# Using NASA Satellite and Reanalysis to Provide Climate Data Products for Energy Industry Applications

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# Why NASA?

**Researching Science Questions** 

- How is the global Earth system <u>changing?</u>
- What are the primary forcings of the Earth system?
- How does the Earth system <u>respond</u> to natural and human-induced changes?
- What are the <u>consequences</u> of changes in the Earth system for human civilization?
- How well can we <u>predict</u> future changes to the Earth system?

**Capabilities for Science Answers** 

- New instrumentation on various observing platforms
- New/improved analysis techniques
- Enhanced modeling and assimilation





## **Meteorological Data Sources**

# NASA's Global Modeling & Assimilation Office (GMAO)

The GMAO (based at GSFC) develops and uses comprehensive models and assimilation systems that support NASA' s Earth science research enterprise and contribute to the nation' s capabilities in climate, weather and composition prediction.

Global Weather and Climate Models + Observations = Assimilation Model

#### Main Observing Systems Assimilated in GEOS-5 6-hr window centered at 00 UTC 11 Nov 2007



Ozone 8.320





Profilers 15,982 Radiosondes 92,612



tterometer 72,008 SSM/I 45,786 SYNOP/Ships 37,615













Operational (NOAA, DoD) Research (NASA) Operational+Research



### **Temperature Information from GMAO GEOS-4**

Daily Maximum Air Temperature For July 4, 2006





### GEWEX Surface Radiation Budget: 24+ years of cloud (from ISCCP), SW and LW fluxes at TOA and Surface

GEWEX SRB SW v3.0 (ISCCP, GMAO)

24 Year Annual Cycle Surface Solar Fluxes (W m<sup>-2</sup>)

(Jan 1984 – Dec 2007) GSW Rel. 3.0 All Sky Surface Downward Flux, 24 Year Average for Jan





### FLASHFlux: Global TOA and Surface Fluxes within 1 week of observation from Terra and Aqua

CERES FLASHFlux (CERES/MODIS, GMAO)



Daily Average Solar Irradiance for Feb 2, 2012 (Wm<sup>-2</sup>)

April 24, 2011



# NASA Applied Earth Science: POWER Project

Applied Sciences Goal: The Applied Sciences program <u>extends</u> NASA Earth Science research and observations <u>for practical use</u> in environmentallyrelated decision and policy making.

 Emphasizes partnerships in variety of application theme areas Key Theme



### POWER = Prediction of Worldwide (renewable) Energy Resource

**Objective**: <u>Improve</u> the Nation's public and private capability for <u>integrating environmental data</u> from NASA research to support energy production and increased energy efficiency.

**Goals:** Through partnerships *derive/validate/provide* parameters relevant to industry needs; link to decision support, transition when possible.





POWER Web Site

<u>http://power.</u> larc.nasa.gov

Provides access to both Long-term and Near-Term Time Data Sets



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



 Prediction
 Surface meteorology and Solar Energy (SSE-release 6.0):

 Of
 A renewable energy resource web site sponsored by NASA's Applied Sciences

 Program in the Science Mission Directorate, Applied Sciences Program

Earth Science for Society:Accelerating the realization of economic and societal benefits from Earth science, information, and technology

Home Renewable Energy Parameters Sustainable Buildings Parameters Agroclimatology Parameters



http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?&step=1&subm V



ATMOSPHERIC SCIENCE DATA CENTER

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Lat 37 Lon -77 Minimum Maximum

