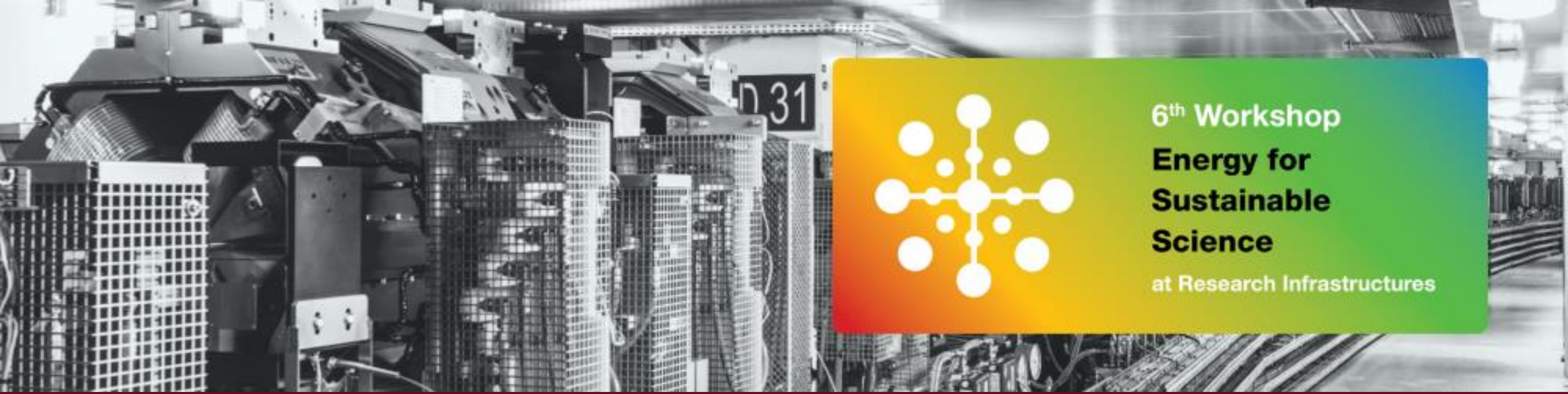


LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

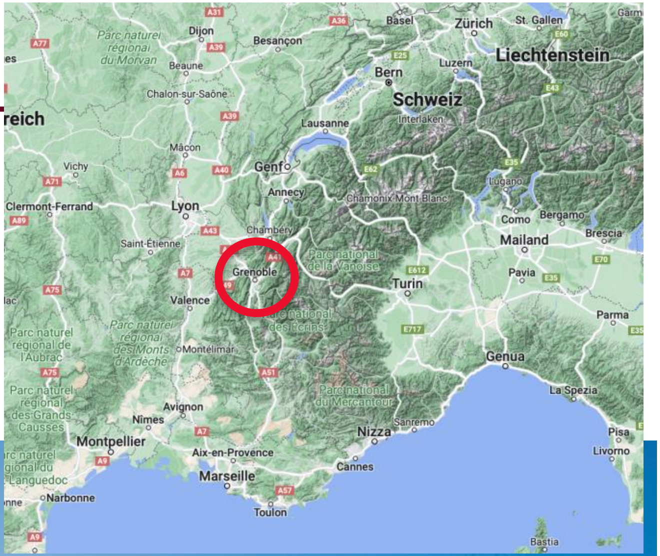
ESSRI Impressions

Benno List, DESY and CERN

IDT WG2 Meeting

4.10.2022

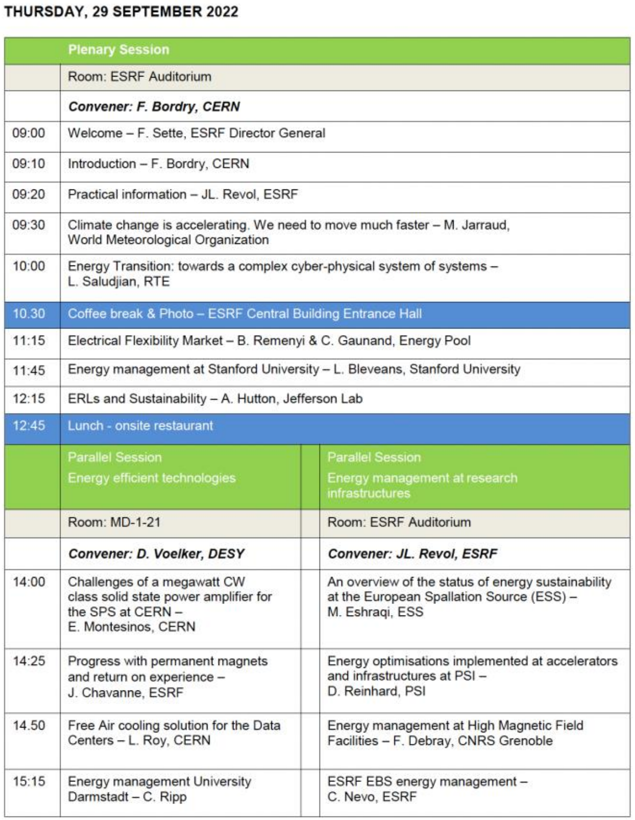
Venue



European Synchrotron Radiation Facility ESRF, Grenoble

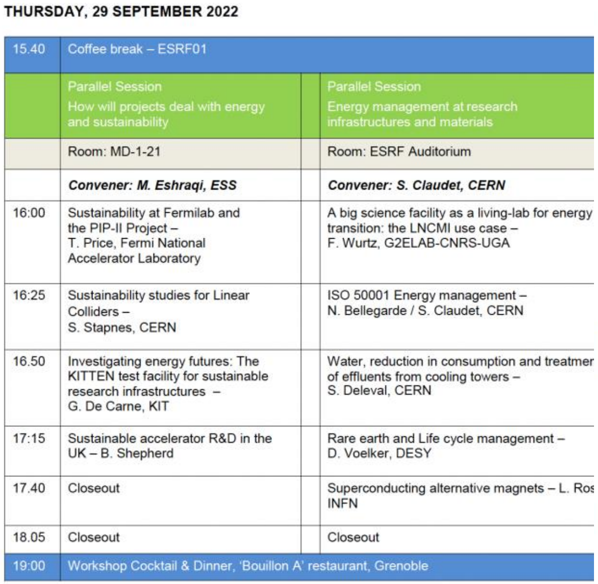
https://www.sbfi.admin.ch/sbfi/fr/home/recherche-et-innovation/cooperation-internationale-r-et-i/organisations-internationales-de-recherche/esrf/_jcr_content/par/image/image.imagespooler.jpg/1474613374641/esrf.jpg

Agenda



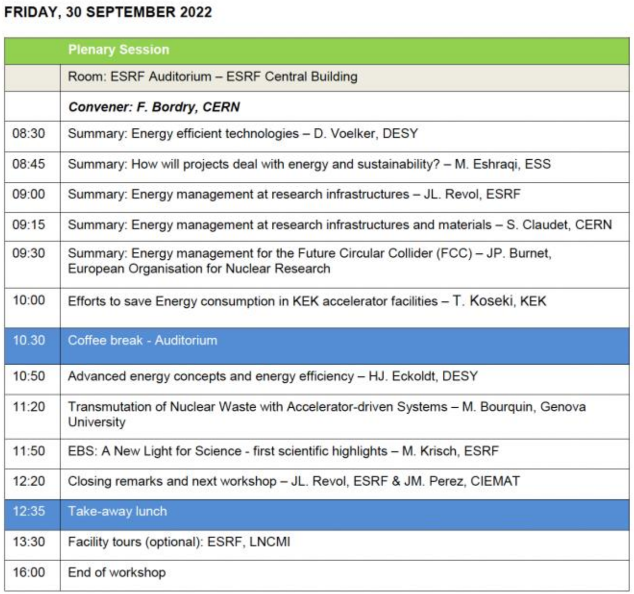
THURSDAY, 29 SEPTEMBER 2022

	Plenary Session	
	Room: ESRF Auditorium	
	Convener: F. Bordry, CERN	
09:00	Welcome – F. Sette, ESRF Director General	
09:10	Introduction – F. Bordry, CERN	
09:20	Practical information – JL. Revol, ESRF	
09:30	Climate change is accelerating. We need to move much faster – M. Jarraud, World Meteorological Organization	
10:00	Energy Transition: towards a complex cyber-physical system of systems – L. Saludjian, RTE	
10.30	Coffee break & Photo – ESRF Central Building Entrance Hall	
11:15	Electrical Flexibility Market – B. Remenyi & C. Gaunand, Energy Pool	
11:45	Energy management at Stanford University – L. Bleveans, Stanford University	
12:15	ERLs and Sustainability – A. Hutton, Jefferson Lab	
12:45	Lunch - onsite restaurant	
	Parallel Session Energy efficient technologies	Parallel Session Energy management at research infrastructures
	Room: MD-1-21	Room: ESRF Auditorium
	Convener: D. Voelker, DESY	***Convener: JL. Revol, ESRF***
14:00	Challenges of a megawatt CW class solid state power amplifier for the SPS at CERN – E. Montesinos, CERN	An overview of the status of energy sustainability at the European Spallation Source (ESS) – M. Eshraqi, ESS
14:25	Progress with permanent magnets and return on experience – J. Chavanne, ESRF	Energy optimisations implemented at accelerators and infrastructures at PSI – D. Reinhard, PSI
14.50	Free Air cooling solution for the Data Centers – L. Roy, CERN	Energy management at High Magnetic Field Facilities – F. Debray, CNRS Grenoble
15:15	Energy management University Darmstadt – C. Ripp	ESRF EBS energy management – C. Nevo, ESRF



