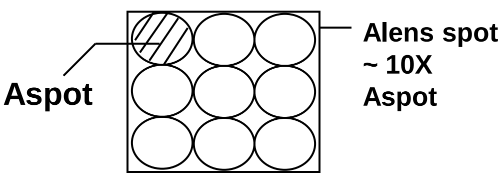
w/o fiber (standard CPV) $f_1 = 1 = f_2$ BUT η_T plummets @ .5% per °C

w/ fiber η_T is ~ independent of concentration

Manufacturability

Losses in demo

- $f_2 = 1$ $\theta_{lens} \sim 20°$
  $\theta_{fiber} \sim 30°$
  NA > .34
- $f_1 = .79$
- Large lens $f_3 \sim .1$



- Smaller lens $f_3 \sim .25$

Bottom line f_2 => no problem
f_3 => easily scaled

f_1 and fiber loss CAN be improved BUT

Simple Refinements & Scalability

none needed

But to use high power fiber w/ NA =.1 one simply needs longer f lens

Claddings can be removed and cores fused at bundle end

so f_1 =1 is achievable

Put in more bundles

Use bigger bundle

Use high temperature epoxy (already sent to CA)

ditto

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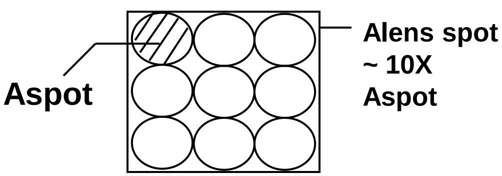

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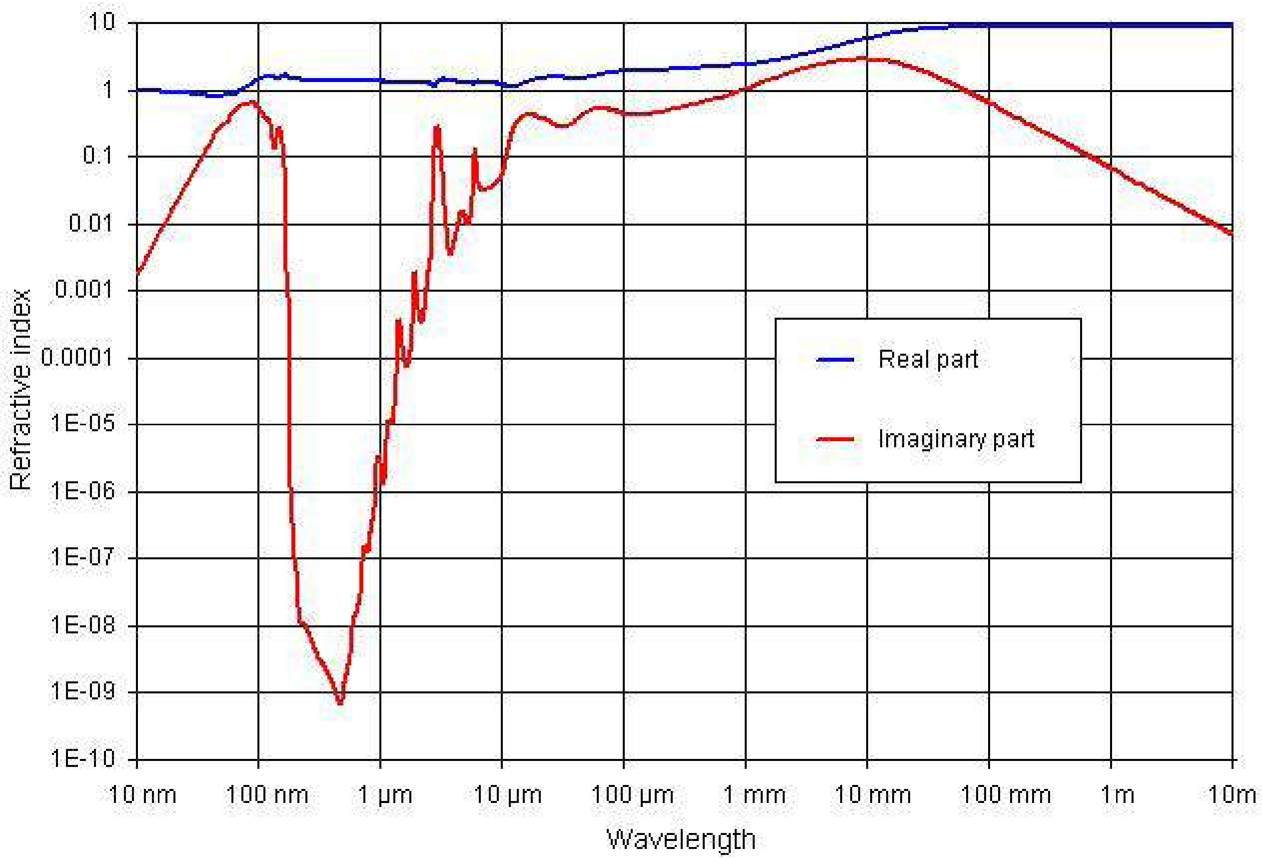
f_1 and fiber loss CAN be improved BUT
to turn our power improvement factors into cost/kW improvement factors *soon*
we need a way to *quickly* reduce the cost of the optical waveguide.