Lat 37 Lon -77 22-year Average

Minimum Maximum 22-year Average K

Minimum K

Maximum K

NASA Surface meteorology and Solar Energy - Available Tables

#### Parameters for Sizing Battery or other Energy-storage Systems:

~			E	quivalen	t Numbe	r Of NO-	SUN Or	BLACK	Days (da	ays)			
Geometry Inform	Lat 37 Lon -77	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	1 day	0.96	0.95	0.95	0.93	0.91	0.92	0.95	0.89	0.92	0.96	0.94	0.96
	3 day	2.61	2.38	2.46	2.66	2.47	1.89	2.16	2.39	2.07	2.37	2.46	2.44
	7 day	5.08	4.51	4.53	3.95	4.48	3.33	3.53	3.58	3.61	4.43	3.58	4.11
	14 day	7.15	6.14	4.08	5.31	6.77	4.35	3.98	4.95	4.57	5.39	4.74	7.12
	21 day	6.19	8.35	5.00	5.24	7.35	4.93	5.12	6.02	3.70	7.40	5.82	8.44
	Month	4.60	7.63	3.60	5.26	9.01	3.67	4.27	5.24	4.17	6.81	6.49	6.65
	1				Pa	ameter D	efinition						

#### Parameters for Sizing Meteorology (Temperature):

Mont

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	N			Mon	thly Av	eraged	Cooling	g Degr	ee Days	s Above	e 18° C				
Lat 37 Lon -77	Lat 37 Lon -77		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Sum
22-year Average	22-year A	verage	0	0	4	22	86	189	257	224	130	34	5	1	952
						Para	neter D	efinition	n						

#### Meteorology (Wind):

Mo	nthly A	verage	d Wind	Speed	At 50	m Abov	ve The	Surface	e Of Th	e Eartl	h (m/s)		
Lat 37 Lon -77	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	6.60	6.71	6.67	6.04	5.13	4.88	4.34	4.17	4.80	5.38	6.27	6.65	5.63

#### Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)

Lat 37 Lon -77	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-13	-11	-14	-10	-13	-11	-10	-16	-8	-11	-8	-11	-11
Maximum	13	8	9	15	16	9	11	10	11	9	10	7	11

It is recommended that users of these wind data review the SSE <u>Methodology</u>. The user may wish to correct for biases as well as local effects within the selected grid region.

All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.

Parameter Definition

# Parameter Validation: Key to Usage

# Power validation significant, included in extensive methodology document

Tab	le I-1: Regression analysis	s of SSE versus	BSRN monthly	averaged value	s for the time	
per	Table I-2: Linear least so for the time period 1983	luares regressio through 2006	on analysis of SS	SE versus NCD	C monthly aver	aged values
	Parameter	Slope	Intercept	R <sup>2</sup>	RMSE	Bias
HOI	Tmax (°C)	0.99	-1.58	0.95	3.12	-1.83
	Tmin (°C)	1.02	0.10	0.95	2.46	0.24
Hoi	Tavg (°C)	1.02	-0.78	0.96	2.13	-0.58
	Tdew (°C)	0.96	-0.80	0.95	2.46	-1.07
<b>.</b> .	RH (%)	0.79	12.72	0.56	9.40	-1.92
Dır	Heating Degree Days (degree days)	1.02	12.47	0.93	77.20	17.28
	Cooling Degree Days (degree days)	0.86	2.36	0.92	28.90	-5.65
	Atmospheric Pressure (hPa)	0.89	102.16	0.74	27.33	-10.20



# **Decision Support: RETScreen**

### www.retscreen.net

- Clean Energy Project Analysis Tool
- Aimed for both
   feasibility and detailed
   scenario analysis
- RETScreen 4 built on Excel; New RETScreen Plus stand-alone
- Partners since 2000
- Over 330,000 users in
  36 different languages



# **RETScreen's Reliance on POWER Data**

- Built-in cities of world
- In situ used if present (red)
- If missing uses
   NASA (blue)
- If partial missing supplement with NASA (most)
- Direct query of SSE data through web



Points represent world's cities (~10,000). Red have in situ observations. Blue defer to NASA LaRC data sets (~5,000). Data for locations between points are found through a direct link to SSE.