THURSDAY, 29 SEPTEMBER 2022

15.40	Coffee break – ESRF01	
	Parallel Session How will projects deal with energy and sustainability	Parallel Session Energy management at research infrastructures and materials
	Room: MD-1-21	Room: ESRF Auditorium
	Convener: M. Eshraqi, ESS	***Convener: S. Claudet, CERN***
16:00	Sustainability at Fermilab and the PIP-II Project – T. Price, Fermi National Accelerator Laboratory	A big science facility as a living-lab for energy transition: the LNCMI use case – F. Wurtz, G2ELAB-CNRS-UGA
16:25	Sustainability studies for Linear Colliders – S. Stapnes, CERN	ISO 50001 Energy management – N. Bellegarde / S. Claudet, CERN
16.50	Investigating energy futures: The KITTEN test facility for sustainable research infrastructures – G. De Carne, KIT	Water, reduction in consumption and treatmer of effluents from cooling towers – S. Deleval, CERN
17:15	Sustainable accelerator R&D in the UK – B. Shepherd	Rare earth and Life cycle management – D. Voelker, DESY
17.40	Closeout	Superconducting alternative magnets – L. Ros INFN
18.05	Closeout	Closeout
19:00	Workshop Cocktail & Dinner, 'Bouillon A' restaurant, Grenoble	



FRIDAY, 30 SEPTEMBER 2022

	Plenary Session
	Room: ESRF Auditorium – ESRF Central Building
	Convener: F. Bordry, CERN
08:30	Summary: Energy efficient technologies – D. Voelker, DESY
08:45	Summary: How will projects deal with energy and sustainability? – M. Eshraqi, ESS
09:00	Summary: Energy management at research infrastructures – JL. Revol, ESRF
09:15	Summary: Energy management at research infrastructures and materials – S. Claudet, CERN
09:30	Summary: Energy management for the Future Circular Collider (FCC) – JP. Burnet, European Organisation for Nuclear Research
10:00	Efforts to save Energy consumption in KEK accelerator facilities – T. Koseki, KEK
10.30	Coffee break - Auditorium
10:50	Advanced energy concepts and energy efficiency – HJ. Eckoldt, DESY
11:20	Transmutation of Nuclear Waste with Accelerator-driven Systems – M. Bourquin, Genova University
11:50	EBS: A New Light for Science - first scientific highlights – M. Krisch, ESRF
12:20	Closing remarks and next workshop – JL. Revol, ESRF & JM. Perez, CIEMAT
12:35	Take-away lunch
13:30	Facility tours (optional): ESRF, LNCMI
16:00	End of workshop

6th workshop of the series

101 participants

Highlights

Climate change is moving fast

We need to move faster

ESSRI workshop 2022 - Grenoble

M Jarraud - Secretary-General Emeritus WMO

(29 September 2022)

Lots of facts and figures

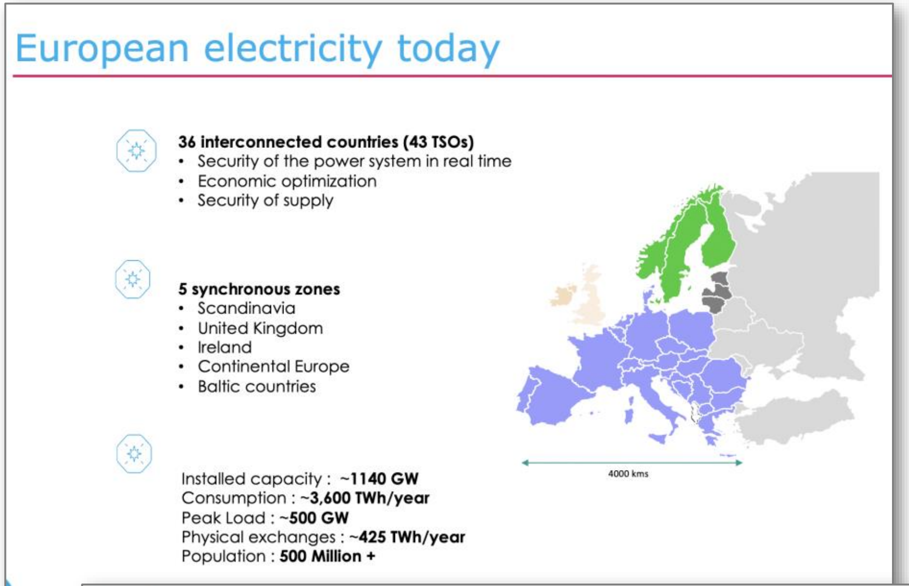
Look at the slides!

https://indico.esrf.fr/event/2/contributions/92/

Public Electricity Power and Grid Stability

L. Saludjian:
(R)evolution of the electrical system and its challenges

https://indico.esrf.fr/event/2/contributions/93/



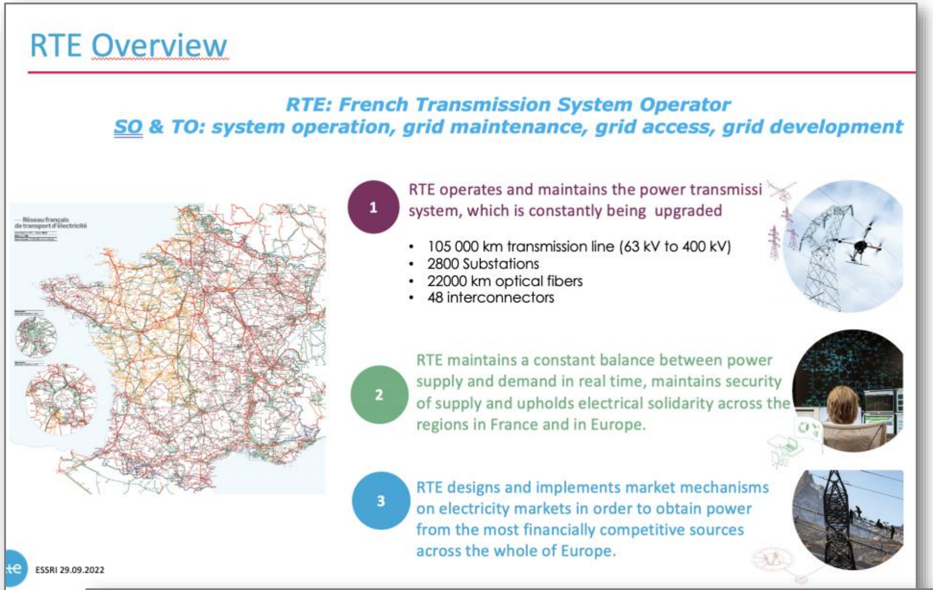
European electricity today

36 interconnected countries (43 TSOs)
- Security of the power system in real time
- Economic optimization
- Security of supply

5 synchronous zones
- Scandinavia
- United Kingdom
- Ireland
- Continental Europe
- Baltic countries

Installed capacity : ~**1140 GW**
Consumption : ~**3,600 TWh/year**
Peak Load : ~**500 GW**
Physical exchanges : ~**425 TWh/year**
Population : **500 Million +**

ESSRI 29.09.20



RTE Overview

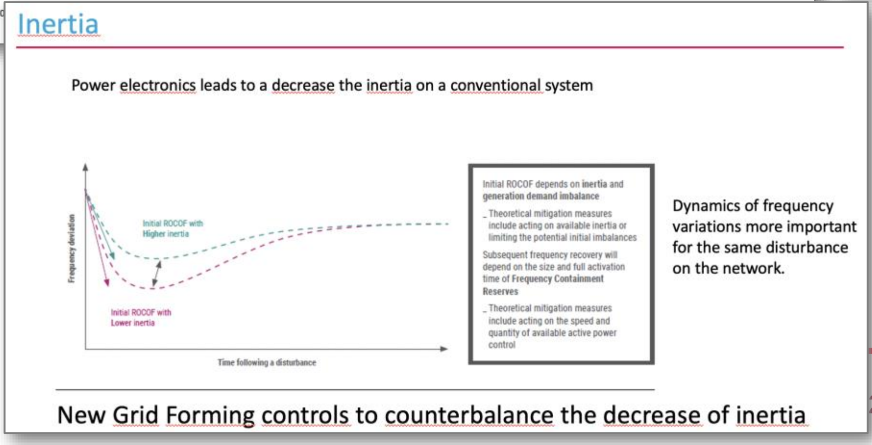
RTE: French Transmission System Operator
SO & TO: system operation, grid maintenance, grid access, grid development

1 RTE operates and maintains the power transmissi system, which is constantly being upgraded
- 105 000 km transmission line (63 kV to 400 kV)
- 2800 Substations
- 22000 km optical fibers
- 48 interconnectors

2 RTE maintains a constant balance between power supply and demand in real time, maintains security of supply and upholds electrical solidarity across the regions in France and in Europe.