Water Based Rod-Waveguide

index of refraction for liquid water (red=absorption)



Good attenuation of IR, but passes some UV => PVI > ~ 1.6

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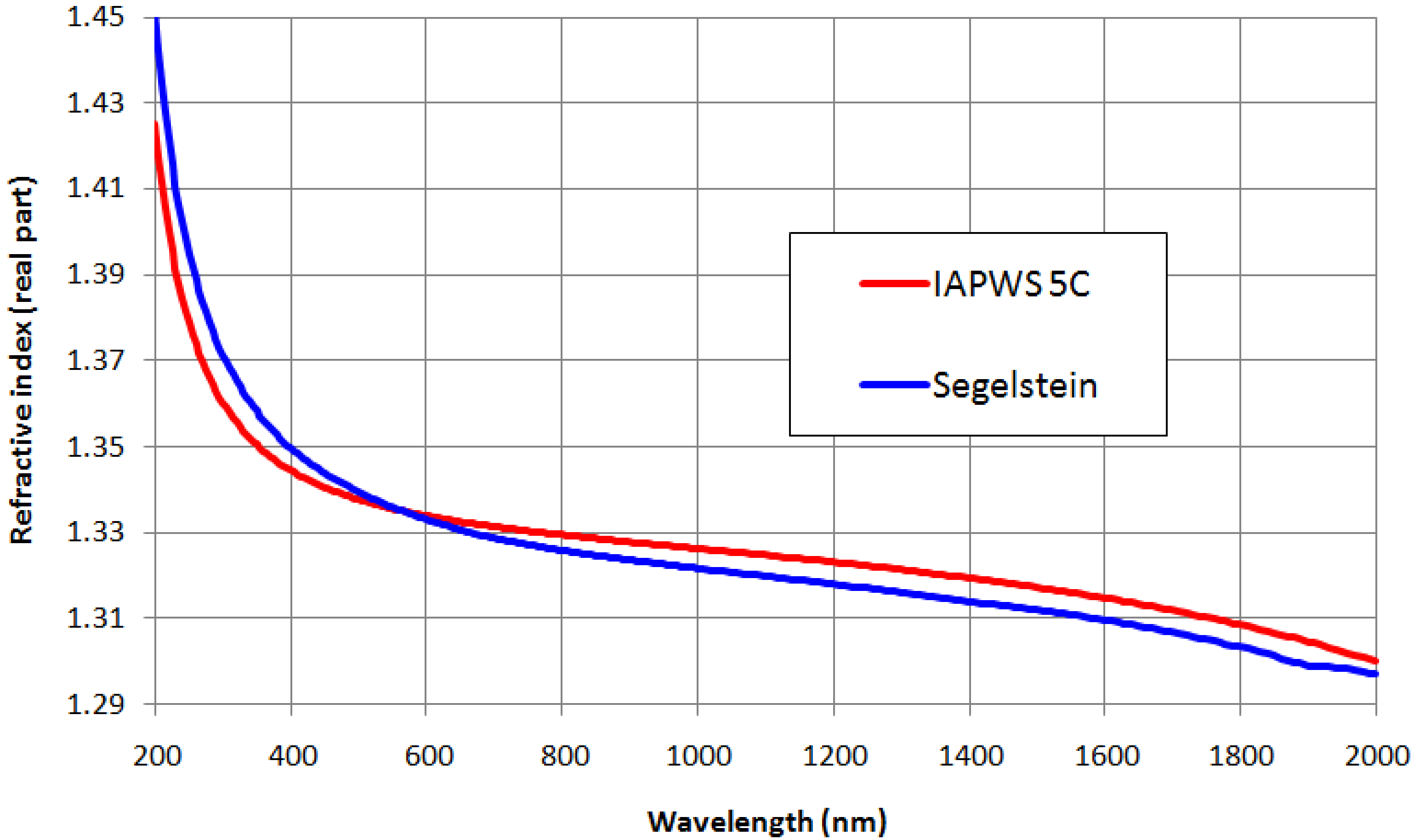

Chromatic aberration can filter the UV, but by itself => PVI > ~ 1.3

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- NEXT:
- Waveguide-filtered concentrators with advanced PVs !!