## Example Usage: RETScreen Clean Energy Projects





# **Sector Impact: Building Climate Zone Maps**

- Derive long-term climate zone maps for building guidelines – determines building codes
- Assess variability of zones
- Working w/ GMAO (MERRA) and ASHRAE



-70

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ZONE



POWER Web Site

<u>http://power.</u> larc.nasa.gov

Provides access to both <u>Long-term</u> and <u>Near-Term Time</u> Data Sets



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Access Data

SSE-Renewable Energy

Sustainable Buildings
 Agroclimatology



 Prediction
 Surface meteorology and Solar Energy (SSE-release 6.0):

 Of
 A renewable energy resource web site sponsored by NASA's Applied Sciences

 Program in the Science Mission Directorate, Applied Sciences Program

Earth Science for Society:Accelerating the realization of economic and societal benefits from Earth science, information, and technology

Home Renewable Energy Parameters Sustainable Buildings Parameters Agroclimatology Parameters

#### Processing, archiving, and distributing solar insolation and meteorological parameters for:

 SSE-RENEWABLE ENERGY: Satellite and modeled derived data supporting Documentation Renewable Energy Technologies (RET's). Over 200 satellite-derived meteorology and solar energy parameters About the POWER Project Monthly averaged parameters for the period July 1, 1983 through June 30, 2005 About Renewable Energy Global coverage on a 1° latitude by 1° longitude grid About Sustainable Buildings Color plots on both global and regional scales About Agroclimatology Solar energy data for 1195 ground sites Global Geometry/Resolution Data for the RETScreen<sup>®</sup> Renewable Energy Project Analysis Software SSE Parameter Accuracy SSE Methodology POWER Publications SUSTAINABLE BUILDINGS: Satellite and modeled derived data for the preliminary Related Links design of buildings and associated renewable-energy power systems. Global coverage on a 1° latitude by 1° longitude grid Monthly averaged solar radiation over the time period July 1,1983 through Atmospheric Science Data Center Science Mission Directorate June 30, 2005 NASA's Applications Program · Monthly averaged air temperature and precipitation over the time period Other Related Sites January 1, 1983 through December 31, 2007 Psychrometer chart and Global and/or regional plots Navigation and Help o Temperature and relative humidity on 3-hourly time steps for Continental US (January 1, 1983 - September 30, 2008) FAQs Near Real-Time Global Radiation and Meteorology: Partners Daily averaged solar radiation from July 1, 1983 through near real-time Release Notes Daily humidity and air temperatures from January 1, 1983 and near real-time Questions/Comments Acknowledgments Please AGROCLIMATOLOGY: Satellite and modeled derived solar and meteorological data supporting agrotechnology Global coverage on a 1° latitude by 1° longitude grid Daily total solar radiation from July 1, 1983 through near real-time Daily averaged dew point and air temperatures from January 1, 1983 through near real-time Daily maximum and minimum air temperatures from January 1, 1983 through near real-time · Daily averaged precipitation from January 1, 1997 - current with two month delay FIRSTGOV + NASA Privacy Statement, Disclaimer, Question/Comments: POWER Project Team and Accessibility Certification NASA Official: Paul Stackhouse + Feedback on Langley Products and Services + Contact NASA Last modified 06/06/2011 09:49:49



### NASA's Near Real-time Daily Averaged Data Time Series

Variable	Parameter	Units
swv_dwn	Average Insolation Incident On A Horizontal Surface	kWh/m^2/day
lwv_dwn	Average Downward Longwave Radiative Flux	kWh/m^2/day
toa_dwn	Average Top-of-atmosphere Insolation	kWh/m^2/day
avg_kt	Average Insolation Clearness Index	0 to 1.0
clr_sky	Average Clear Sky Insolation On A Horizontal Surface	kWh/m^2/day
clr_kt	Average Clear Sky Insolation Clearness Index	0 to 1.0
PS	Average Atmospheric Pressure	kPa
T2M	Average Air Temperature At 2 m	degrees C
T2MN	Minimum Air Temperature At 2 m	degrees C
T2MX	Maximum Air Temperature At 2 m	degrees C
Q2M	Average Humidity Ratio At 2 m	
RH2M	Relative Humidity At 2 m	%
DFP2M	Dew/Frost Point Temperature At 2 m	degrees C
TSKIN	Average Earth Skin Temperature	degrees C
WS10M	Wind Speed At 10 m	m/s

April 24, 2011 Note: Precipitation will be included in future data products



# Energy Monitoring with RETScreen Plus

Objective: Enable "users to monitor, analyze and report key energy performance data to facility operators, managers and senior decision-makers."