3 RTE designs and implements market mechanisms on electricity markets in order to obtain power from the most financially competitive sources across the whole of Europe.

ESSRI 29.09.2022



Inertia

Power electronics leads to a decrease the inertia on a conventional system

Initial ROCOF depends on **inertia** and **generation demand imbalance**

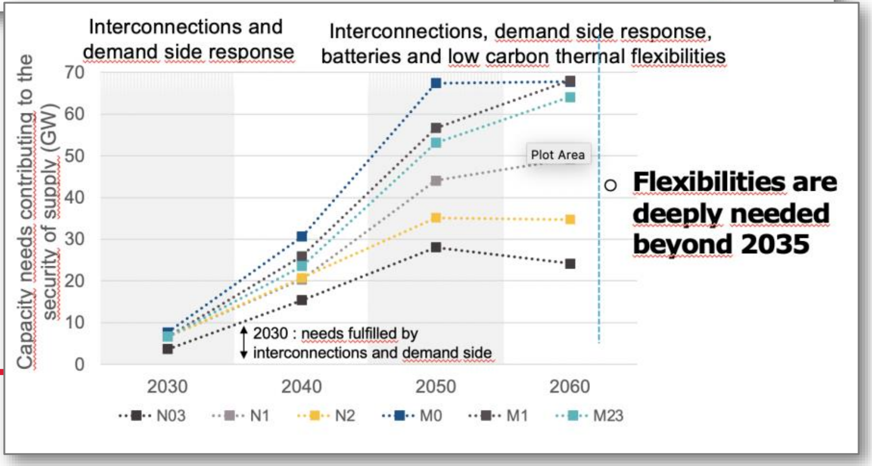
_ Theoretical mitigation measures include acting on available inertia or limiting the potential initial imbalances

Subsequent frequency recovery will depend on the size and full activation time of **Frequency Containment Reserves**

_ Theoretical mitigation measures include acting on the speed and quantity of available active power control

Dynamics of frequency variations more important for the same disturbance on the network.

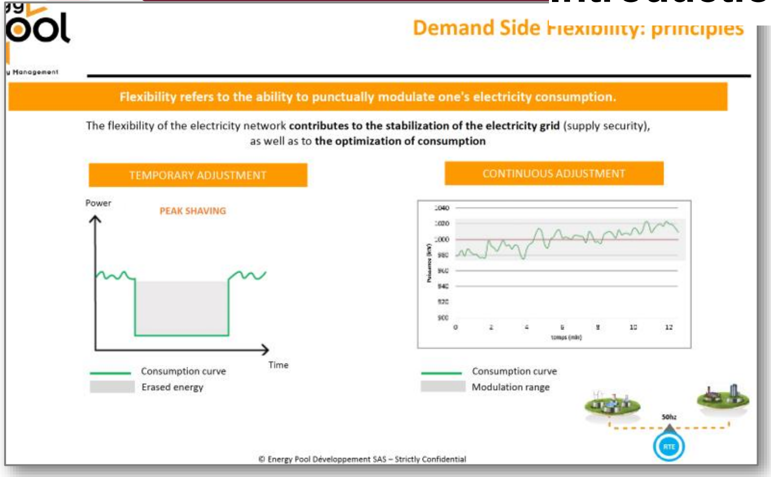
New Grid Forming controls to counterbalance the decrease of inertia



2030 : needs fulfilled by interconnections and demand side

- **Flexibilities are deeply needed beyond 2035**

C. Gaunand & B. Remenyi:
Introduction to Demand Side Flexibility



Demand Side Flexibility: principles

Flexibility refers to the ability to punctually modulate one's electricity consumption.

The flexibility of the electricity network **contributes to the stabilization of the electricity grid** (supply security), as well as to **the optimization of consumption**

TEMPORARY ADJUSTMENT

CONTINUOUS ADJUSTMENT

🟩	Consumption curve
▨	Erased energy

🟩	Consumption curve
▨	Modulation range

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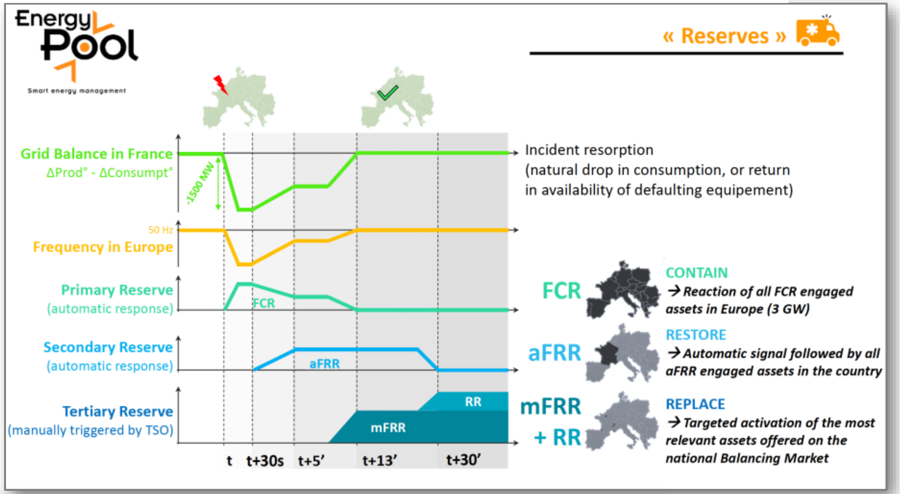


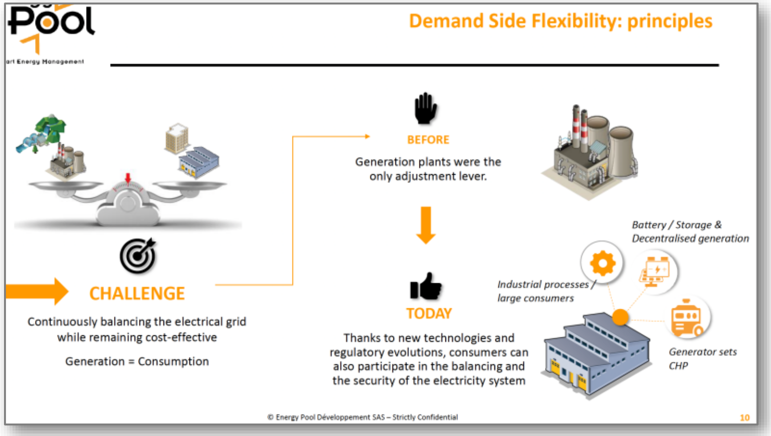
« Reserves »

Incident resorption (natural drop in consumption, or return in availability of defaulting equipement)

CONTAIN
→ Reaction of all FCR engaged assets in Europe (3 GW)

RESTORE
→ Automatic signal followed by all aFRR engaged assets in the country

REPLACE
→ Targeted activation of the most relevant assets offered on the national Balancing Market



Demand Side Flexibility: principles

CHALLENGE

Continuously balancing the electrical grid while remaining cost-effective

Generation = Consumption

BEFORE

Generation plants were the only adjustment lever.

TODAY

Thanks to new technologies and regulatory evolutions, consumers can also participate in the balancing and the security of the electricity system

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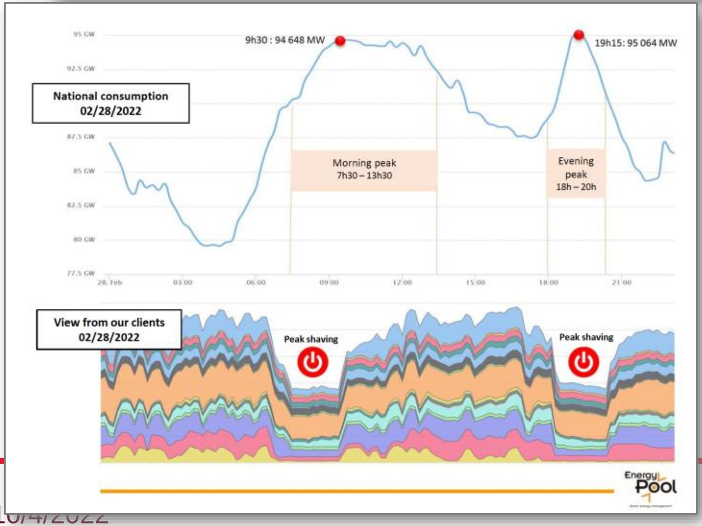
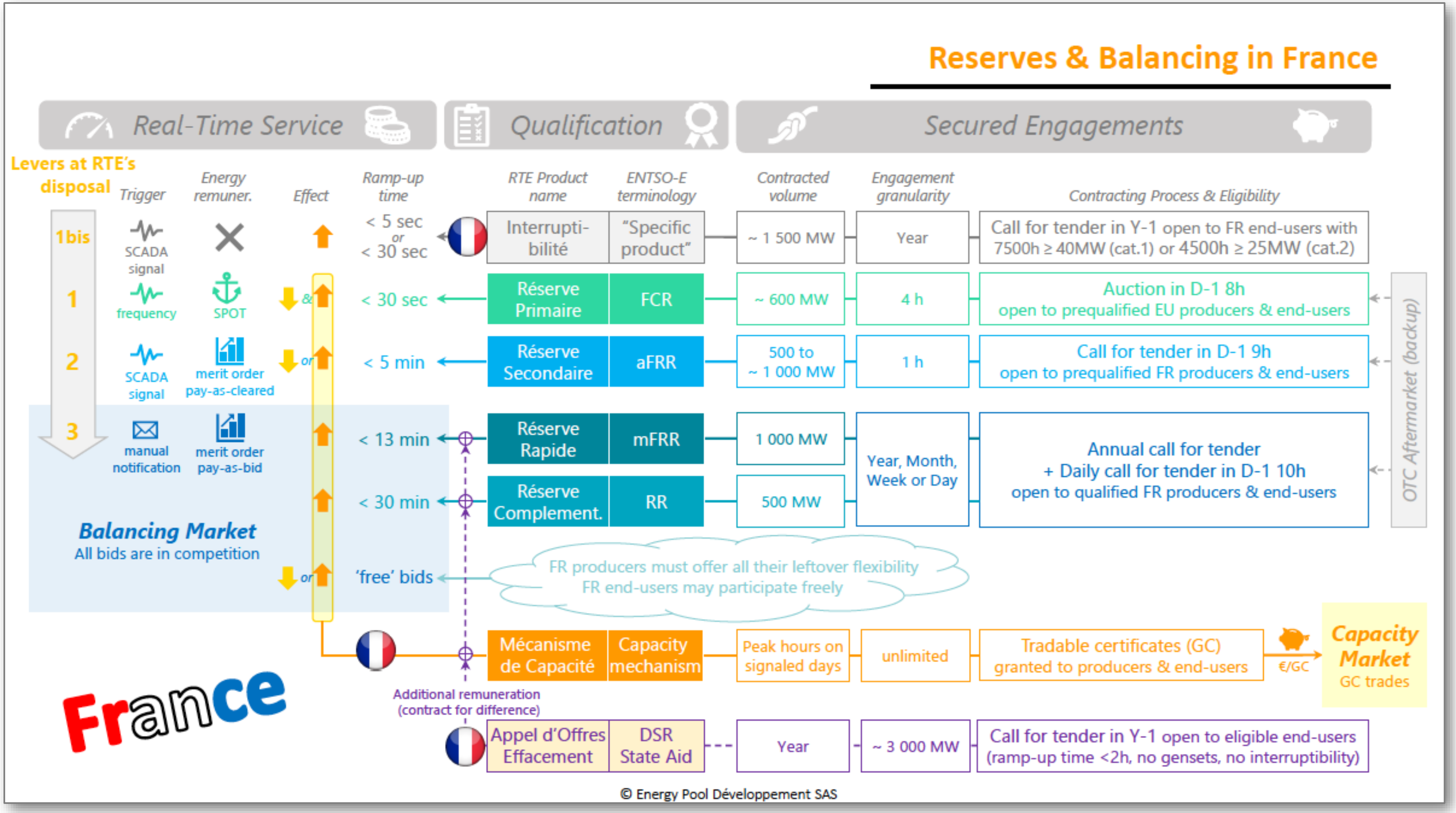


National consumption 02/28/2022

View from our clients 02/28/2022

https://indico.esrf.fr/event/2/contributions/94/



Reserves & Balancing in France

Real-Time Service | Qualification | Secured Engagements

Levers at RTE's disposal

Levers	Trigger	Energy remuner.	Effect	Ramp-up time	RTE Product name	ENTSO-E terminology	Contracted volume	Engagement granularity	Contracting Process & Eligibility
1bis	SCADA signal	✕	↑	< 5 sec or < 30 sec	Interruptibilité	"Specific product"	~ 1 500 MW	Year	Call for tender in Y-1 open to FR end-users with 7500h ≥ 40MW (cat.1) or 4500h ≥ 25MW (cat.2)
1	frequency	SPOT	↓ & ↑	< 30 sec	Réserve Primaire	FCR	~ 600 MW	4 h	Auction in D-1 8h open to prequalified EU producers & end-users
2	SCADA signal	merit order pay-as-cleared	↓ or ↑	< 5 min	Réserve Secondaire	aFRR	500 to ~ 1 000 MW	1 h	Call for tender in D-1 9h open to prequalified FR producers & end-users
3	manual notification	merit order pay-as-bid	↑	< 13 min	Réserve Rapide	mFRR	1 000 MW	Year, Month, Week or Day	Annual call for tender + Daily call for tender in D-1 10h open to qualified FR producers & end-users
			↑	< 30 min	Réserve Complement.	RR	500 MW		
			↓ or ↑	'free' bids	FR producers must offer all their leftover flexibility FR end-users may participate freely				
					Mécanisme de Capacité	Capacity mechanism	Peak hours on signaled days	unlimited	Tradable certificates (GC) granted to producers & end-users
					Appel d'Offres Effacement	DSR State Aid	Year	~ 3 000 MW	Call for tender in Y-1 open to eligible end-users (ramp-up time <2h, no gensets, no interruptibility)

Balancing Market
All bids are in competition

OTC Aftermarket (backup)

€/GC

Capacity Market
GC trades

Additional remuneration (contract for difference)

France

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Electricity market and grid stability

- Electric grid relies on synchronous mechanical generators (turbines)
  - Disturbances lead to drop in voltage and frequency
  - Synchronous generators react to frequency shift with highly variable output -> stabilize the system
- New power sources (PV, wind) and consumers don't react to disturbances
  - -> provide no inertia
  - -> no stabilization of the system
  - System becomes unstable
- Grid stabilization requires consumers that react to signals from grid:
  Demand Side Flexibility
  - **Peak shaving**: reduce load (planned)
  - **Continuous adjustment** (within predefined power trange)
  - **Load shedding** in emergency
  - **Cost** as incentive for participation
- **In the future:**
  - Static / inflexible load is **bad**
  - Dynamic / flexible load is **good**
    -> stabilizes grid
    -> saves cost (rebates / premiums)

My Conclusions for Linear Accelerators

- **Linear Accelerator is ideal for grid stabilization**
  - No stored beam -> fast recovery time
  - Continuous rep-rate modulation
- **Accelerator labs: make transition from passive to active electricity consumer**
  - Passive: reduce load during times of high spot market prices
  - currently: long term contracts with stable prices -> little / no incentive to do that
    -> this is changing!
  - Active: Cooperate with grid operator (TSO) to modulate load for grid stabilisation:
    Demand Side Flexibility

Linear accelerator:

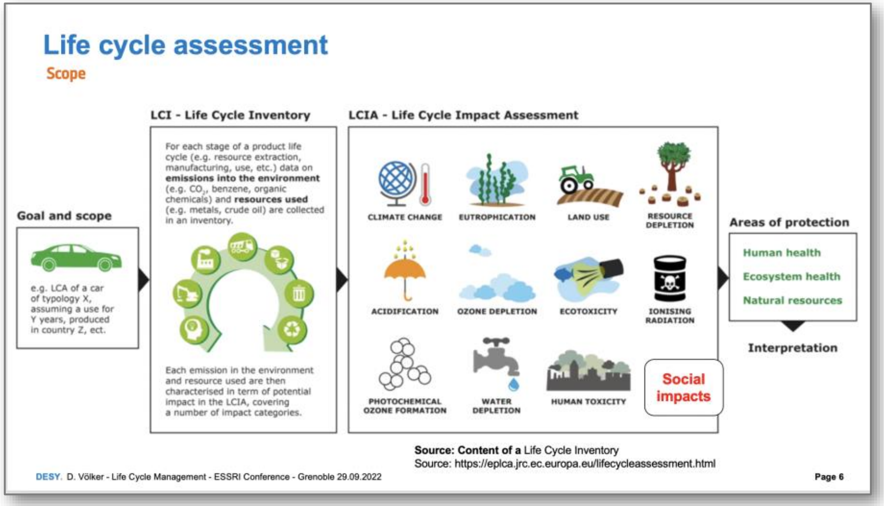
- RF power (~30-40%) directly proportional to rep-rate
- Other systems (cryogenics, HVAC, Damping Ring RF) follow partially / with delay
- Design all systems (if possible) for high flexibility: **maximise dynamic load fraction**
- Energy buffers: **decouple** electric load from performance on a short term basis

Develop as unique selling point for linear accelerators

-> Define new Performance Indicators for quantification

Live Cycle Assessments

D. Völker: Rare Earth and Life Cycle Management



Life cycle assessment

Scope

For each stage of a product life cycle (e.g. resource extraction, manufacturing, use, etc.) data on **emissions into the environment** (e.g. CO_2, benzene, organic chemicals) and **resources used** (e.g. metals, crude oil) are collected in an inventory.