### <u>Usage:</u>

- Determine & obtain building energy and meteorological information for any location in world
- 2. Use multivariate analysis to determine system performance as a function of meteorological variability
- 3. Monitoring building energy performance for system changes, target higher efficiency and reporting verification

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t Data	Analytics Rep	orting							
ources naturelles da	Natural Resources Canada								Canad
	<u>RET.</u>	Scre	P <b>CN</b> *[ Plus				7/1		R
			Clean	Energy Project	Analysis Softwa	are			
Projec	t information		See	project database					
	Project name		NASA L	angley Solar Systen	n				
Pr	roject location		Har	mpton, VA USA					
	Prepared for			NASA					
	Prepared by		Pa	ul Stackhouse					
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Province /	State				Virginia			-	
Climate da	ata location				Newport News			•	
Latitude				*N	37.1				
Longitude				°E	-76.5		Source		
Elevation					16		Ground		
Heating de	esign temperature			°C •	-5.1		Ground		
Cooling de	esign temperature			·C •	33.1		Ground		
Earth temp	perature amplitude				20.7		11000	Heating	Cooling
Earth tem; Month	Air tem	perature R	elative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	degree-days 18 °C	10 °C
Earth tem; Month	Air tem	perature R	elative humidity %	Daily solar radiation - horizontal kWh/m²/d +	Atmospheric pressure kPa •	Wind speed m/s v	Earth temperature ↓ C →	degree-days 18 °C °C-d 🗸	10 °C
Earth temp Month January	Air tem	perature R	elative humidity % 66.9%	Daily solar radiation - horizontal kWh/m²/d + 2.22	Atmospheric pressure kPa • 101.6	Wind speed m/s -	Earth temperature	degree-days 18 °C °C-d • 428	10 °C °C-d
Month January February	Air tem	perature R	<b>elative humidity</b> % 66.9% 66.5%	Daily solar radiation - horizontal kWh/m²/d - 2.22 2.97	Atmospheric pressure kPa • 101.6 101.6	Wind speed           m/s         -           3.9         -           4.0         -	Earth temperature 2.5 4.5	degree-days 18 °C <sup>°</sup> C-d ↓ 428 347	0 0
Earth temp Month January February March	Air tem	perature R	<b>Selative humidity</b> % 66.9% 66.5% 64.3%	Daily solar radiation - horizontal kWh/m²/d • 2.22 2.97 3.89	Atmospheric pressure kPa - 101.6 101.6 101.4	Wind speed m/s ▼ 3.9 4.0 4.4	Earth temperature	degree-days 18 °C	0 °C-d
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Earth tem Month January February March April May	Air tem *C 4 5 9 1 1	Perature R 4.2 4.3 9.0	Selative humidity           %           66.9%           66.5%           64.3%           66.0%           71.8%           73.9%	Daily solar radiation - horizontal kWh/m²/d • 2.22 2.97 3.89 5.04 5.59 5.59	Atmospheric pressure kPa 101.6 101.6 101.4 101.2 101.2	Wind speed m/s 3.9 4.0 4.4 4.3 3.9 2.7	Earth temperature 2.5 4.5 8.7 14.9 20.4 20.4	degree-days 18 °C 428 347 270 111 0 0	10 °C °C-d 0 0 0 129 279 400
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Earth tem Month January February March April May June June July August	Air tem	perature R .2 .6 .3 4.3 9.0 3.6 6.2 5.1	Kelative humidity           %         (6.9%)           66.5%         64.3%)           66.0%         71.8%)           73.9%         74.4%)           76.9%         79.8%)	Daily solar radiation - horizontal kWh/m²/d  2.22 2.97 3.89 5.04 5.59 5.89 5.73 5.29	Atmospheric pressure 101.6 101.6 101.4 101.2 101.2 101.2 101.2 101.2 101.3	Wind speed           m/s         •           3.9         •           4.0         •           4.3         •           3.9         •           3.7         •           3.6         •	Earth temperature 2.5 4.5 8.7 14.9 20.4 24.6 26.2 24.9	degree-days 18 °C *C-d ▼ 428 347 270 111 0 0 0 0 0 0	10 °C °C-d 0 0 129 279 408 502 468