Each emission in the environment and resource used are then characterised in term of potential impact in the LCIA, covering a number of impact categories.

Source: Content of a Life Cycle Inventory
Source: https://eplca.jrc.ec.europa.eu/lifecycleassessment.html

DESY. D. Völker - Life Cycle Management - ESSRI Conference - Grenoble 29.09.2022

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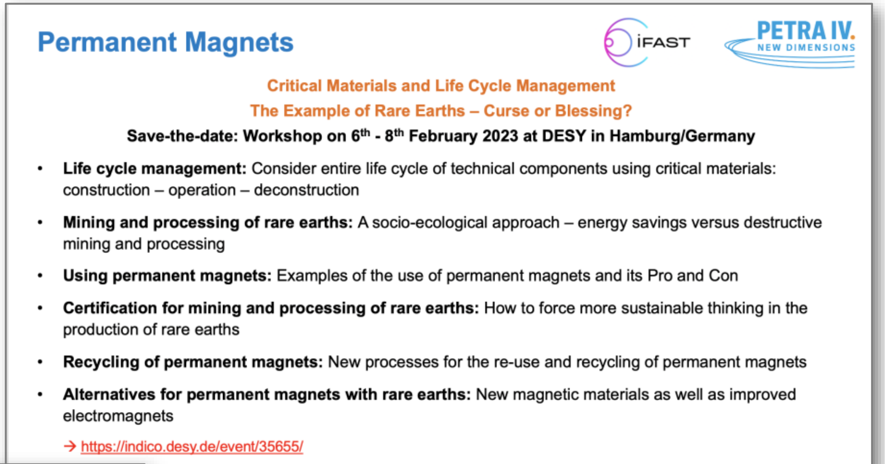

Permanent Magnets

Critical Materials and Life Cycle Management
The Example of Rare Earths – Curse or Blessing?

Save-the-date: Workshop on 6th - 8th February 2023 at DESY in Hamburg/Germany

- **Life cycle management:** Consider entire life cycle of technical components using critical materials: construction – operation – deconstruction
- **Mining and processing of rare earths:** A socio-ecological approach – energy savings versus destructive mining and processing
- **Using permanent magnets:** Examples of the use of permanent magnets and its Pro and Con
- **Certification for mining and processing of rare earths:** How to force more sustainable thinking in the production of rare earths
- **Recycling of permanent magnets:** New processes for the re-use and recycling of permanent magnets
- **Alternatives for permanent magnets with rare earths:** New magnetic materials as well as improved electromagnets

→ https://indico.desy.de/event/35655/

e Management - ESSRI Conference - Grenoble 29.09.2022

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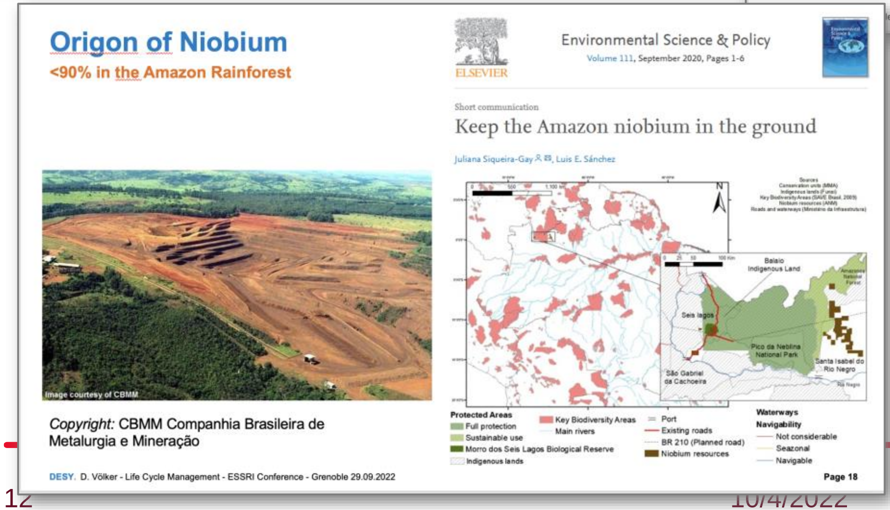

Origon of Niobium

<90% in the Amazon Rainforest

Image courtesy of CBMM

Copyright: CBMM Companhia Brasileira de Metalurgia e Mineração

ELSEVIER

Environmental Science & Policy
Volume 111, September 2020, Pages 1-6

Short communication

Keep the Amazon niobium in the ground

Juliana Siqueira-Gay, Luis E. Sánchez

DESY. D. Völker - Life Cycle Management - ESSRI Conference - Grenoble 29.09.2022

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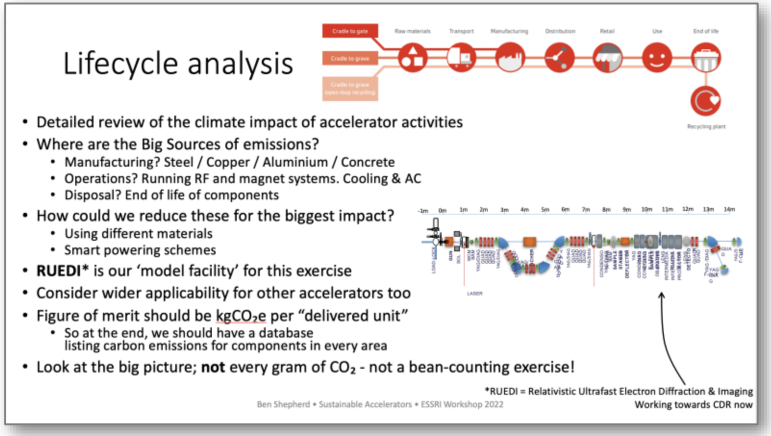
https://indico.esrf.fr/event/2/contributions/113/

B. Sheperd: Sustainable Accelerator R&D

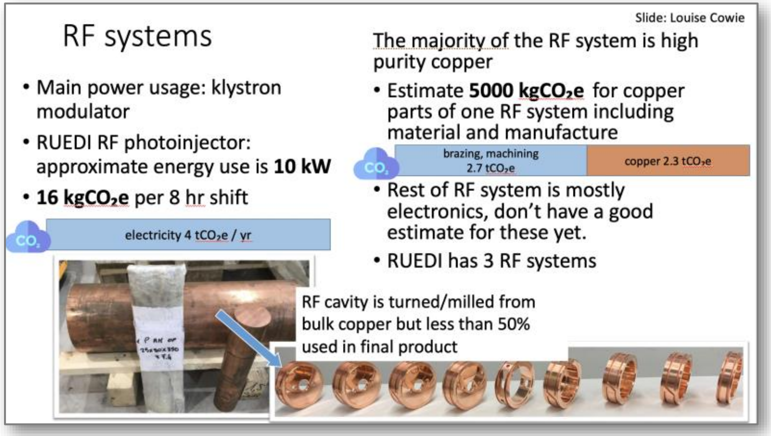


Lifecycle analysis

- Detailed review of the climate impact of accelerator activities
- Where are the Big Sources of emissions?
  - Manufacturing? Steel / Copper / Aluminium / Concrete
  - Operations? Running RF and magnet systems. Cooling & AC
  - Disposal? End of life of components
- How could we reduce these for the biggest impact?
  - Using different materials
  - Smart powering schemes
- **RUEDI*** is our 'model facility' for this exercise
- Consider wider applicability for other accelerators too
- Figure of merit should be $kgCO_2e$ per "delivered unit"
  - So at the end, we should have a database listing carbon emissions for components in every area
- Look at the big picture; **not** every gram of CO_2 - not a bean-counting exercise!

*RUEDI = Relativistic Ultrafast Electron Diffraction & Imaging
Working towards CDR now

Ben Shepherd • Sustainable Accelerators • ESSRI Workshop 2022



Slide: Louise Cowie

RF systems

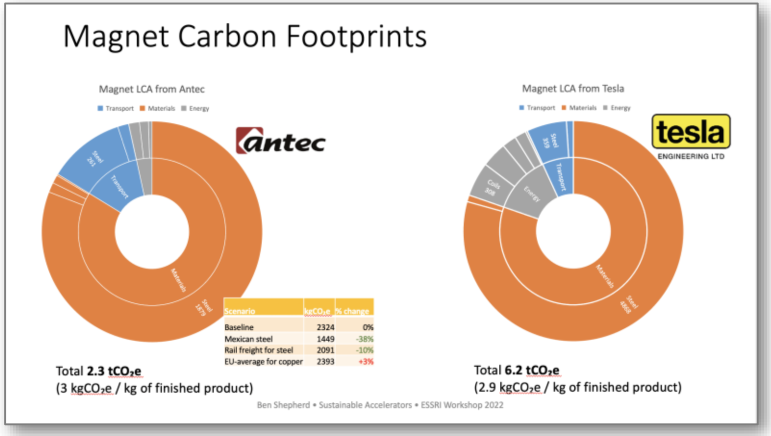
- Main power usage: klystron modulator
- RUEDI RF photoinjector: approximate energy use is **10 kW**
- **16 $kgCO_2e$** per 8 hr shift