Earth temp Month January February March April May June July August Septembe	Air tem ************************************	perature R 1.2 1.6 1.3 4.3 9.0 3.6 6.2 5.1 1.7	Selective humidity           %           66.9%           66.5%           64.3%           66.0%           71.8%           73.9%           74.4%           76.9%           77.3%	Daily solar radiation - horizontal kWh/m²/d • 2.22 2.97 3.89 5.04 5.59 5.89 5.73 5.29 4.32	Atmospheric pressure           kPa            101.6            101.4            101.2            101.2            101.2            101.3	Wind speed           m/s         •           3.9         •           4.0         •           4.3         •           3.9         •           3.7         •           3.6         •           3.5         •	Earth temperature	degree-days 18 °C <sup>°</sup> C-d ▼ 428 347 270 1111 0 0 0 0 0 0 0 0	10 °C *C-d 0 0 0 129 279 408 502 468 351
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Arth temp Month January February March April May June July August Septembe October Novembe Decembe	Air tem *C 4 5 9 1 1 1 2 2 2 2 2 1 1 1 1 2 2 2 1 1 1 1 1 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1	perature         R           1.2	Selative humidity           %           66.9%           66.5%           64.3%           66.0%           71.8%           73.9%           74.4%           76.9%           77.3%           75.4%           71.0%           68.0%	Daily solar radiation - horizontal kWh/m²/d ▼ 2.22 2.97 3.89 5.04 5.59 5.89 5.73 5.29 4.32 3.36 2.46 1.95	Atmospheric pressure           kPa         ▼           101.6         101.4           101.2         101.2           101.2         101.2           101.3         101.4           101.6         101.6           101.7         101.7	Wind speed           m/s         •           3.9         •           4.4         •           3.9         •           3.6         •           3.5         •           3.4         •           3.5         •           3.7         •	Earth temperature 2.5 4.5 8.7 14.9 20.4 24.6 26.2 24.9 21.5 15.7 10.1 4.4	degree-days 18 °C *C-d ▼ 428 347 270 1111 0 0 0 0 0 0 0 0 0 0 0 0 0	"C-d           0           0           0           10 °C           0           0           129           279           408           502           468           351           180           33           0
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Earth temp Month January February March April May June July August Septembe October Novembe Decembe Annual Source	Air tem *C 4 5 5 5 5 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2	Perature R 	Selative humidity           %           66.9%           66.5%           64.3%           73.9%           74.4%           76.9%           77.3%           75.4%           71.1%           68.0%           71.1%           Ground	Daily solar radiation - horizontal kWh/m²/d ↓ 2.22 2.97 3.89 5.04 5.59 5.89 5.73 5.29 4.32 3.36 2.46 1.95 4.06 Ground	Atmospheric pressure           kPa         ▼           101.6         101.4           101.2         101.2           101.2         101.2           101.3         101.4           101.6         101.4           101.7         101.4	Wind speed           m/s         •           3.9         •           4.0         •           3.9         •           3.9         •           3.7         •           3.6         •           3.5         •           3.4         •           3.7         •           3.8         •           Ground         •	Earth temperature 2.5 4.5 8.7 14.9 20.4 24.6 26.2 24.9 21.5 15.7 10.1 4.4 14.9 NASA	degree-days 18 °C *C-d ▼ 428 347 270 1111 0 0 0 0 0 0 0 0 0 0 0 0 0	la eytee a 10 °C - 0 0 0 0 0 129 279 279 279 408 502 468 351 180 33 0 2,350 Ground