The majority of the RF system is high purity copper

- Estimate **5000 $kgCO_2e$** for copper parts of one RF system including material and manufacture

- Rest of RF system is mostly electronics, don't have a good estimate for these yet.
- RUEDI has 3 RF systems

RF cavity is turned/milled from bulk copper but less than 50% used in final product



Magnet Carbon Footprints

Magnet LCA from Antec

Scenario	$kgCO_2e$	% change
Baseline	2324	0%
Mexican steel	1449	-38%
Rail freight for steel	2091	-10%
EU-average for copper	2393	+3%

Total **2.3 tCO_2e**
(3 $kgCO_2e$ / kg of finished product)

Magnet LCA from Tesla

Total **6.2 tCO_2e**
(2.9 $kgCO_2e$ / kg of finished product)

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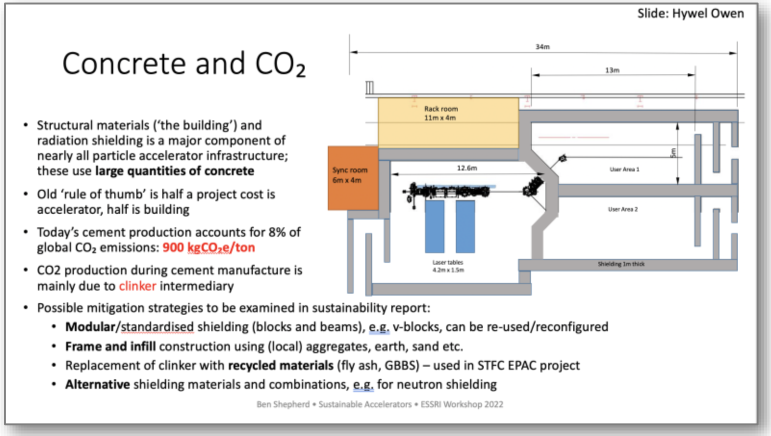

Slide: Hywel Owen

Concrete and CO_2

- Structural materials ('the building') and radiation shielding is a major component of nearly all particle accelerator infrastructure; these use **large quantities of concrete**
- Old 'rule of thumb' is half a project cost is accelerator, half is building
- Today's cement production accounts for 8% of global CO_2 emissions: 900 $kgCO_2e$/ton
- CO2 production during cement manufacture is mainly due to clinker intermediary
- Possible mitigation strategies to be examined in sustainability report:
  - **Modular**/standardised shielding (blocks and beams), e.g. v-blocks, can be re-used/reconfigured
  - **Frame and infill** construction using (local) aggregates, earth, sand etc.
  - Replacement of clinker with **recycled materials** (fly ash, GBBS) – used in STFC EPAC project
  - **Alternative** shielding materials and combinations, e.g. for neutron shielding

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Digital Twins

FCC

2

ENERGY MANAGEMENT FOR
FUTURE CIRCULAR COLLIDER

Jean-Paul Burnet (CERN)

Technical and Infrastructure Working Group
Electricity & Energy Management Work Package

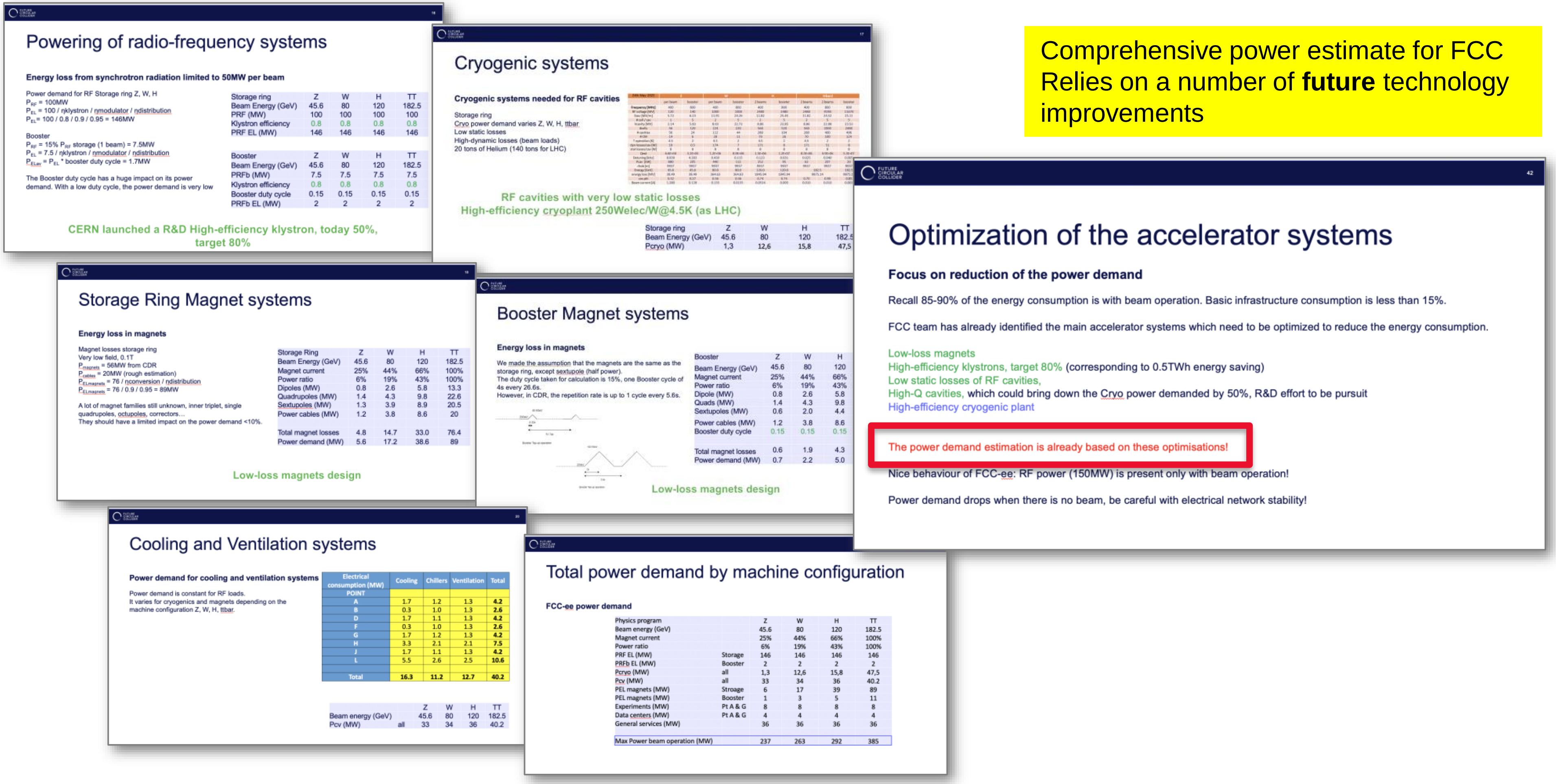
http://cern.ch/fcc

6th Workshop
Energy for
Sustainable
Science
at Research Infrastructures

https://indico.esrf.fr/event/2/contributions/119/

Power Estimate

Comprehensive power estimate for FCC
Relies on a number of **future** technology improvements



Powering of radio-frequency systems

Energy loss from synchrotron radiation limited to 50MW per beam

Power demand for RF Storage ring Z, W, H
P_{RF} = 100MW
P_{EL} = 100 / ηklystron / ηmodulator / ηdistribution
P_{EL}= 100 / 0.8 / 0.9 / 0.95 = 146MW

Booster
P_{RF} = 15% P_{RF} storage (1 beam) = 7.5MW
P_{EL} = 7.5 / ηklystron / ηmodulator / ηdistribution
P_{ELav} = P_{EL} * booster duty cycle = 1.7MW

The Booster duty cycle has a huge impact on its power demand. With a low duty cycle, the power demand is very low

Storage ring	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
PRF (MW)	100	100	100	100
Klystron efficiency	0.8	0.8	0.8	0.8
PRF EL (MW)	146	146	146	146

Booster	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
PRFb (MW)	7.5	7.5	7.5	7.5
Klystron efficiency	0.8	0.8	0.8	0.8
Booster duty cycle	0.15	0.15	0.15	0.15
PRFb EL (MW)	2	2	2	2

CERN launched a R&D High-efficiency klystron, today 50%, target 80%

Cryogenic systems

Cryogenic systems needed for RF cavities

Storage ring
Cryo power demand varies Z, W, H, ttbar
Low static losses
High-dynamic losses (beam loads)
20 tons of Helium (140 tons for LHC)

RF cavities with very low static losses
High-efficiency cryoplant 250Welec/W@4.5K (as LHC)

Storage ring	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
Pcryo (MW)	1,3	12,6	15,8	47,5

Storage Ring Magnet systems

Energy loss in magnets

Magnet losses storage ring
Very low field, 0.1T
$P_{magnets}$ = 56MW from CDR
P_{cables} = 20MW (rough estimation)
$P_{ELmagnets}$ = 76 / ηconversion / ηdistribution
$P_{ELmagnets}$ = 76 / 0.9 / 0.95 = 89MW

A lot of magnet families still unknown, inner triplet, single quadrupoles, octupoles, correctors…
They should have a limited impact on the power demand <10%.