### Monitoring and Targeting Case: NASA LaRC Badge and Pass Office



### 🖞 Badge and Pass Office Solar Energy Project 🗜

#### **Overview**

**Current Status** 

Weather Conditions

Installed in September 2010, this 39.5 KW groundmounted solar energy system and will produce around 50,000 kilowatt-hours of electricity each year. The system consists of 168 photovoltaic modules mounted in two arrays located behind the Badge and Pass Office. This project demonstrates the performance of solar energy and the benefit of renewable energy being in our overall energy strategy.



ENERGY SYSTEMS GROUP





### Monitoring and Targeting Case 1: NASA LaRC Badge and Pass Office





# **POWER for Energy Forecasting**

Collaborated with Battelle and Ventyx to evaluation NASA long-term data sets (GMAO) and high resolution forecasts (SPORT)



Distribution Corporation Service Area

Ventyx corporation now including daily data in "Velocity Suite" tool for Energy Utility Industry  Gas utilities use daily averaged data
 Most recent daily averaged 4 years of POWER/FLASHFlux delivered for 4 regions => deliveries continued



Home > Enterprise Solutions > Business Operations > Business Operations Products > Ventyx Velocity Suite

Enterprise Solutions Overview Vent

Work & Asset Operations

Control Operations >

Technical Mining Operations

#### Business Operations -

Asset Intensive Enterprise Resource Planning

#### Ventyx Velocity Suite

#### Investment grade data and intelligence

Ventyx Velocity Suite provides analysts with the ability to quickly evaluate the activities of market participants and industry dynamics across commodities using a single integrated solution. Using Ventyx Velocity Suite, analysts can look at coal production, daily gas prices, plant capacity factors, weather normalized loads and transmission all at the same time.



- NASA long-term and near-term time data sets are tailored to energy industry data needs with partnerships such as with RETScreen and ASHRAE
- Current accuracies sufficient to determine statistics of meteorological and solar variability for project feasibility and climatological information (i.e., building climate zones)
- Time series data together with RETScreen Plus tool together provide a new capability to assess building energy system performance at any location in the world.
- The potential usefulness grows as these global data sets are improved in quality and in resolution, a byproduct of continuing research





### Monitoring and Targeting Case 2: Apartment Building Cluster, Höganäs, Sweden

- Apartment building complex in Sweden
- Use RETScreen Plus & NASA temperature data to assess energy usage before and after energy efficiency upgrade



## Monitoring and Targeting Case 2: Apartment Building Cluster, Höganäs, Sweden

Pass 1: Identified system upgrade point



## Monitoring and Targeting Case 2: Apartment Building Cluster, Höganäs, Sweden

Pass 2: Define system before change, assess impact







- RETScreen Plus and NASA resolve system specification misunderstanding
  - Contractor provided climatological specifications for system with constant 20 degree tilt, but system plans showed a 25 degree tilt.
  - Original RETScreen Plus analysis using NASA surface irradiance produced a poor fit with unexplained behavior.
  - Behavior was only explained by changing the tile angle of the panels in RETScreen Plus.
     Subsequent measurements verified that the system has a 26 degree tilt.



### NASA GEOS 5.2 (1 x 1) vs NCDC Surface Obs





No. of Stations = 4287 (plot) 4296 (total)

No. of plot points = 1564585



### **CERES FLASHFlux Seasonal Insolation**





## CERES FLASHFlux Solar Flux Validation vs SURFRAD

Scatter Plot of Daily Averaged Shortwave Surface Fluxes Observed at SURFRAD Stations and FLASHFlux Data (June 1, 2008 - May 31, 2010)





Daily Averaged Ensemble Differences: Bias << 1% RMS < 16% well within industry needs