Storage Ring	Z	W	H	TT
Beam Energy (GeV)	45.6	80	120	182.5
Magnet current	25%	44%	66%	100%
Power ratio	6%	19%	43%	100%
Dipoles (MW)	0.8	2.6	5.8	13.3
Quadrupoles (MW)	1.4	4.3	9.8	22.6
Sextupoles (MW)	1.3	3.9	8.9	20.5
Power cables (MW)	1.2	3.8	8.6	20
Total magnet losses	4.8	14.7	33.0	76.4
Power demand (MW)	5.6	17.2	38.6	89

Low-loss magnets design

Booster Magnet systems

Energy loss in magnets

We made the assumption that the magnets are the same as the storage ring, except sextupole (half power).
The duty cycle taken for calculation is 15%, one Booster cycle of 4s every 26.6s.
However, in CDR, the repetition rate is up to 1 cycle every 5.6s.

Booster	Z	W	H
Beam Energy (GeV)	45.6	80	120
Magnet current	25%	44%	66%
Power ratio	6%	19%	43%
Dipole (MW)	0.8	2.6	5.8
Quads (MW)	1.4	4.3	9.8
Sextupoles (MW)	0.6	2.0	4.4
Power cables (MW)	1.2	3.8	8.6
Booster duty cycle	0.15	0.15	0.15
Total magnet losses	0.6	1.9	4.3
Power demand (MW)	0.7	2.2	5.0

Low-loss magnets design

Cooling and Ventilation systems

Power demand for cooling and ventilation systems

Power demand is constant for RF loads.
It varies for cryogenics and magnets depending on the machine configuration Z, W, H, ttbar.

Electrical consumption (MW)	Cooling	Chillers	Ventilation	Total
POINT				
A	1.7	1.2	1.3	4.2
B	0.3	1.0	1.3	2.6
D	1.7	1.1	1.3	4.2
F	0.3	1.0	1.3	2.6
G	1.7	1.2	1.3	4.2
H	3.3	2.1	2.1	7.5
J	1.7	1.1	1.3	4.2
L	5.5	2.6	2.5	10.6
Total	16.3	11.2	12.7	40.2

		Z	W	H	TT
Beam energy (GeV)		45.6	80	120	182.5
Pcv (MW)	all	33	34	36	40.2

Total power demand by machine configuration

FCC-ee power demand

Physics program		Z	W	H	TT
Beam energy (GeV)		45.6	80	120	182.5
Magnet current		25%	44%	66%	100%
Power ratio		6%	19%	43%	100%
PRF EL (MW)	Storage	146	146	146	146
PRFb EL (MW)	Booster	2	2	2	2
Pcryo (MW)	all	1,3	12,6	15,8	47,5
Pcv (MW)	all	33	34	36	40.2
PEL magnets (MW)	Stroage	6	17	39	89
PEL magnets (MW)	Booster	1	3	5	11
Experiments (MW)	Pt A & G	8	8	8	8
Data centers (MW)	Pt A & G	4	4	4	4
General services (MW)		36	36	36	36
Max Power beam operation (MW)		237	263	292	385

Optimization of the accelerator systems

Focus on reduction of the power demand

Recall 85-90% of the energy consumption is with beam operation. Basic infrastructure consumption is less than 15%.

FCC team has already identified the main accelerator systems which need to be optimized to reduce the energy consumption.

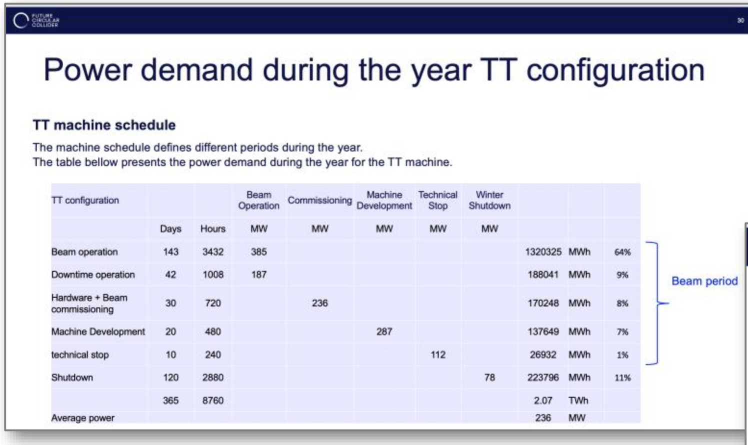
Low-loss magnets
High-efficiency klystrons, target 80% (corresponding to 0.5TWh energy saving)
Low static losses of RF cavities,
High-Q cavities, which could bring down the Cryo power demanded by 50%, R&D effort to be pursuit
High-efficiency cryogenic plant

The power demand estimation is already based on these optimisations!

Nice behaviour of FCC-ee: RF power (150MW) is present only with beam operation!

Power demand drops when there is no beam, be careful with electrical network stability!

Energy Consumption



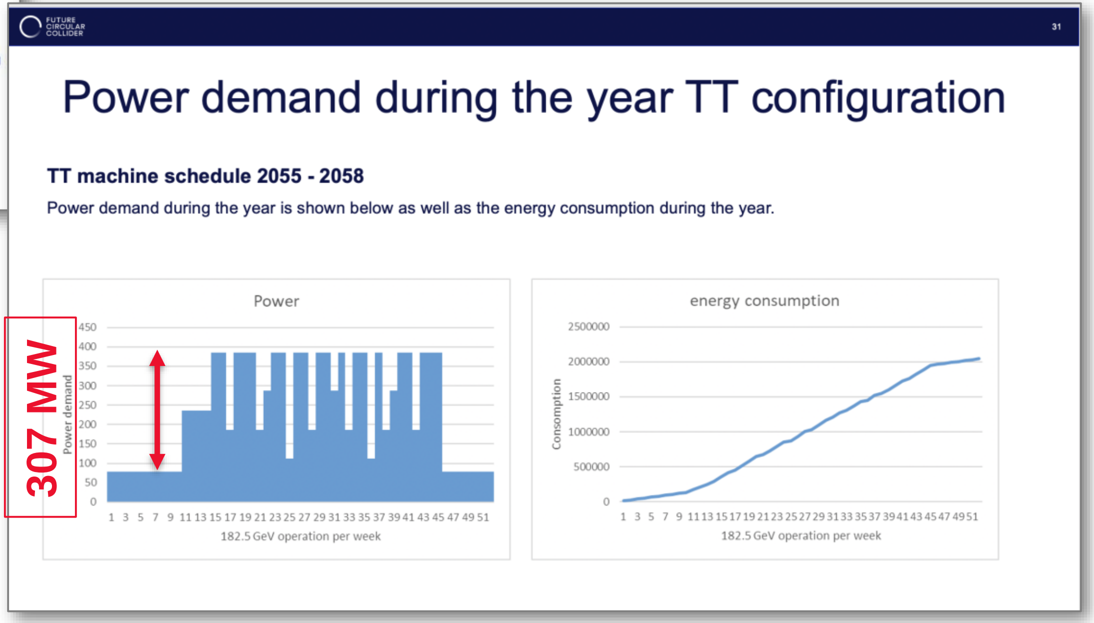
Power demand during the year TT configuration

TT machine schedule

The machine schedule defines different periods during the year.
The table bellow presents the power demand during the year for the TT machine.

TT configuration			Beam Operation	Commissioning	Machine Development	Technical Stop	Winter Shutdown			
	Days	Hours	MW	MW	MW	MW	MW			
Beam operation	143	3432	385					1320325	MWh	64%
Downtime operation	42	1008	187					188041	MWh	9%
Hardware + Beam commissioning	30	720		236				170248	MWh	8%
Machine Development	20	480			287			137649	MWh	7%
technical stop	10	240				112		26932	MWh	1%
Shutdown	120	2880					78	223796	MWh	11%
	365	8760						2.07	TWh	
Average power								236	MW	

Beam period



FUTURE CIRCULAR COLLIDER

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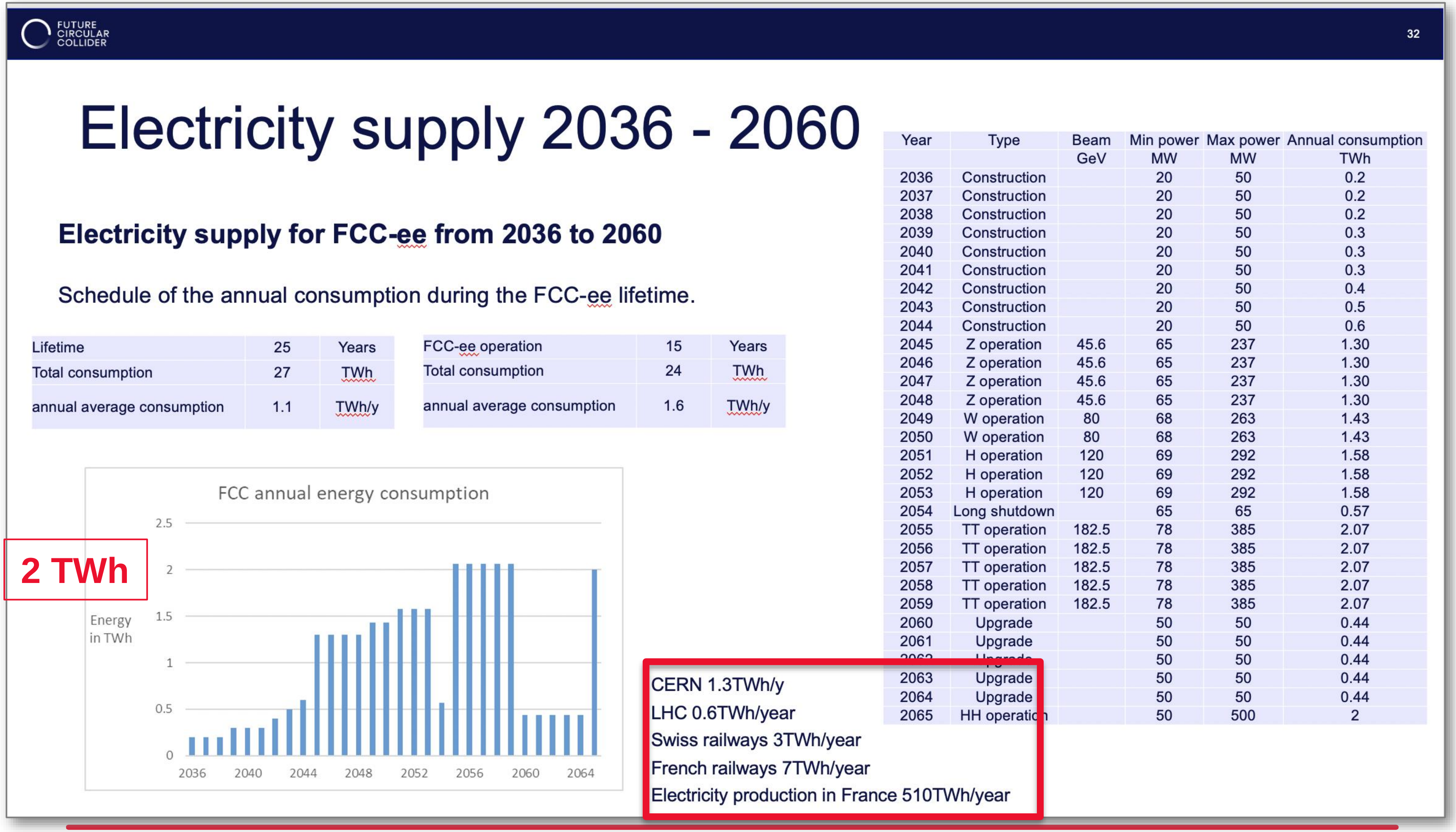
Power demand during the year TT configuration

TT machine schedule 2055 - 2058

Power demand during the year is shown below as well as the energy consumption during the year.



Electricity supply 2036 - 2060

Electricity supply for FCC-ee from 2036 to 2060

Schedule of the annual consumption during the FCC-ee lifetime.

Lifetime	25	Years
Total consumption	27	TWh
annual average consumption	1.1	TWh/y

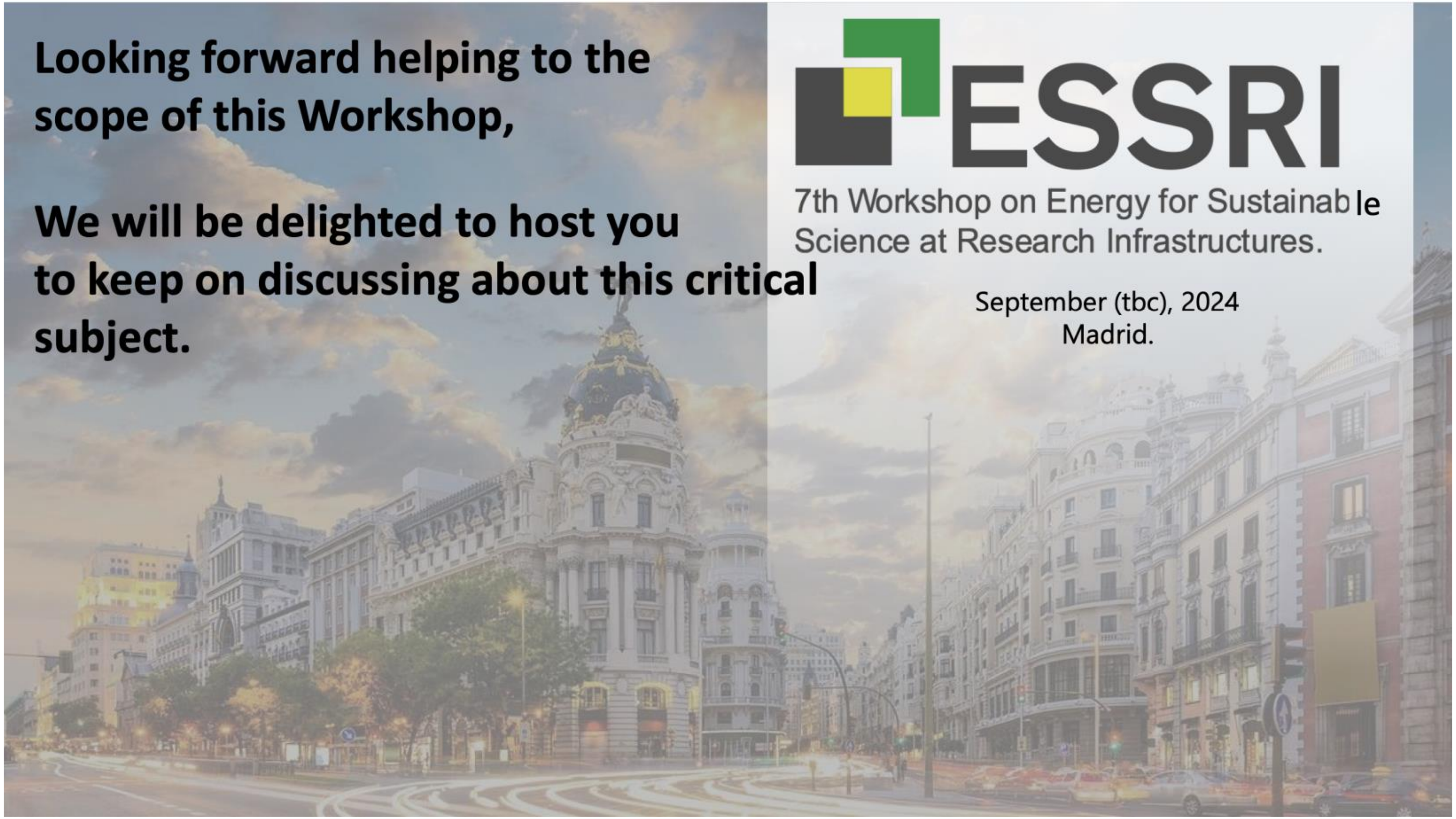
FCC-ee operation	15	Years
Total consumption	24	TWh
annual average consumption	1.6	TWh/y

Year	Type	Beam GeV	Min power MW	Max power MW	Annual consumption TWh
2036	Construction		20	50	0.2
2037	Construction		20	50	0.2
2038	Construction		20	50	0.2
2039	Construction		20	50	0.3
2040	Construction		20	50	0.3
2041	Construction		20	50	0.3
2042	Construction		20	50	0.4
2043	Construction		20	50	0.5
2044	Construction		20	50	0.6
2045	Z operation	45.6	65	237	1.30
2046	Z operation	45.6	65	237	1.30
2047	Z operation	45.6	65	237	1.30
2048	Z operation	45.6	65	237	1.30
2049	W operation	80	68	263	1.43
2050	W operation	80	68	263	1.43
2051	H operation	120	69	292	1.58
2052	H operation	120	69	292	1.58
2053	H operation	120	69	292	1.58
2054	Long shutdown		65	65	0.57
2055	TT operation	182.5	78	385	2.07
2056	TT operation	182.5	78	385	2.07
2057	TT operation	182.5	78	385	2.07
2058	TT operation	182.5	78	385	2.07
2059	TT operation	182.5	78	385	2.07
2060	Upgrade		50	50	0.44
2061	Upgrade		50	50	0.44
2062	Upgrade		50	50	0.44
2063	Upgrade		50	50	0.44
2064	Upgrade		50	50	0.44
2065	HH operatio		50	500	2

2 TWh

CERN 1.3TWh/y
LHC 0.6TWh/year
Swiss railways 3TWh/year
French railways 7TWh/year
Electricity production in France 510TWh/year

Next Workshop



Looking forward helping to the scope of this Workshop,

We will be delighted to host you to keep on discussing about this critical subject.

ESSRI

7th Workshop on Energy for Sustainable Science at Research Infrastructures.

September (tbc), 2024
Madrid.